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SPECIAL ISSUE: CATFISH 2020—THE 3RD INTERNATIONAL CATFISH SYMPOSIUM

Catfish 2020, A Clear Vision of the Future

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Abstract

The Third International Catfish Symposium was held in Little Rock, Arkansas, in 2020 and provided another milestone to gauge advances in knowledge related to conservation and management of these valuable fishes. Attendees from 29 states and 4 countries gathered to communicate research and information on the conservation, ecology, and management of the world's catfishes. During 3 d of technical sessions and workshops, 74 oral presentations and 17 posters were shared with 198 attending fisheries professionals. Plenary and oral presentations were recorded and are available online (https://www.youtube.com/channel/UCHNt7ZV05DLWoe4qJO798Pw/videos), aligning with the symposium theme of "Communicating Catfish Science." Technical sessions explored current research and management issues that included population demographics, introduced catfish populations, sampling methods, harvest management, human dimensions, conservation, habitat use and movement, biology, and aging methods. Ultimately, 38 manuscripts were peer reviewed and published as this special issue of the *North American Journal of Fisheries Management*. Interest in catfish science, as gauged by publications in six peer-reviewed fisheries journals, has grown steadily since a 1910 catfish aquaculture article appeared in the *Transactions of the American Fisheries Society*. Biology and ecology topics became prominent in the 1970s and 1980s, while articles on techniques and fisheries management have grown steadily through 2020. Ecology, fisheries management, and techniques were the most published topics in the three international catfish symposia. Future research and management efforts will continue similar work but also seek to address the expanding role of catfish as invasive species and a better understanding of the ecology and conservation of small-bodied native catfish. Among the greatest challenges will be adapting current tools and identifying future knowledge gaps as we experience a changing climate. This will require an enhanced understanding of transforming ecosystems and advanced adaptive management applications. The decadal occurrence of a dedicated symposium has served to summarize progress and focus future efforts to advance catfish science.

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The growing field of catfish science has been enhanced by periodic reviews that have summarized accomplishments and laid out informational needs for effective conservation and management of these important fish species (Irwin et al. 1999; Michaletz and Travnichek 2011). While considerable research has been aimed toward the culture of commercially important species, considerably less information has been available on the conservation, ecology, and management of the diverse order Siluriformes. Beginning in 1998, the First International Ictalurid Symposium (Catfish 2000) was organized with the aim of providing a formal forum by which information and ideas could be exchanged among fisheries managers and researchers. The proceedings were published as a book (Irwin et al. 1999) and represented the first volume to focus on the biology and management of catfishes in addition to summarizing information from previous decades (Irwin and Hubert 1999). The Second International Catfish Symposium was held in 2010 (Catfish 2010), and the proceedings, also published as a book (Michaletz and Travnichek 2011), evaluated the publication history and summarized the state of knowledge of catfish science, including highlighting recent advances and identifying areas of focus for future catfish science efforts (Kwak et al. 2011). Growth areas were predicted in the conservation of lesser-studied species, broadened ecological scales, and refinement and expansion of techniques used to study populations, with an emphasis on altering management to meet increased constituent demands. The Third International Catfish Symposium was held in 2020 (Catfish 2020), and the proceedings are published in this special issue of the *North American Journal of Fisheries Management*. Our objectives in this article are to (1) identify catfish article publication trends from 2011 to 2020, (2) summarize material presented at Catfish 2020 in the context of advances in catfish science since Catfish 2010, and (3) provide a framework for future efforts needed to continue the advancement of catfish science.

TRENDS IN CATFISH SCIENCE

Similar to the 2010 proceedings publication (Kwak et al. 2011), we compiled catfish science literature with publication dates beginning in 2011 and extending through 2020 from the six primary North American fisheries journals: *Fisheries*, *Transactions of the American Fisheries Society*, *North American Journal of Fisheries Management*, *North American Journal of Aquaculture* (previously *The Progressive Fish-Culturist*), *Journal of Aquatic Animal Health*, and *Canadian Journal of Fisheries and Aquatic Sciences* (previously *Journal of the Fisheries Research Board of Canada*). Searching for articles with catfish-related terms in the title or keywords, we then categorized each publication into one of the six broad symposium categories: biology, ecology, conservation, fisheries management, techniques, or aquaculture. A primary purpose for organizing the original symposium was to focus on the less-explored first five topics.

Aquaculture has historically been the most studied topic in catfish science (Irwin and Hubert 1999). The long-held focus on enhancing culture and production methods is not surprising, as the American Fisheries Society was originally formed over 150 years ago as the American Fish Culturists' Association. Aquaculture has grown dramatically since the mid-1980s and now exceeds 40% of total global seafood production, with catfishes among the top-five taxa in annual per-capita consumption (Shamshak et al. 2019). While the global "blue revolution" has seen an expanded emphasis in non-Asian countries (Garlock et al. 2020), U.S. catfish farmers continue to face many challenges for economic viability (Engle et al., in press). As biology is a key component in enhancing production and is the basis for understanding catfish ecology, it was the predominant topic published in the 1970s and 1980s (Figure 1). The impetus for Catfish 2000, Catfish 2010, and Catfish 2020 grew from within the acknowledged importance of aquaculture and emphasizes the importance of the conservation, ecology, and management of the diverse order Siluriformes as an extension of our catfish science knowledge base.

The need for understanding catfish ecology to aid in their conservation and management outside of production systems continues to grow, and fisheries agencies continue to address the challenges of overexploitation, habitat alterations, and dam construction and operation, which remain relevant today (Whelan et al. 2020). The need for a better understanding of how to manage and conserve catfishes is reflected in the shift in publication emphasis. The increase in base biological knowledge translates into a better understanding of interactions with their environment—hence, the subsequent shift through time to more ecological publications. Similarly, these advances led to more focused management efforts and the techniques needed to evaluate them. However, information on the topic of catfish conservation remained a minor focus.

The proceedings of the first and second catfish symposia were published in book form (Irwin et al. 1999; Michaletz and Travnichek 2011), and although peer reviewed, they were not as widely disseminated and are not included within Figure 1. The organizers of Catfish 2020 emphasized the need to increase the distribution of information coming from this venue and therefore pursued publishing this symposium as a special issue within the *North American Journal of Fisheries Management*. While adhering to standards of a primary fisheries journal may have ultimately reduced submissions, it ensured both the highest level of peer review scrutiny and enhanced dissemination of knowledge advances resulting from the symposium. The breakdown of article topics

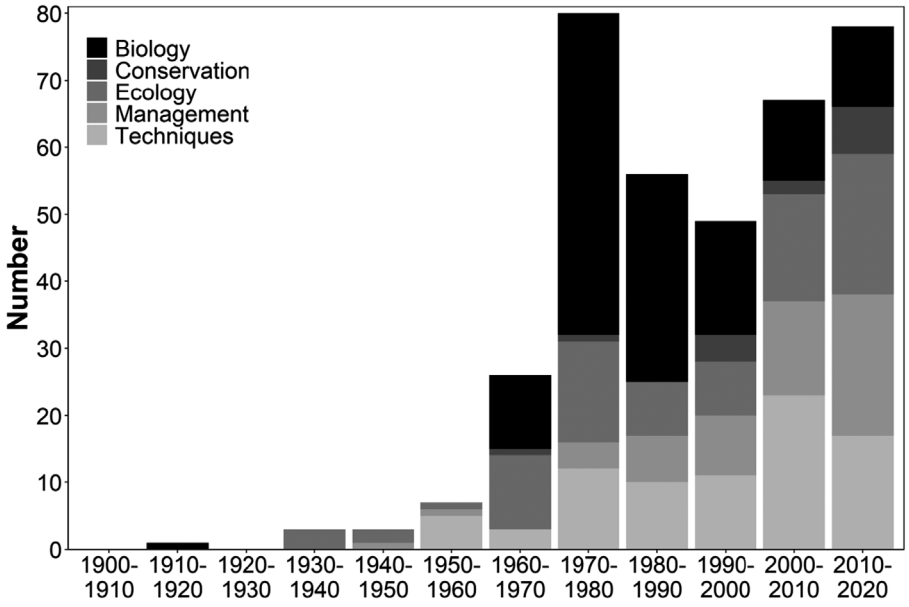

FIGURE 1. A summary of non-aquaculture catfish articles published between 1900 and 2020 from six primary North American fisheries journals (listed in the main text) by topic category.

from all three symposia (Figure 2) shows a smaller proportional shift over the past two decades in comparison to the past century. Similarly, there was the same lower emphasis on basic catfish biology information, making up less than 5% of symposium articles in Catfish 2010 and Catfish 2020, respectively. Ecology topics were proportionally the highest within the symposia. Fisheries management and techniques were also popular, comprising 20–35% and 15–25% of articles, respectively. Catfish conservation papers have become more common but are still only a minor component of the science and research being conducted.

SUMMARY OF PROGRESS

Ecology and Conservation

Understanding the relationship and interactions of catfish species with their environment continues be a major focus of research and management investigations. The two primary drivers appear to be the breadth and diversity of the species themselves and the expanding or changing habitats with which they interact. There have been some advances in native catfish research, including work on habitat use of artificial structures (Cope et al. 2019; Johnson et al. 2021, this special issue), utilization of dead mussel shells for spawning (Brumley and Lienesch 2020), and genetic diversity (McCall and Fluker 2020; Cope et al. 2021, this special issue) of madtoms; the growth of Brown Bullhead *Ameiurus nebulosus* (Hartman 2017) and Stonecats *Noturus flavus* (Puchala et al. 2018); and distributions of rare species like the Yaqui Catfish *Ictalurus pricei* within their native ranges (Hafen et al. 2021, this special issue).

Catfish have garnered substantial attention as invasive species, with researchers reporting expanded ranges that result in negative impacts or differing dynamic rate functions and reproductive characteristics for catfishes outside their historical ranges. This pattern in nonnative catfish populations is seen with Blue Catfish *I. furcatus* (Fabrizio et al. 2021; Hilling et al. 2021; Nepal and Fabrizio 2021; all this special issue), bullheads *Ameiurus* spp. (Barabe 2021; Sikora et al. 2021; both this special issue), Channel Catfish *I. punctatus* (Pennock et al. 2018; Hedden et al. 2021, this special issue), and Flathead Catfish *Pylodictis olivaris* (Hedden et al. 2016; Massie et al. 2018; Schmitt et al. 2019; Smith et al. 2021, this special issue), which was summarized by Montague and Shoup (2021, this special issue). The extent, ecology, and impacts of nonnative, invasive catfish populations are becoming better understood over time, and Fabrizio et al. (2021) described the conflicts involved in managing invasive catfish. However, research advances in control or eradication of invasive catfishes have been minimal, with limited success. In general, fish removals are not considered a feasible approach to invasive catfish control (e.g., Bonvechio et al. 2011; Pennock et al. 2018), but Barabe's (2021) evaluation of invasive Black Bullhead *A. melas* removal from a California stream demonstrated that eradication is possible in specific situations.

Research on how catfish and their populations adapt or react to changes in environmental conditions has been a

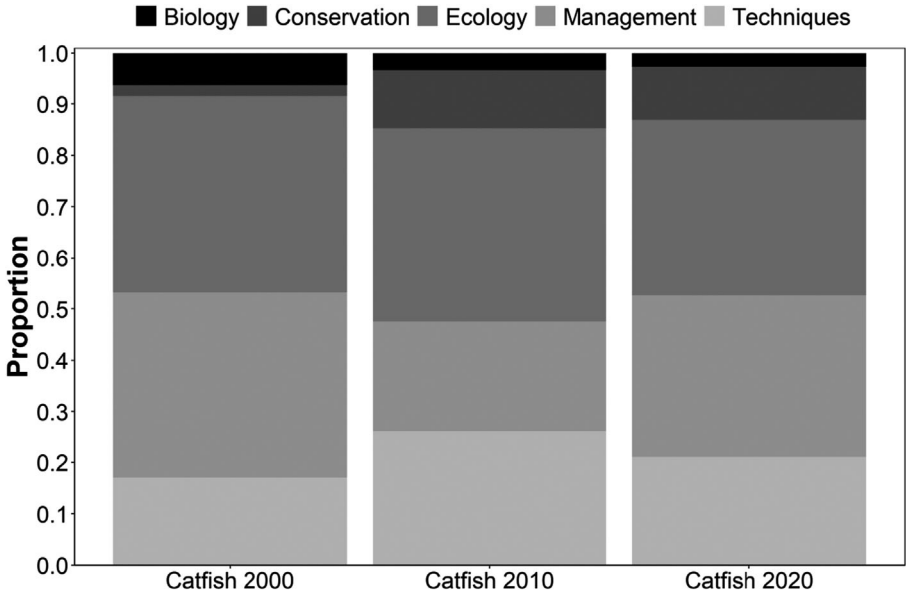

FIGURE 2. The proportion of published articles from each catfish symposium by topic category.

major focus of the past decade. Both broad- and fine-scale investigations reveal the plasticity of these species. For example, altered Missouri River hydrology impacted population characteristics for both Channel and Flathead catfish (Hamel et al. 2021, this special issue), and Channel Catfish exhibited differences in hatching success and early growth between regulated and unregulated reaches of the Tallapoosa River (Erickson et al. 2021, this special issue). River fragmentation similarly alters populations. For Channel Catfish, both abundance and size structure differences were detected in the fragmented Minnesota River (Sindt 2021, this special issue), whereas the free-flowing portions of the Wabash River supported higher Channel Catfish genetic diversity than the highly impounded Ohio River with isolated populations (Sotola et al. 2017). Both Blue Catfish and Flathead Catfish (Blank et al. 2021, this special issue) utilized different habitats between impounded and unimpounded systems. Although this work indicates the adaptability of catfishes to their environment, little work has been attempted to predict impacts of a changing climate other than bioenergetics modeling for Brown Bullhead (Hartman 2017). This is a significant knowledge gap that may need to be addressed by future research and management investigations.

Fisheries Management

Directed management of recreational fisheries for Blue, Channel, and Flathead catfish continues to be an important topic among catfish researchers in the 21st century. This trend is evident in recent journal publications, including proceedings from Catfish 2020. In the most recent decade, catfish management papers comprised 27% of non-aquaculture catfish science publications in the six major fisheries journals (Figure 1). Similarly, applied management of catfish populations was the focus of 32% of published papers from the Catfish 2020 symposium. These works demonstrate that proper management of catfish fisheries remains relevant to fisheries managers and researchers.

Although catfish populations have been managed—and subsequently studied—for decades, information gaps remain. These gaps frequently occur when considering metrics with potential for dynamic change (angler motivations and exploitation), integration of new harvest methods and populations, or evaluation of management strategies at a broad geographic scale. Biologists in Missouri responded to growing concern among angling groups about harvest of large Blue and Flathead catfish in the Mississippi and Missouri rivers by undertaking research to examine size-specific exploitation. They discovered that despite relatively low exploitation at a population level, there was strong size-selective harvest of mid- to large-sized fish (Winders and McMullen 2021, this special issue). Similar concerns of overexploitation prompted scientists in Texas to examine the impacts of hand fishing on a Flathead Catfish population, although they determined that hand fishing did not influence population abundance or size structure (Bodine et al. 2021, this special issue). An unregulated lotic Channel Catfish fishery that has gained recent angler attention was evaluated in West Virginia to better understand the population and determine whether regulation was needed. Population dynamics differed between reaches of the study system, but overall population stability and the transient nature of the study

population resulted in no suggested regulatory action (Keplinger 2021, this special issue). Biologists in Ohio conducted a study to identify factors associated with Channel Catfish abundance and growth in impounded systems. They suggested that management should be directed at large impoundments with relatively low densities to promote quality fisheries. Furthermore, they suggested that supplemental stockings may be having a deleterious effect on fisheries by slowing growth and resulting in high-density populations comprised largely of small fish (Tyszko et al. 2021a, this special issue). The studies referenced above provide evidence that despite the large catfish management literature base, certain situations will require additional work to appropriately inform management.

A large portion of recent catfish management research continues to focus on evaluation of harvest regulations. Historically, commercial and recreational catfish fisheries were managed to provide human sustenance (Graham 1999; Hubert 1999; Jackson 1999). Increased angler interest in trophy opportunities in the late 20th and early 21st centuries resulted in a need for altered harvest regulations to balance traditional harvest with emergent trophy motivations (Arterburn et al. 2002). For Iowa reservoirs, researchers suggested that a protected slot length limit or a maximum length limit would increase the size structure of Flathead Catfish populations (Muhlbauer and Krogman 2021, this special issue). Conversely, restrictive harvest regulations may not be successful in the development of trophy Flathead Catfish fisheries when slow growth and high natural mortality prevent individuals from reaching trophy sizes (Schall and Lucchesi 2021, this special issue). An increased minimum length limit was suggested to increase abundance of large Blue Catfish without reducing yield in a Missouri population characterized by slow growth (Michaletz et al. 2021, this special issue). Similarly, a minimum length limit was identified as an appropriate strategy to allow Channel Catfish harvest but prevent growth and recruitment overfishing in a lentic West Virginia population (Chestnut-Faull et al. 2021, this special issue). Creel survey data were analyzed collectively from 86 Texas impoundments, with results suggesting that most Blue and Channel Catfish populations could be managed with no minimum length limit to promote harvest without negatively impacting populations (Nisbet et al. 2021, this special issue). Varying recommendations from the five studies listed above demonstrate the necessity of individualized management plans to obtain site-specific goals as suggested by Stewart et al. (2016).

Development of alternative angling opportunities is another area that has received recent emphasis from catfish managers. For example, scientists have recently experimented with stocking Channel Catfish × Blue Catfish hybrids (hybrid catfish) to provide an alternative to traditional Channel Catfish fisheries and to increase angler catch. In Texas, hybrid catfish were stocked concurrently with Channel Catfish in a small, urban put-and-take fishery. However, very few hybrid catfish were encountered, suggesting limited application in this capacity (Hungerford et al. 2021, this special issue). A similar experiment was conducted in two Kansas catfish fisheries with a put–grow–take management strategy. These experiments demonstrated greater growth potential of hybrid catfish relative to Channel Catfish in wild systems, but there was no evidence of differing angler catch (Neely et al. 2021b, this special issue). Researchers in Iowa used a survey approach to better understand catfish angler motivations and inform future management plans. They discovered a broad array of motivations that differed between active, lapsed, and potential catfish anglers and between urban and rural anglers. Ultimately, future catfish management plans in Iowa will focus on developing urban angling opportunities but will require unique and alternative angler recruitment and retention strategies specific to both audience and location (Krogman and Stubbs 2021, this special issue). These three studies demonstrate that traditional catfish management strategies continue to provide quality angling opportunities, but examination of new ideas that may improve efficacy of management actions and provide alternative opportunities are paramount to maintaining relevancy of recreational catfish angling.

Techniques

The lack of precise and accurate methods for sampling catfish populations has been a major hindrance to the field of catfish science for many decades (Michaletz and Dillard 1999; Brown 2007; Bodine et al. 2013). At Catfish 2010, this was a perceived need that resulted in the formation of an ad hoc committee during the associated business meeting to summarize the current state of sampling methods, which resulted in the publication of Bodine et al. (2013). The past decade has seen the production of additional sampling-based research that addressed the needs highlighted by Bodine et al. (2013), but additional needs exist for some sampling approaches, particularly those related to sampling Flathead Catfish, the most poorly studied of the three largest ictalurid species (Blue, Channel, and Flathead catfish; Bodine et al. 2013), as well as the lesser-known madtom species.

Much of the recent literature on sampling methods has focused on precision. Adequate precision (typically defined as a relative SE $\leq$ 25) for Channel Catfish CPUE can be achieved with 20 gill-net sets (Koch et al. 2014) or 16–20 tandem hoop-net sets (Stewart and Long 2012; Tyszko et al. 2021b, this special issue). The effort required to achieve adequate precision for Channel Catfish CPUE using other hoop-net designs can be as high as 68 net-nights (Sindt 2018), but using nets with restricted throats can improve catch rates (Smith et al. 2016), which could

also improve precision. For Blue Catfish, 5-min low-frequency electrofishing (LFE) samples provide similar precision and population parameters as 10-min samples, resulting in greater efficiency when sampling in reservoirs (Shoup and Bodine 2021, this special issue), but this does not seem to be the case for river LFE sampling (Moran and Stoeckel 2021, this special issue). Blue Catfish LFE samples can be made even more efficient without the use of chase boats in rivers, but it may come at the cost of a size bias toward smaller fish (Moran and Stoeckel 2021). Blue, Channel, and Flathead catfish can be effectively sampled with bank poles (Dean et al. 2021, this special issue), but more research is needed to determine the sampling effort required to produce adequate precision for population metrics obtained with this gear. Madtom presence can best be detected using ten 100-m seine transects, but this approach will be biased toward smaller individuals (Wagner et al. 2019). Electrofishing is also an effective approach for madtoms, but it overestimates size distributions and requires greater replication (twenty 100-m transects) to provide the same level of detection as seines.

Recent studies of techniques have also focused on quantifying and improving the accuracy of data obtained when sampling catfishes. Contact selectivity (one form of size bias) has now been estimated for Channel Catfish (Shoup and Ryswyk 2016; Smith et al. 2017) and Black Bullhead (Smith et al. 2017) caught with the North American standardized gill net (Bonar et al. 2009). These selectivity values can be used as correction factors to improve accuracy of size-specific catch data (e.g., proportional size distribution, length frequencies, mortality, etc.) by dividing the catch rate of fish in each size-class by its associated selectivity value. Similar data are available for size-specific catchability of tandem-set hoop nets (Tyszko et al. 2021b) and could be used to produce more accurate size structure data when using this gear. More studies are needed to quantify gear accuracy for other catfish sampling approaches, but these types of studies are difficult to conduct because they require populations with known characteristics, which usually means intensively marking fish to create a known population that can then be sampled.

Another catfish science technique that has received significant research in the past decade is marking and tagging fish, in part because catfish are particularly difficult to tag given that they often expel transmitters or tags (Holbrook et al. 2012; Neely et al. 2021a, this special issue). In fact, of the peer-reviewed studies published in the past decade covering fishery techniques, the majority of them have dealt with methods for marking or tagging fish (Holbrook et al. 2012; Bodine and Flemming 2013, 2014; Neely et al. 2017; Becher et al. 2018; Spurgeon et al. 2020). This marking and tagging information for the three largest North American ictalurids (Blue, Flathead, and Channel catfish) was well summarized at Catfish 2020 in a review by Neely et al. (2021a), which provides useful guidance on the relative strengths and weaknesses of each method as it relates to various objectives in catfish science. Very recently, guidance for tagging madtoms has also become available (D'Amico et al. 2021; Schumann et al. 2021).

Many other catfish science techniques have been advanced by individual studies over the past decade, including those presented at Catfish 2020. These techniques include the use of Aqui-S 20E as an anesthetic for Channel Catfish (Bowker et al. 2017), the use of Bayesian statistical methods to allow uncertainty of population parameters to be incorporated into yield-per-recruit population models (Oliver et al. 2021, this special issue), evaluations of the effects of different otolith preparation methods on precision of age estimates (Sakaris and Bonvechio 2021, this special issue), and an approach combining angler creel data with ESRI Tapestry information to develop angler recruitment, retention, and reactivation management plans (Schlechte et al. 2021, this special issue). The addition of new technologies may allow us to better detect rare and less- studied species. For example, the refinement of environmental DNA methods and applications could help to focus limited resources to detect imperiled madtoms.

PATH FOR THE FUTURE

The past two decades of organized catfish symposia have likely focused and enhanced work on these important species. In addition to serving as a valuable information outlet, they have established the opportunity to summarize and, more importantly, collaboratively plan efforts to address knowledge gaps in the coming decades. The latest symposium has laid out a clear path for future work.

Ecology and conservation of catfish have been a strong focus of catfish science in this publication and serve to identify future information needs. The three large North American catfish species continue to be well studied, but the paucity of information on small-bodied native catfishes continues to be a large knowledge need to address both conservation and management concerns. Our understanding of the impacts and dynamics of invasive, nonnative catfish populations continues to advance, but development of control or eradication mechanisms is lacking. Relative to the coordinated efforts, multiple control and eradication approaches, and funding allocated to invasive carps (Conover et al. 2007), similar efforts and advances for invasive catfishes are lacking. Quantitative methods for population parameter and vital rate estimation have increasingly been employed for catfishes, and this is an area for future attention and further development.

Management of recreational catfish fisheries, particularly for Blue Catfish, has continued to shift from the

traditional harvest-based paradigm to the development of trophy angling opportunities during the past decade. These management approaches are multi-faceted and typically include some sort of length-based harvest regulation derived from individual-based population models. Unfortunately, the relatively long life span of catfishes can result in intramodel variation that may reduce the accuracy of simulated harvest regulations. This inherent variation further highlights the importance of long-term, field-based evaluation of harvest regulations to ensure that management goals are being met. Further investigation into biological, environmental, and social mechanisms that influence the effectiveness of harvest regulations in restructuring catfish populations is warranted as management objectives continue to change.

Additional research is needed to better inform sampling approaches. In particular, gear accuracy (which requires access to a known population or marked population) must be evaluated for almost all gears in order to quantify gear biases so that the optimal gear(s) can be selected or the bias can be corrected. Most gear evaluation studies to date have only compared the catch of multiple gears (i.e., efficiency), which is not a measure of accuracy. Even when gears produce similar results, they could all be biased (i.e., do not match the true population characteristics). The accuracy and precision of sampling approaches for Blue and Channel catfish are relatively well studied, but sampling approaches for other catfishes have not been well studied and warrant further investigation.

An overarching challenge lies ahead for catfish science when integrating the information needs summarized here with the uncertainties associated with a changing climate and its subsequent alteration of ecosystem function. Climate change is altering freshwater fish populations and assemblages, and the impact is projected to continue and become more intensive for many species (Lynch et al. 2016; Myers et al. 2017). Recent research suggests that many warmwater fish species exist in habitats near their upper thermal tolerance limits and are particularly vulnerable to warming temperatures (Barbarossa et al. 2021; Campos et al., in press). Thus, catfishes may be vulnerable to climate warming, especially those that face other ecological and biological stressors, such as madtom species. The nonstationarity of ecosystems will require thinking aimed toward the future rather than the past or current conditions, and global change research on catfish is a critical future priority. Fortunately, the regular occurrence of catfish managers and researchers coming together to share their work lays out a promising path to the future.

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