Lake Erie Grass Carp Adaptive Response Strategy 2024-2028

Photo source: R. Mapes, University of Toledo - Lake Erie Center

Lake Erie Committee

Great Lakes Fishery Commission

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Executive Summary

Foraging from abundant Grass Carp (*Ctenopharyngodon idella*) could adversely affect vegetated habitats, fish communities, and fisheries of Lake Erie and other connected Great Lakes.

Our intent is to prevent Grass Carp from attaining densities that cause adverse impacts through science-based, adaptive management to inform response efforts.

Current status of Grass Carp and its management in Lake Erie:

- ✓ Abundance appears below a threshold of causing detectable levels of adverse impacts and may have declined since 2018 in the Sandusky River (OH), owing to intensive response efforts.
- ✓ Tagged Grass Carp are mostly inhabiting the western basin of Lake Erie, with limited movement to eastern areas of Lake Erie, minimally to Lake Huron, and some fish return to western Lake Erie.
- ✓ Agencies have captured 1,064 Grass Carp during 2012-2023, averaging 34 fish annually through 2017 and 165 fish annually thereafter, reflecting the use of dedicated "strike" teams after 2017.
- ✓ Reproductively viable (diploid) Grass Carp are present in the population, constituting 59% of 796 fish with confirmed ploidy condition during 2018-2023 (61% of 932 tested during 2012-2023).
- ✓ Spawning has been documented in large rivers (e.g., Maumee, Sandusky, and Huron rivers, Ohio), typically during May-July if water temperature and flow rates are suitable (17^{o}-24^{o}C; $\geq$85th percentile velocity), or later (August) in summers with drought conditions.
- ✓ Eggs have been collected in three Ohio rivers but very few larvae or juveniles have been captured.
- ✓ Targeted agency removal efforts during spawning events are the most effective and efficient means of removing adult Grass Carp in Lake Erie.
- ✓ A combination of seasonal barriers and removal of adult fish is predicted to be most effective for reaching management targets (373 removed annually, 47% annual adult mortality rate).

Objectives:

- ✓ Improve the collective understanding of Grass Carp population dynamics, behavior, and impacts in Lake Erie to inform effective management actions.
- ✓ Implement control to minimize population expansion, by removing fish and/or blocking access to preferred habitats
- ✓ Minimize the likelihood of introduction and establishment of new breeding populations of Grass Carp in the tributaries and nearshore areas of Lake Erie and Lake St. Clair

Key management considerations:

- ✓ Efficiency, effectiveness, and societal acceptance of agency Grass Carp removal efforts
- ✓ Sources and levels of natural reproduction, new introductions, and spread of Grass Carp
- ✓ Accuracy of Grass Carp abundance/density estimates
- ✓ Uncertainty of the density threshold(s) at which Grass Carp herbivory becomes detrimental

Management priorities for 2024-2028

- ✓ Continue to learn how, when, and where to efficiently remove Grass Carp in the Lake Erie basin
- ✓ Detect where Grass Carp reproduction is occurring in the Lake Erie basin and connecting waters

- ✓ Identify new sources of Grass Carp and minimize their spread throughout the region
- ✓ Determine how to best detect and assess adverse impacts of Grass Carp herbivory in the region

Implementation:

- ✓ Response efforts are coordinated via the Great Lakes Fishery Commission's Lake Erie Committee, comprising fisheries managers from Michigan, New York, Ohio, Ontario, and Pennsylvania, and executed through federal, provincial, state, and university partners, including the U.S. Fish and Wildlife Service, the U.S. Geological Survey, Department of Fisheries and Oceans Canada, and the University of Toledo, and natural resource management agencies of the Lake Erie Committee.
- ✓ Knowledge gained during implementation of an initial Lake Erie Grass Carp Adaptive Response Strategy (2019-2023) guided development of the 2024-2028 Strategy, with technical review and advice provided by a Grass Carp Advisory Committee that was formed by the Council of Lake Committees in 2020 and populated with representatives from partner agencies.
- ✓ Future revisions will be informed by changes in the status and trends of extant Grass Carp in the basin; in the sources and pathways for new introductions; in evidence of adverse impacts from Grass Carp herbivory on aquatic vegetation; in the availability of new science, tools, and resources for detection, monitoring, and control; and from societal responses to management efforts.

Introduction

Foraging from abundant nonindigenous Grass Carp (*Ctenopharyngodon idella*) could adversely affect vegetated habitats, fish communities, and fisheries of Lake Erie and other connected Great Lakes. As selective herbivores, Grass Carp in sufficient densities could reduce the biomass and diversity of vegetation in wetlands, bays, and other nearshore areas, affecting habitats for fishes and other aquatic organisms, as well as nutrient cycling and turbidity in lakes (van der Lee et al. 2017). Only 10% of Lake Erie's original coastal marshes remain (Herdendorf 1987), increasing a need for their protection.

Fisheries management within the Lake Erie basin is coordinated under the auspices of the Great Lakes Fishery Commission's (GLFC) Lake Erie Committee (LEC). The LEC is comprised of senior fisheries managers from Michigan, New York, Ohio, the Province of Ontario, and Pennsylvania, who also coordinate with invasive species managers within their organizations. This document incorporates knowledge gained by the LEC and its partners during implementation of its initial 2019-2023 adaptive response plan to strategically coordinate management and research efforts for reducing the likelihood that a reproducing Grass Carp population will expand to detrimental levels. Although Grass Carp have already invaded Lake Erie and reproduction has been documented, the LEC does not consider the population to be established based on the criteria of Cudmore et al. (2017).

A coordinated interagency response to Grass Carp, through a strategic and adaptive approach to reduce or eradicate local populations, can minimize their potential impacts in Lake Erie. These five-year plans identify short-term response efforts necessary to prevent Grass Carp from reaching densities that inflict ecological damage and support potential future eradication of this species from Lake Erie, if ever feasible (e.g., Herbst et al. 2021).

The Strategy

The purpose of this adaptive response strategy is to guide interagency efforts of the LEC and its partners toward the following goal:

Prevent Grass Carp from attaining densities capable of adversely affecting vegetated habitats and associated fish communities and fisheries in Lake Erie.

Guiding Principles:

- The establishment of a Grass Carp population that is capable of adversely affecting habitats, fish stocks, or fisheries, is unacceptable and should be prevented.
- Eradication of existing Grass Carp in Lake Erie is unattainable using existing tools and technologies; management efforts will focus on effective and efficient control of carp in specific areas to minimize impacts and to support future eradication efforts, if feasible in Lake Erie.
- Given the large size and complexity of Lake Erie and its connected waters, limited control capabilities and resources, and challenges in detecting and monitoring fish of low abundance and their effects on the ecosystem, an adaptive response approach will be used to inform site-specific actions to effectively and efficiently reduce Grass Carp densities where and when most necessary, based on the best available science.
- Each LEC member agency will determine which actions will be employed within its jurisdiction, as well as criteria used to determine when an action is warranted.
- The strategy encompasses both diploid and triploid Grass Carp, which differ in their risk of ecological impacts, sources and pathways of entry, and the regulated use of triploid fish in three states.
- The strategy is a living document, to be reviewed and revised in accordance with any changes in the status and trends of Grass Carp in the Lake Erie basin during 2024-2028.

Objectives:

1. **Improve the collective understanding of Grass Carp population dynamics, behavior, and impacts in Lake Erie to inform effective management actions.**
   a) Determine preferred habitats and behavior (movement, feeding, spawning) in Lake Erie and connecting waters
   b) Determine densities of adult Grass Carp in specific areas of Lake Erie and major tributaries
   c) Determine colonization (within area) and expansion (across area) rates of populations
   d) Identify environmental factors that promote aggregation and collection of Grass Carp
   e) Determine levels of reproduction and factors affecting recruitment in Lake Erie
   f) Identify likely outcomes from management options using simulation models
   g) Determine how to detect and account for responses in flora or fauna to various densities of Grass Carp.

2. **Implement control to minimize expansion of Grass Carp in Lake Erie**
   a) Remove Grass Carp from the Lake Erie basin, particularly diploid fish in identified spawning locations; actions to be determined by LEC member agencies with focus on

i. Opportunistic removal
   - fisheries (commercial, angling/bowfishing)
   - by-catch during monitoring or research projects of any agency or other group

ii. Targeted removal
   - science-based targeting of specific conditions and locations where Grass Carp are likely to be concentrated (see Obj. 1)
   - use of gears most efficient at capturing Grass Carp in specific areas

iii. Incident response removal
   - robust interagency response to mitigate a high-risk incident through an opportunity to effectively capture highly-aggregated carp within a constrained area
   - likely using an Incident Command System structure and/or engaging participants under an extant mutual aid agreement (https://gsgp.org/media/xxojjjp1/ais-mutual-aid-agreement-signed-3-26-15.pdf)
   - rarely invoked, requiring a high likelihood of success for justifying extensive allocation of resources to address a serious risk, as determined by the host/requesting agency

b) Conduct applied research to develop and employ innovative capture and control tools and technologies targeting Grass Carp, such as
   i. attractants for improving capture of Grass Carp with passive gears (nets, trotlines) or to concentrate Grass Carp for traditional active sampling gears (trammel nets, electrofishing)
   ii. barriers to facilitate removal of Grass Carp in Lake Erie tributaries

c) Facilitate use of rapid ploidy tests to identify diploid fish for timely response actions

3. Minimize the likelihood of introduction and establishment of new breeding populations of Grass Carp in the tributaries and nearshore areas of Lake Erie and Lake St. Clair.

a) Maintain or improve federal, provincial, and state laws and enforcement to prevent entry of diploid Grass Carp into the Lake Erie watersheds
   i. monitor triploid supply chain for ploidy compliance
   ii. ensure that current Grass Carp regulations are being enforced
   iii. increase awareness of bait harvesters and anglers on the threats of Grass Carp

b) Where feasible given a potential for impacts on other organisms or human uses, utilize barriers to block movements of Grass Carp to potential spawning areas and/or new habitats

Management considerations and priorities for 2024-2028:

Given our current levels of understanding, we believe that the threat of Grass Carp impacts to vegetated habitats and fish communities in Lake Erie can be mitigated through the strategic application of adaptive, science-based management actions in 2024-2028 and beyond. While many factors affect management decisions (see Background section that follows), key considerations that will inform response efforts and research during 2024-2028 include improving our understanding of the

i. efficiency, effectiveness, and societal acceptance of agency Grass Carp removal efforts,
ii. sources and levels of natural reproduction, new introductions, and spread of Grass Carp,
iii. accuracy of Grass Carp abundance/density estimates, and

iv. density threshold(s) at which Grass Carp herbivory becomes detrimental.

Hence, management priorities for 2024-2028 are to:

i. continue to learn how, when, and where to efficiently remove Grass Carp in the Lake Erie basin,
ii. detect where natural reproduction may be occurring in the Lake Erie Basin and connecting waters,
iii. identify new sources of Grass Carp and spread throughout Lake Erie and connecting waters, and
iv. determine how to best detect and assess adverse impacts of Grass Carp herbivory in the Lake Erie basin.

Implementation:

Progress toward the goal will accrue over time through the implementation of the three objectives. This strategy is intended to coordinate actions of state, provincial, federal, and university partners during 2024-2028, with periodic review and advice provided by an interagency Grass Carp Advisory Committee (GCAC) formed by the Council of Lake Committees. In 2028, the LEC will evaluate progress toward the objectives of the strategy. Lessons learned during this period will be used to determine future actions, as informed by changes in the status and trends of extant Grass Carp in the basin, in the sources and pathways for new introductions, from evidence of adverse impacts from Grass Carp herbivory on aquatic vegetation, in the availability of new science, tools, and resources for detection, monitoring, and control, and from societal responses to response efforts.

Background

The first documented Grass Carp from Lake Erie was caught by an Ohio commercial fisher in 1985 and additional captures of adult fish occurred intermittently thereafter. Early on, agency fisheries managers believed that these Grass Carp were escapees from triploid (sterile) stockings in private lakes within the Lake Erie watershed and of minimal threat to the ecosystem. In 2012, however, diploid (fertile) Grass Carp were captured from the Sandusky River (Ohio) and likely originated from there during 2011 (Chapman et al. 2013), constituting the first evidence of natural reproduction by Grass Carp in Lake Erie and the Great Lakes Basin. These results triggered focused efforts by fisheries agencies to capture additional Grass Carp in Lake Erie, determine ploidy status (diploid or triploid), and seek additional evidence of natural reproduction. During 2012-2017, over 178 Grass Carp were captured and about 77% of 136 fish with definitive ploidy assignment were diploid, indicating a potential for additional reproduction in Lake Erie (Table 1). Moreover, chemical signatures of the otoliths from the diploid Grass Carp indicated that some fish were originating from areas other than the Sandusky River. Subsequently, Grass Carp eggs were collected from the Maumee and Sandusky rivers (multiple years, 2018-2023) and the Huron River, OH (2023), but were not found in other sampled tributaries. Removal efforts increased substantially after 2017, particularly in the Maumee and Sandusky rivers, largely due to U.S. federal funding afforded to the GLFC for Grass Carp control in the Great Lakes. Funding was used to procure additional equipment (vessels, gears) and staff for dedicated “strike team” field responses administered through the University of Toledo, ODNR, MDNR, the USFWS, and the GLFC to capture Grass Carp in rivers and inshore areas of western Lake Erie, augmenting extant AIS monitoring programs of various government agencies. In total, 1,064 Grass Carp were captured from Lake Erie waters during 2012-2023 (Table 1). Most (68%) fish were captured from the Sandusky and Maumee rivers, reflecting focused

attention to areas where reproduction was confirmed, and adult densities were highest. Funds were also directed at various studies to address management needs identified in the 2019-2023 strategy.

Table 1. Annual numbers of Grass Carp captured from basins and major watersheds of Lake Erie and Lake St. Clair (including connecting rivers), and percentages of diploid fish collected during 2012-2023 (n= number of fish with definitive dipoid or triploid assignment).

	Western Basin									
Year	Sandusky River Ohio	Maumee River Ohio	Other Ohio waters	Michigan waters	Ontario waters	Lake St. Clair	Central Basin	Eastern Basin	Total	Percent diploid (n)
2012	6	0	0	5	0	0	0	0	11	72.7 (11)
2013	0	1	0	7	0	0	6	0	14	16.7 (7)
2014	0	0	0	22	0	0	7	0	29	75.0 (28)
2015	4	0	12	7	1	0	2	0	26	69.2 (13)
2016	3	0	4	23	1	0	4	5	40	94.3 (35)
2017	23	1	10	16	0	0	8	0	58	78.6 (42)
2018	38	3	6	7	2	0	3	1	60	56.9 (51)
2019	70	15	12	11	0	0	78	1	187	42.7 (171)
2020	93	8	9	4	0	0	3	0	117	70.3 (91)
2021	110	48	7	1	0	0	18	0	184	60.7 (168)
2022	51	75	8	0	0	0	6	7	147	55.5 (137)
2023	107	64	6	1	0	0	5	8	191	70.2 (178)
Totals	505	215	74	104	4	0	140	22	1064	

Although focused efforts provided higher catches of Grass Carp and additional evidence of reproduction in the Lake Erie Basin, other information did not indicate substantial increases in population abundance, expansion, or impacts. Annual adult mortality rates ranged from 4.0 to 13.6% during 2014-2022, were positively related to levels of catch and increased after strike teams were deployed, suggesting that increased removal efforts were measurably affecting the population (Lang 2022). Percent of confirmed diploid fish declined from 77% of 136 fish during 2012-2017 (annual range 16-94%; Table 1) to 59% of 796 fish during 2018-2023 (annual range 42-70%). Adverse impacts from Grass Carp grazing were not evident in vegetated areas of the lake, acknowledging that specific methods or surveys may be needed to detect such impacts (King et al. 2023).

Summary of key findings from implementation of the 2019-2023 Strategy (Table 1 and Appendix A):

- Annual captures of adult Grass Carp from Lake Erie were higher during 2019-2023 (mean=165, range 117-191 fish) than in 2012-2018 (mean=34, range 11-60).
- Efforts to remove adult ($\geq$ age 5) Grass Carp and to collect Grass Carp eggs were more productive than removing young ($\leq$ age-3) Grass Carp that were difficult to find and capture.
- Removal efforts in Canadian waters were focused on Lake Erie, Lake Ontario, and the Huron-Erie Corridor, with boat electrofishing, trap nets, hoop nets, mini fykes, and gill nets.

- Removal efforts in U.S. waters largely involved electrofishing and focused on suspected Grass Carp spawning events in the Sandusky River, Maumee River, in Michigan waters, and some other areas of Lake Erie.
- Grass Carp movements to riverine spawning locations were affected by photoperiod, temperature, and discharge rate; conditions that typically occurred about 45 days after spring spawning of walleye (Bopp et al. 2023), May to July (17^{o}- 24^{o} C water temperature) during high ($\geq$85th percentile) flow events, and did not occur every year in any area, even with suitable conditions. More recent work by Flanigan et al. (2023) found evidence of spawning in August of drought years.
- USGS models (SpawnCast, FluEgg) were used to identify potential spawning areas (twelve in the Maumee River, three in the Sandusky River) and informed response efforts to remove fish.
- Estimates of Grass Carp abundance ranged from 100 to 340 fish in the Sandusky River during 2018-2020, with some indication of decline in 2021-2022 following increased response efforts.
- Adult Grass Carp, tagged in western Lake Erie, largely remained there year-round but some moved to the eastern basin and north to Lake Huron (and some returned to western Lake Erie).
- Diploid Grass Carp were captured from several central basin tributaries in Ohio; nine fish from the Cuyahoga River in 2019, one fish from each of the Huron and Grand rivers in 2021, and one fish from the Black River in 2022.
- From annual surveys of many rivers during 2019-2023, Grass Carp eggs were collected only from the Maumee River (2019), the Sandusky River (all years except 2020; awaiting confirmation for 2023), and the Huron River (OH; 2022); larvae were rarely collected in any river.
- Revised outputs from a Grass Carp Population model, developed by Michigan State University researchers, indicated that annual removal of 373 adult Grass Carp from Lake Erie, or a 47% mortality rate on adult fish, would be needed (along with a spawning barrier in the Sandusky River) to meet management goals, and that capture efficiency increases with Grass Carp abundance.
- The use of attractants (rapeseed and algae pellets) to enhance Grass Carp capture require further study.
- Tagged and released Grass Carp ("Judas" fish) were tracked to help identify areas for fish removals, which were most efficiently accomplished with electrofishing gear in Ohio rivers.
- Options for constructing both behavioral and physical-hydraulic barriers on the Sandusky River to interrupt Grass Carp spawning behavior were identified in an initial feasibility study (completed, 2021), with follow-up feasibility and design work initiated in 2022 for a behavioral barrier (per ODNR decision).

Management Considerations

Important considerations in developing this response strategy include:

- Recognizing limitations of current tools and technologies to eradicate the existing Lake Erie population of Grass Carp, or to maintain or alter population abundance, biology, or behavior of carp that are already present in the Lake Erie basin;

- Addressing the most likely sources and pathways of additional introductions into the Lake Erie basin, including escapees from inland waterbodies into tributaries of Lake Erie/Lake St. Clair, movements

of fish from Lake Huron, human-mediated releases into Lake Erie/Lake St. Clair or tributaries via bait buckets, commercial fish haulers, or other means;

- Accommodating various socio-economic factors, including
  - the regulated use of triploid (only) Grass Carp in three (New York, Ohio, Pennsylvania) of the LEC's five management jurisdictions on Lake Erie and in the upper Maumee River watershed of Indiana,
  - societal concerns about trade-offs or collateral issues (e.g., truncated activities during response efforts) that may limit control options for managers,
  - limitations on agency resources (costs, staff, time) that emphasize a need for efficient decision-making and effective outcomes to sustain agency commitments for monitoring and response programs;

- Recognizing the importance of inter-jurisdictional regulatory complexity and promoting consistency with
  - policies/plans involving Grass Carp of all LEC agencies,
  - different laws and enforcement capabilities among LEC jurisdictions
  - roles and commitments among management agencies of the LEC and with other signatory management and science agencies, as expressed under the GLFC's ***A Joint Strategic Plan for the Management of Great Lakes Fisheries,*** http://www.glfc.org/pubs/misc/jsp97.pdf.
  - Grass Carp related position statements issued by the GLFC's Council of Lake Committees (CLC) and the LEC, and with the CLC's environmental principles for sustainable fisheries,
  - the Canadian Asian Carp Response Plan, https://asiancarp.ca/SURVEILLANCE-PREVENTIONAND-RESPONSE/Asian-Carp-Response-Plan, as it pertains to Grass Carp
  - the U.S. Asian Carp Management Plan (Conover 2007) and efforts of the Invasive Carp Regional Coordination Committee, https://invasivecarp.us/,
  - efforts of the Great Lakes St. Lawrence Governors and Premiers, including implementation of a Mutual Aid Agreement, http://www.gsgp.org/media/1564/ais-mutual-aid-agreement-3-26-15.pdf, to respond to serious threats from aquatic invasive species and to encourage continued cooperative actions by the states and provinces to combat aquatic invasive species, and
  - a binational strategy to address aquatic invasive species under Annex 6 of the 2012 Great Lakes Water Quality Agreement;

- Addressing knowledge gaps to bolster effective decision-making and actions, with a focus on
  - estimating Grass Carp abundance or densities in Lake Erie and removal targets for control of population growth and spread,
  - understanding habitat preferences associated with spawning and aggregating behaviors of Grass Carp to inform collection programs in Lake Erie,
  - assessing wetlands and habitat use by Grass Carp (and other species potentially affected by Grass Carp), to understand changes in habitat suitability and identify areas for monitoring carp populations,

- uncertainty in projections of ecological impacts (Cudmore et al. 2017) that link responses in submerged aquatic vegetation to Grass Carp densities (density thresholds) in the Lake Erie basin;
- detection/monitoring of Grass Carp impacts on vegetation or associated fauna
- continued use of a Grass Carp model that arose from a formal Structured Decision Making exercise (e.g., Runge et al. 2013) to evaluate options (Jones et al. 2017) for controlling Grass Carp in Lake Erie at socially and environmentally acceptable levels, including:
    - targeted Grass Carp numbers for removal
    - sampling and removal methods
    - use of barriers in selected areas, and
    - critical uncertainties (abundance and gear efficiency).

- Incorporating new knowledge from coordinated inter-jurisdictional efforts conducted throughout the Lake Erie Basin.

Acknowledgements

Implementation of the LEC's Lake Erie Grass Carp Adaptive Response Strategy during 2019-2023 could not occurred without collaboration of all partner organizations, including the GLFC; the U.S. Fish and Wildlife Service; the U.S. Geological Survey; Department of Fisheries and Oceans Canada; the University of Toledo; and natural resource management agencies from Michigan, New York, Ohio, Ontario, and Pennsylvania. Technical review of the 2019-2023 strategy was provided by the Grass Carp Advisory Committee (see Appendix A).

References

Bopp, J.J., T.O. Brenden, M.D Faust, C.S. Vandergoot, R.T. Kraus, J.J. Roberts, L.R. Nathan. 2023. Drivers and timing of grass carp movement within the Sandusky River, Ohio: implications to potential spawning barrier response strategy. Biol Invasions 25, 2439–2459 (2023). https://doi.org/10.1007/s10530-023-03049-9.

Chapman, D.C. J.J. Davis, J.A. Jenkins, P.M. Kocovsky, J.G. Miner, J. Farver, and P.R, Jackson. 2013. First evidence of grass carp recruitment in the Great Lakes Basin, Journal of Great Lakes 39(4):547-554

Conover, G., R. Simmonds, and M. Whalen, editors. 2007. Management and control plan for bighead, black, grass, and silver carps in the United States. Asian Carp Working Group, Aquatic Nuisance Species Task Force, Washington, D.C. 223 pp.

Cudmore, B., L.A. Jones, N.E. Mandrak, J.M. Dettmers, D.C. Chapman, C.S Kolar, and G. Conover. 2017. Ecological Risk Assessment of Grass Carp (Ctenopharyngodon idella) for the Great Lakes Basin. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/118. 115 p.

Flanigan, K., R. Brown, C. Hilling, J. Roberts, C. Kemp, R. Young, C. Mayer. 2023. Evidence of late season Grass Carp spawning in the Sandusky River, Ohio. Poster presentation, University of Toledo Water Task Force Research Showcase, October 20, 2023.

Herbst, S.J., L.R. Nathan, T.J. Newcomb, M.R. DuFour, J. Tyson, E. Weimer, J. Buszkiewicz, and J.M. Dettmers. 2021. An adaptive management approach for implementing multi-jurisdictional response to grass carp in Lake Erie. Journal of Great Lakes Research 47: 96-107. https://doi.org/10.1016/j.jglr.2020.07.006

Herdendorf, C.E. 1987. The ecology of the coastal marshes of western Lake Erie: A Community Profile. U.S. Fish and Wildlife Service Biological Report 85(7.9) Washington, D.C. 171 p. + appendices

Jones, L. A., D.A R. Drake, N. E. Mandrak, C.L. Jerde, M.E. Wittmann, D.M. Lodge, A.S. vander Lee, T.B. Johnson, M.A. Koops. 2017. Modelling survival and establishment of Grass Carp, Ctenopharyngodon idella, in the Great Lakes Basin. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/101. 52 p.

King, N.R., J.L. Hanson, T.J. Harrison, P.M. Kočovský, C.M. Mayer. 2023. Assessment of three methods to evaluate the distribution of submersed aquatic vegetation in western Lake Erie. Hydrobiologia 850:1737–1750. https://doi.org/10.1007/s10750-022-05077-3

Lang, K. (2022). Dead Giveaway: Rising Mortality Rates Suggest Effectiveness of Lake Erie Grass Carp (Ctenopharyngodon idella) Control [Master's thesis, University of Toledo]. OhioLINK Electronic Theses and Dissertations Center. http://rave.ohiolink.edu/etdc/view?acc_num=toledo1651772333192628

Runge, M C., J B. Grand, and M.S. Michell. 2013. Structured decision making. Pages 51–72 in P. R. Krausman and J. W. Cain, editors. Wildlife management and conservation: Contemporary principles and practices. Johns Hopkins University Press.

van der Lee, A.S., T B Johnson, and M.A. Koops, 2017. Bioenergetics modeling of grass carp: estimated individual consumption and population impacts in Great Lakes wetlands. Journal of Great Lakes Research, 43: 308-318.

Appendix A. An Evaluation of accomplishments within the Lake Erie Committee's Adaptive Response Strategy (Grass Carp Advisory Committee, Council of Lake Committees, April 2023)

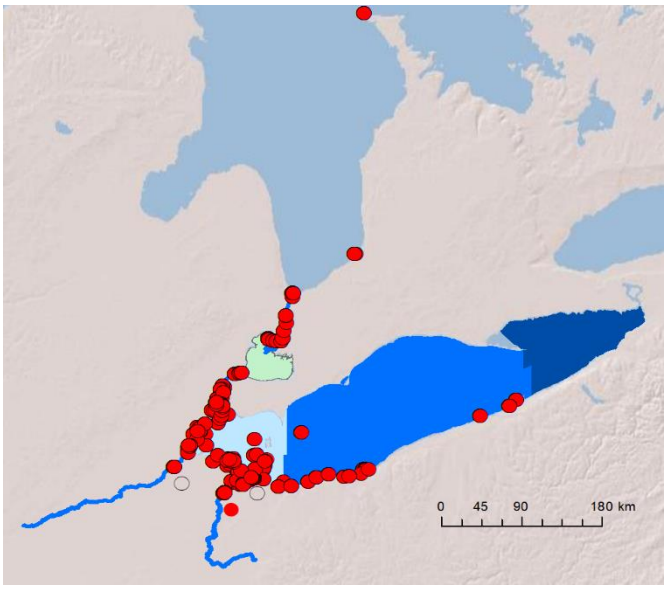
PURPOSE: "Future revisions to the strategy will be informed by changes in Grass Carp population status in the Lake Erie basin, in the sources and pathways for new introductions, and in the availability of new science, tools, and resources for detection, monitoring, and control." Below is a high-level summary of the field work, research, and available data through 2022 throughout the Lake Erie basin as an evaluation of accomplishments within the Lake Erie Committee Adaptive Response Strategy.

OBJECTIVES

Improve the collective understanding of Grass Carp population dynamics, behavior, and impacts in Lake Erie to inform effective management actions.

a) Determine preferred habitats, movement, and behavior in Lake Erie and connecting waters

- ✓ Telemetry data has been the primary means of addressing uncertainties regarding Grass Carp movement.
    - Since 2014, a total of 42 fish are believed to have survived tagging. Eight of the fish have been harvested during removal efforts.
    - The movement of tagged fish has been monitored by 71 receivers in Lake Erie nearshore habitat (<5m depth; <1km offshore) and 65 receivers from fine-scale positioning arrays within various habitats (Sandusky River and hot ponds).
    - Basin-wide seasonal movement patterns exist for 2014-2022 to inform location and timing of removal efforts. Fish are mostly concentrated in the western basin of Lake Erie year-round but travel as far as eastern basin in the fall (September-November). In the summer months (June-August), one fish was detected in the northern part of Lake Huron but has not



been detected since (Figure 1). A second Grass Carp moved north into Lake Huron and back to Lake Erie.

i. Figure 1.: Telemetry seasonal patterns of Grass Carp from 2014-2021 showing movement during the months of June-August

- ✓ Telemetry data also aids in quantifying timing of arrival at known spawning locations and overlap with other species.
    - The arrival of Grass Carp at Brady's Island occurs approximately 80 days after the majority of walleye have left (Bopp et al. 2023; Biol. Invasions)
- ✓ Environmental variations may impact Grass Carp location and behavior; movements upstream to spawning locations can be predicted by photoperiod, temperature, and discharge.
    - **Model predicting spawning as indexed by fertilized eggs based on temp and discharge is available from S. Jaffe thesis and submitted manuscript. Could be correlated to telemetry movement data.**
- ✓ Currently using large, fine-scale telemetry arrays to examine non-native and native fish behavioral responses to abiotic and biotic factors (e.g., removal activities, bait deployment, river discharge, temperature, wind, etc.) to refine removal techniques and evaluate potential impacts of proposed barrier on the Sandusky River.
- ✓ Bait and attractants have been tested for their ability to congregate Grass Carp around feeding stations. Some indication that they may alter fish behavior, however additional studies are required.
- ✓ Ongoing analyses from Justin Bopp looking at VPS data particularly the lower Sandusky River and Brady's Island arrays looking at habitat selection and other factors.
- ✓ R. Hunter (U.T.) is identifying high probability capture locations by mapping fine-scale habitat in the Sandusky River and upper Maumee River, across season, and comparing to capture data.
    - Future combination of the habit data, capture locations, and telemetry-derived location would allow determination of habitat preference and improve capture numbers and efficiency.
- ■ Next Steps: Focus on tagging fishes from various habitat types to understand behavior of the different migratory groups identified and their preferred habitat related to a time series with more focus on Maumee River tagged fish.

b) Determine densities of adult Grass Carp in specific areas of Lake Erie and major tributaries

- ✓ Dr. Qian originally estimated abundance of Grass Carp from 2018-2020 with a modified N-mixture model using capture data from the Sandusky River. There were estimated to be less than 200 Grass Carp in the river at any given time. Spatial distribution is uneven, more in the upper middle section. Revision of the model structure from aggregated to year-specific and additions of 2021 and 2022 capture data suggest a downward trend through time (Figure 2). Measuring fish density using the number of fish/river Km is likely inappropriate for the Maumee River Running the Sandusky model using mark-recapture data may yield meaningless results. More discussion is needed on Maumee-specific model formulation related to fish densities.
- ✓ Justin Bopp's population model was conducted using preliminary catchability and F were derived from abundance estimates and mark-recapture estimates (using two mark-recapture approaches) in

the Sandusky River. Despite different methodologies, abundance estimates were comparable from 2018-2020, ranging from 100-340 fish in the Sandusky River.

- Next steps for the population model included using values of F (likely from 2019) to evaluate relative impact of removal effort on Grass Carp abundance in the model. Other modifications to the model included redefining the spatial regions, survival, seasonal movement, abundance estimates at age, and uncertainty in high-quality reproduction events. Parameters that have not been updated since Dufour et al. 2021 include survival and abundance at age <5 years, stock-recruitment relationship, spawn-per-recruit, and age at maturity.

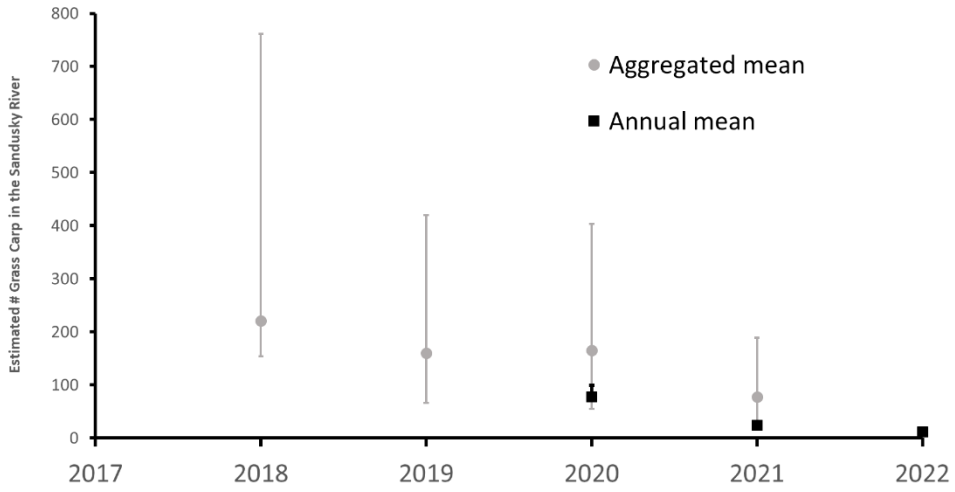


Figure 2. Annual population estimates for Sandusky River generated from a modified N-mixture model.

c) Determine colonization (within area) and expansion (across area) rates of populations

- ✓ Basin-wide telemetry data suggests that Grass Carp are mostly colonizing the western basin of Lake Erie but can travel large distances to the eastern basin, between Maumee and Sandusky Rivers during spawning and as far as Lake Huron and back to western Lake Erie.
- ✓ Other tributaries in Lake Erie (Grand, Cuyahoga, Huron), Lake Michigan (St. Joseph), Lake Huron (Tittabawassee) have been sampled for eggs and larvae to search for evidence of spawning.

d) Identify factors that promote aggregation and collection of Grass Carp

- ✓ Grass Carp physical habitat data and conditions are recorded during removal efforts. This can/has been used to identify habitat conditions that may promote aggregation of Grass Carp including conditions & locations required for spawning to occur.

- ✓ R. Hunter is identifying habitat types where Grass Carp capture is most likely to occur by modeling the relationship between fine-scale, seasonal habitat data (side scan sonar) and capture locations in the Sandusky and upper Maumee Rivers.
- ✓ "SpawnCast", developed by USGS, has been a helpful tool to predict when spawning may occur so field crews can allocate effort to spawning locations.
- ✓ Ongoing quantitative method evaluation has identified tradeoffs between detection probability and per-boat hour capture efficiency. On average, combining trammel nets with electrofishing takes 3 times longer to capture a grass carp than electrofishing alone.

<u>e) Determine levels of reproduction and factors affecting recruitment in Lake Erie</u>

- ✓ Egg sampling is currently the only consistent measure of early life history. They are easier to capture than adults and provide an early assessment of reproduction, as compared to capturing adult fish when they are susceptible to capture (5+ years old).
    - Adult removal methods have captured only 16 Grass Carp age-3 or younger, including a single age-1 fish. Commercial efforts have captured 21 age-3 or younger, including 6 age-1 fish in 2012. Juvenile fish continue to evade captures despite efforts allocated towards their capture over the last five years. Crews from the University of Toledo and USGS-CERC targeted juvenile Grass Carp in 2021 and 2022 using gill nets (11 net nights), mini-fyke nets (251 net nights), beach seines (47 hauls), mini-trawl (58 tows), and backpack/boat electrofishing (>16 hours) in potential river and wetland habitats in the Sandusky and Maumee Rivers.
- ✓ Egg sampling has taken place in high-risk tributaries to determine spatial extent of Grass Carp spawning. To date, evidence of reproduction has only been observed in the Sandusky and Maumee Rivers. Egg captures can be inconsistent and seem to have declined in abundance since 2019 likely due to a shift in prioritizing other streams than the Sandusky River, such as the Cuyahoga and the Grand River (Figure 3).
    - 2022 Egg Sampling Sandusky: >700 likely Grass Carp eggs collected at three sites north of the Fremont spawning grounds. Three larvae have been visually ID'd as Grass Carp; however, we are awaiting genetic confirmation. Larval fish ID ongoing.
    - 2022 Egg Sampling Maumee: No Grass Carp eggs collected. One larva has been visually ID'd to Grass Carp and is awaiting genetic confirmation.

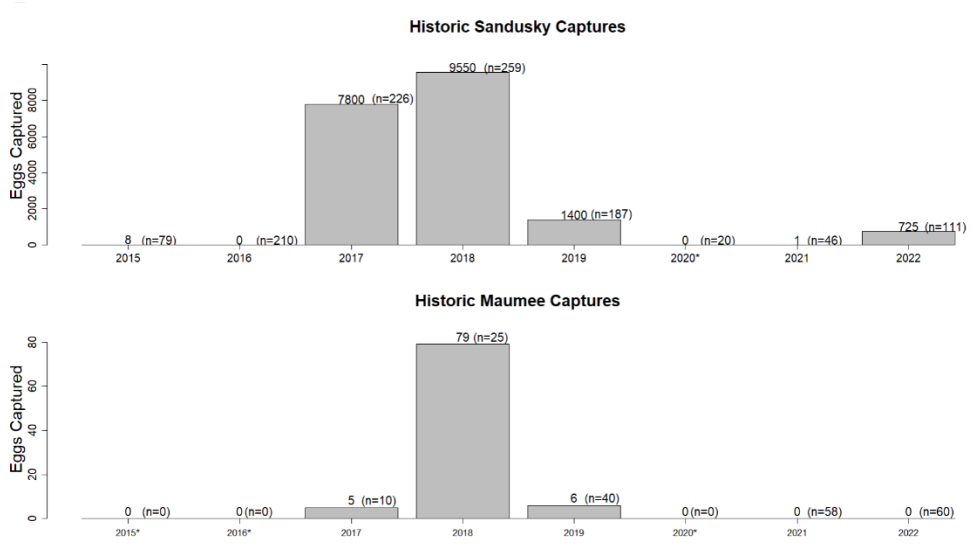


Figure 3. Results of egg sampling in Sandusky and Maumee Rivers.

- ✓ FluEgg Modeling (USGS) is being used to identify potential spawning areas. Twelve potential spawning areas have been identified in the Maumee River and three locations in the Sandusky River.
    - Maumee River: Three between Independence Dam and Grand Rapids Dam, Nine below Grand Rapids Dam.
    - Sandusky River: Embke spawning area (RKM 25.0) near Brady's Island, Ice control structure (RKM 28.9), Downstream from Old Fort bridges (RKM 43.0)
- ✓ Grass Carp spawning activity has been observed May – July (water temperature ≥ 17^{o} and < 24^{o} C) associated with high flows (~85^{th} percentile and higher)
- ■ Next Steps: To utilize SpawnCast in other tributaries that provide access challenges such as the Cuyahoga, Grand, Huron and other streams in that region. Priority tributaries for egg sampling include the Cuyahoga and St. Joseph River. Need to fine-tune understanding of marginal flow and temperature conditions on recruitment and spawning success.

<u>f) Determine expected outcomes from management options using simulation models</u>

- ✓ The goal of the Structured Decision-Making (SDM) process (2016-2017) was to develop a strategy for controlling Grass Carp in Lake Erie to socially and environmentally acceptable levels that would fulfill public trust, minimize management costs, and minimize collateral damage.
- ✓ The Grass Carp Population Model developed by Michigan State University researchers was developed as part of the SDM process has been used to project Grass Carp abundance (time and season) and evaluate actions from SDM. The original model run indicated a seasonal barrier in the Sandusky River, paired with a removal goal of 390 Grass Carp/year, was the most likely to achieve management objectives.
    - Parameters of the model were updated in 2022 with new information to produce a revised removal goal estimate of 373. The top ranked management alternative continues to be a combination of seasonal barriers and removals of Grass Carp.
    - Key takeaway from model simulation trials for different abundances, aggregations, site location, is that mean relative effort decreased as the probability of capture increased. Effort required for detection also decreased as abundance increased.
    - For local removals, the model shows that mean relative effort was an order of magnitude greater for all abundances at low probabilities of capture, but as probability of capture increased, the mean relative effort decreased considerably across all abundance levels.
- ✓ UT-led studies examine the relationship between mortality rates and removal efforts.
    - The annual morality rate is correlated with the number of Grass Carp removed annually. There is a positive relationship. Roughly every 100 Grass Carp removed produces a 5% increase in mortality.
    - Both methods used to calculate mortality showed that Grass Carp mortality rates are increasing, despite the relatively short time-span and limited number of catches. The more effort we exert, the more fish we catch. The more fish we catch, the greater that

mortality increases. These results suggest that control efforts are having a measurable effect on the population.
    - Current control efforts are well-timed to prevent future population increase and spread.
- Next Steps: While we are nowhere near the estimated 47% mortality required to suppress population growth, increased effort, concentrated removals, and a spawning barrier continue to be the best methods to manage the Grass Carp population.

g) Determine baseline conditions for wetlands and/or associated fish communities in Lake Erie to support scientific evaluation of impacts from Grass Carp

- ✓ Nicole King conducted wetland vegetation surveys (rake, hydroacoustics, and OBIA of satellite imagery) A manuscript with these data is published in Hydrobiologia (https://doi.org/10.1016/j.jglr.2020.06.005).
- ✓ To date, little effort has been directed at documenting impacts that Grass Carp may be having on near shore vegetation. Monitoring submerged vegetation in a large ecosystem such as Lake Erie is difficult and expensive. Future studies may take advantage of existing data from the Great Lakes Coastal Wetland Monitoring Program (Central Michigan University) or other available baseline data.

Implement controls to minimize population expansion, by removing fish and/or blocking access to preferred habitats.

a) Remove Grass Carp from the Lake Erie basin, particularly in identified spawning locations.

- ✓ A total of 1,067 Grass Carp have been captured from 2012 to 2022 (Figure 4) of which 534 (50%) tested diploid (i.e., reproductively viable).
- ✓ A total of 127 Grass Carp were captured in the Western Basin of Lake Erie in 2022 with most fish being collected in the Maumee River (n=75) and Sandusky River (n=52). There were an additional 20 Grass Carp captured in other Ohio (n=13) and New York (n=7) tributaries and harbors of Lake Erie.

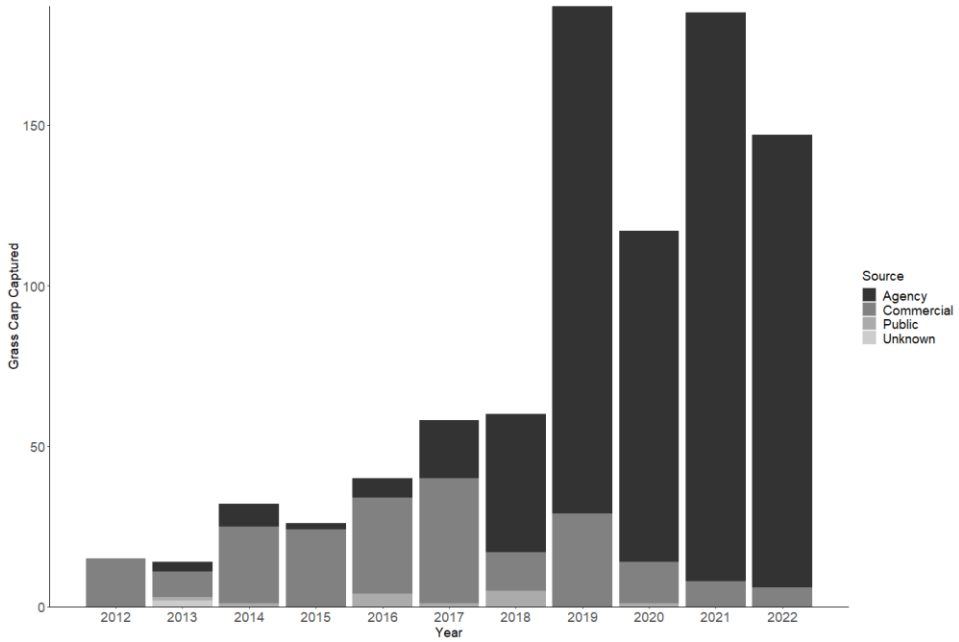


Figure 4. Annual captures of Grass Carp by source

- ✓ Removal effort between 2018-2022 was 45% in the Sandusky River, 24% in the Maumee River, 24% in all MI waters of Lake Erie, and 7% in other OH waters of Lake Erie.
- ✓ Spawning response effort continues to produce the highest capture rates primarily in the Maumee and Sandusky rivers, although they are short in duration and unpredictable, and not occurring at all during some years (Figure 5).
- ✓ High CPE (catch per effort) of exploratory efforts in 2019 was due to a large capture of primarily triploid fish in the Cuyahoga River

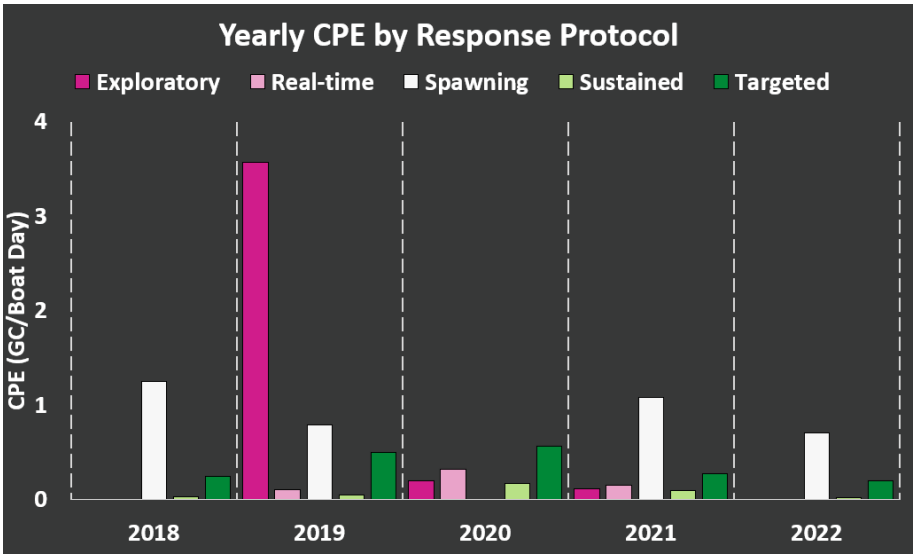


Figure 5. Annual Catch per Effort (CPE) of Grass Carp by response protocol.

- ✓ The development of "SpawnCast" by USGS was helpful for coordinating response efforts by forecasting physical conditions of the target rivers that are optimal for spawning.

- ✓ Sustained and targeted CPE has trended down since '20 for previously sampled locations such as the Sandusky and lower Maumee Rivers. However, program-wide CPE is remaining relatively constant because new hotspots (*e.g.,* upper Maumee River) are being found. Spawning CPE shows high variability, for example, no spawning responses occurred in 2020 due to lower flows and pandemic-related restrictions.
- ✓ Efforts in Canadian waters have been focused on Lake Erie, Lake Ontario, and the Huron-Erie Corridor using boat electrofishing, trap nets, hoop nets, mini fykes, and gill nets.

■ Next Steps: USFWS-Green Bay Grass Carp team developed for Lake Michigan in 2022.

b) <u>Conduct applied research to develop and employ innovative capture and control tools and technologies targeting Grass Carp, such as:</u>

- ✓ The use of telemetry, eDNA, oocyte development, and GSI (gonadosomatic index) was incorporated in testing the effectiveness of bait as attractants (algae and rapeseed) with the goal of controlling Grass Carp through attraction and removal using behavioral and biological traits of Grass Carp.
    - o 800 hoop net sets caught over 10,000 fish (six grass carp) at bait/attractant stations. Results indicate that rapeseed and algae pellets individually or in combination may be a plausible method for altering Grass Carp behavior, however additional studies are needed.
    - o eDNA resulted in variable results over time corresponding with position data, relatively low eDNA concentrations, besides from samples collected during spawning and upstream movements near Brady's Island.
    - o Next steps include moving the study outside of the Great Lakes basin where Grass Carp are more abundant which may provide increased ability to assess the effectiveness of baits and attractants.
    - o Oocyte development provided early support for multiple cell development stages in individuals, indicative of batch spawning or multi spawning events/year.
- ✓ Tracking of "Judas fish" was used to actively track Grass Carp and detect judas fish in conjunction with other protocols in the 2020-2021 seasons. Initial analysis is promising, showing higher probability of capturing Grass Carp after judas fish were detected. Judas fish are rarely recaptured, and crews are typically catching new fish.
- ✓ Robert Hunter has evaluated the efficiency of capture and control efforts with a gear comparison study.
    - o While nets contribute to capture, per boat-hour capture efficiency is significantly decreased when using nets due to the time it takes to set and retrieve nets.
    - o Consider using nets only in high capture probability locations. Treat removal effort as electrofishing that occasionally uses nets where best suited based on capture probability.

Minimize the likelihood of introduction and establishment of new breeding populations of Grass Carp in the tributaries and nearshore areas of Lake Erie and Lake St. Clair.

<u>a) Maintain or improve federal, provincial, and state laws and enforcement to prevent entry of diploid Grass Carp into the Lake Erie watersheds</u>

- ✓ **Federal, provincial, and state laws and enforcement surrounding the control and future introduction of diploid Grass Carp have been maintained, with no changes to regulations.**

b) If feasible, use hydrological barriers to block movements of Grass Carp to potential spawning areas and/or new habitats

- ✓ Determine feasibility of using hydrological barriers to facilitate removal of Grass Carp in Lake Erie tributaries:
    - The Ohio DNR, in partnership with Michigan DNR and GLFC, had evaluated construction of
      seasonal barrier on the Sandusky River to interrupt Grass Carp spawning behavior. A feasibility study by the consulting firms AECOM and Kleinschmidt Group, Inc., was concluded in January 2021 and identified options for constructing both behavioral and physical-hydraulic barriers.
    - Seasonal Barrier Feasibility Studies: Both behavioral and physical barrier options were explored. Behavioral barrier located downstream of Brady's Island. Physical barrier located downstream of State Street Bridge. Locations optimized barrier type while minimizing impacts, maintain river connectivity, and not impair fish and recreational activities.
        - Behavioral Barrier scope: Goal: Reduce the reproductive potential to amplify the effects of removal and other possible control technologies. Criteria: Block passage of at least 75% of adult Grass Carp that encounter the barrier. Uncertainty: AECOM developed an evaluation matrix that looked at technologies and impacts.
    - Oblique Bubble Screen: First round of experiments with surrogate Grass Carp eggs. Completed experiments with live Grass Carp eggs and larvae. Preliminary observations from live Grass Carp egg/larval experiments

ii.

- Next steps: Based on the options presented, Ohio DNR decided to proceed to the design phase of a behavioral barrier near Brady's Island. The partners are now working with the USACE through the GLFER program to further examine feasibility and design. An Action Plan request and funding request from GLRI have been submitted, and work on the design phase is anticipated to begin in 2022.
- Once the Seasonal Barrier Feasibility Study is completed (~2024), need to determine funding source for implementation, identify other possible locations for barrier applications in the basin, Coordinate with the Telemetry Task Group for information on Grass Carp movements.

c) Monitor the frequency and trends of reported Grass Carp in Lake Huron, particularly near Saginaw Bay and the St. Clair River in the main basin, as potential sources of fish

iii.

- ✓ Identifying sources of Great Lakes Grass Carp using otolith microchemistry
    - To determine whether water Sr:Ca and Ba:Ca signatures of known and potential Grass Carp spawning tributaries to Lake Erie are consistent with data from prior years/studies.
    - Determine whether diploid and unknown ploidy Grass Carp are aquaculture-source or wild fish using otolith stable isotope analysis.
    - Identify natal river of wild Grass Carp using otolith microchemistry (Sr:Ca and Ba:Ca)

- ✓ A total of 23 fish have been captured in the Lake Michigan Basin since 2021, with 14 from the St. Joseph River. Seven total fish have come from public bowfisher harvests and 16 from agency efforts.
- ✓ No fish have been captured or observed in the Tittabawassee River or Saginaw Bay watershed during follow up efforts since the incidental capture of a single diploid fish in 2020.