Sculpin Workshop

Great Lakes Fishery Commission

USGS Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI

June 5 – 6, 2017

WORKSHOP REPORT

For the Reestablishment of Native Deepwater Fishes Research Theme

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WORKSHOP OVERIEW

The Sculpin Workshop was held June 5–6, 2017, in Ann Arbor, Michigan. The purpose of this workshop was to discuss historical and current research relevant to sculpin biology, ecology, and re-establishment efforts in the Great Lakes and Lake Champlain in support of the Great Lakes Fishery Commission (GLFC) Board of Technical Experts' Re-establishment of Native Deepwater Fishes research theme (Zimmerman and Krueger 2009). The species considered were slimy sculpin (*Cottus bairdi*), deepwater sculpin (*Myoxocephalus thompsonii*), and spoonhead sculpin (*Cottus ricei*). The objectives of the workshop were to 1) consolidate and update the current body of knowledge on sculpin in relation to this theme, 2) evaluate and update sculpin-related hypotheses from Zimmerman and Krueger (2009), and 3) use this information to guide future research proposals and plans regarding sculpin and native deepwater fish re-establishment.

Eighteen attendees representing five academic institutions, one provincial agency, and one binational and two federal agencies participated in the workshop. The workshop featured two presentations, one on sculpin spawning and one on fish and mussel fauna in relation to thermal and chlorophyll characteristics at Julian's Reef, Lake Michigan, as well as facilitated discussions regarding the status and importance of sculpin research, revisiting Zimmerman and Krueger (2009) hypotheses for sculpin, and brainstorming and development of new ideas for sculpin research and restoration.

Workshop participants concluded that although most Zimmerman and Krueger (2009) hypotheses were still relevant, some are currently more feasible to explore than others, based on existing information availability and on-going or proposed research efforts (Table 1). The group also formulated the following six broad topics that should be addressed in future research: (1) genetics; dispersal, and early-life history; (2) spawning; (3) round goby (*Neogobius melanostomus*) -sculpin interactions; (4) age, growth, and mortality; (5) diet; and (6) use of long-term datasets.

Table 1. Hypotheses for Great Lakes sculpins from the Re-Establishment of Native Deepwater Fishes theme paper (Zimmerman and Krueger 2009), current state of knowledge, and future considerations

Hypothesis	State of Knowledge	Future Considerations
H1. Temporal and spatial differences in sculpin spawning and early life history are adaptations to local spawning conditions.	Sculpin spawning is still poorly understood in the Great Lakes / Lake Champlain	Year-round sampling of gametes, eggs, and larvae should be implemented to determine spatiotemporal patterns in spawning. Histological sampling and gonadosomatic index (GSI) should be used to gain a better understanding of spawning timing and fecundity. Larval survival should be studied to gain insight into recruitment. Analysis of genetics would be beneficial for reliable species identification and demographics. This work should be accomplished basin-wide, though approaching the question one lake at a time could lead to greater inference for sculpin spawning, including habitat use, as well as the best gears and techniques for sampling.
H2. Benthic versus pelagic habitats of sculpin fry influence dispersal distances and contemporary population structure within and among lakes.	Isolation by distance analyses indicate that slimy sculpin are genetically panmictic in lakes Champlain and Ontario. More information is needed.	A review of studies of other sculpin species (e.g., mottled sculpin, *Cottus bairdi*; fourhorn sculpin, *Myoxocephalus quadricornis*) may offer useful insight on this topic. Isolation by distance analyses of samples from opposite sides of each lake would answer questions about population structure. Samples from offshore reefs surrounded by deepwater would provide increased resolution for population structure.
H3. Variables influencing early life history events (egg and fry life stages) have a larger influence on slimy, spoonhead, and deepwater sculpin population dynamics than variables influencing juvenile and adult survival.	This hypothesis has not been evaluated.	Recruitment events potentially could be studied by capturing the smallest age class and analyzing length distributions. This method would require determining the best way to sample this age class, including gears to use, habitats to target, and timing for sampling. Age-length distribution data would be preferable, but would first require the determination of a reliable aging structure in sculpins. Studies of the population dynamics of juveniles and adults also cannot occur until a successful aging method is developed.
H4. The decline of amphipods Diporeia spp. and the increase	An MS thesis at MSU is underway to determine how	Behavioral studies on sculpin (deepwater and slimy) and round goby interactions, similar to previous studies of

of quagga mussels in the profundal zone will affect sculpin species.	depth distribution patterns and sculpin condition are influenced by these events. While dreissenid mussel invasion is hypothesized to be responsible for *Diporeia* collapse, no mechanism for this has yet been identified and confirmed.	mottled sculpin, would also be highly valuable. Synthesis of previous and development of new diet studies of benthic fishes would offer insight into effects of all of these events on benthic trophic dynamics.
H5. Live transfer is a feasible option for reintroducing sculpins to Lake Ontario.	Deepwater sculpin transfer seems most feasible. Transfer of slimy sculpin is possible, but may require culturing. Spoonhead sculpin are too scarce for feasible transfer.	Given that deepwater sculpin appear to have recovered in Lake Ontario, this hypothesis is not as relevant now.

WORKSHOP AGENDA
June 5

1:00 – 3:30	Discuss status of sculpin research in the Great Lakes/Lake Champlain • Which hypotheses/topics have been studied or completed from Zimmerman and Krueger (2009)? • Which lakes and which species? Which hypotheses are no longer relevant?
3:30 – 3:45	Break
3:45 – 5:00	Discussion of new topics, hypotheses, ideas for study • Which lakes? • Which species?

June 6

8:30 – 10:00	Continue discussing new topics What is the availability of data for these projects? • Projects with data available (which lakes?) • Projects with samples available that need to be processed • Projects that would require data collection not already occurring (e.g., more days at sea, etc.)
10:00 – 10:15	Break
10:15 – Noon	Continue data discussion Collaborations to be made Next steps

WORKSHOP PROCEEDINGS

Summary of Sculpin Presentations

Presentation 1 – David Jude (presented by John Janssen)
The results of an investigation of deepwater sculpin spawning in Grand Traverse Bay were presented. Sampling via remotely operated vehicle (ROV) occurred December 2016 – March 2017 at depths of 3–133 m; about 10 hours of video footage has been collected. No spawning sites were identified, but female deepwater sculpin were found to be gravid in January and spent in February. While this study did not reveal spawning locations for deepwater sculpin, it has offered some insight into the timing of sculpin spawning in Grand Traverse Bay.

Presentation 2 – John Janssen
The goal of this study was to find lake trout (*Salvelinus namaycush*) fry. This lake trout study took place on Julian’s Reef, Lake Michigan. Sampling (ROV suction sampling) occurred in late May, 2017, at depths of 30–40 m, and 60 m. While slimy sculpins were not the primary focus of this study, several young (probably yearling) slimy sculpins were captured as bycatch. Round gobies are now abundant at Julian's Reef, but some slimy sculpin reproduction seems evident there. Dead quagga mussel beds were also observed.

The larval deepwater sculpin work is in presented in Wang (2013). Chlorophyll content was higher in coastal waters with spikes near the thermal bar. Sculpins were more prevalent and seemed to have greater somatic growth inside the thermal bar than outside the thermal bar and greater mean total length nearshore rather than offshore, which seems to be concurrent with chlorophyll patterns. Future studies should investigate the influence of quagga mussels on chlorophyll content (e.g., Lakes Michigan and Superior) and effects of alewife (*Alosa pseudoharengus*) on deepwater sculpin.

Summary of Discussion Topics

Assessment of Zimmerman and Krueger (2009) Sculpin Hypotheses

Hypothesis 1. *Temporal and spatial differences in sculpin spawning and early life history are adaptations to local spawning conditions.*

- ***Q1.1*** *Does the spawning of slimy, spoonhead, and deepwater sculpins differ temporally and spatially within and among lakes? What environmental variables (e.g., substrate, depth, temperature) are associated with these differences?*

- ***Q1.2*** *Does emergence time of fry differ among slimy, spoonhead, and deepwater sculpins within and among lakes? What environmental variables are associated with these differences?*

Spawning– Limited information exists on spawning and early life history of all sculpin species in the Great Lakes. Spawning habitat has yet to be successfully identified in the Great Lakes or Lake Champlain. Identification of such habitat and associated environmental variables, along with further research of spawning timing, would be necessary to make comparisons among lakes and species. Measurements of fecundity, histological assessment of gonads, and gonadosomatic index (GSI) calculations should be performed for each species in each lake to better understand sculpin spawning. While some GSI data for deepwater sculpin are being collected for Lake Ontario, sampling should be more consistent, performed year-round, and expanded to acquire other data necessary to understand the reproductive ecology of Great Lakes sculpins.

Early life history– "Emergence time of fry" was defined as hatching, and "fry" were considered to be the larval stage for our purposes. Larval sampling should be performed to assess spatiotemporal patterns and estimate recruitment and larval survival. A study of larval drift in streams would provide information about slimy sculpin early life history, as well.

Sampling considerations– Year-round sampling of sculpin gonads is necessary to better understand reproduction in each species. The group discussed options for expanded sampling in the winter, and noted that Wisconsin DNR has a vessel with a heated deck that could be used for winter sampling and the potential to contract with commercial trawlers in Lake Michigan that are collecting bloater (*Coregonus hoyi*) in January.

Hypothesis 2*. Benthic versus pelagic habitats of sculpin fry influence dispersal distances and contemporary population structure within and among lakes.*

- ***Q2.1*** *What is the typical population structure of slimy, spoonhead, and deepwater sculpins? Does the spatial scale that defines a population differ among species?*

- ***Q2.2*** *Are spatial patterns in gene flow among populations associated with physical characteristics, such as bathymetry or current direction?*

- ***Q2.3*** *Do sculpins have source and sink populations? Are environmental variables (e.g., food availability, temperature, or contaminant levels) associated with highly productive source populations? Are downstream populations of deepwater sculpin (e.g., Lake Huron) regularly infused by drift of larvae from upstream populations (e.g., Lake Superior)?*

This hypothesis is important for understanding sculpin ecology, but little information is available. Isolation by distance (IBD) analyses in Lake Champlain indicated that slimy sculpin are genetically panmictic (Euclide et al. 2017). Two samples of slimy sculpins from the eastern and western ends of Lake Ontario showed no IBD. The group suggested checking with Wendy Stott, USGS, about whether population structure analyses have been performed. The Stott lab has been working on some multi-species analyses that include sculpins. After results are published, any remaining uncertainties could be addressed through a similar analysis (samples from opposite sides) for each lake and species would provide information about the level of genetic differentiation within each lake. This information would provide a starting point for answering questions 2.2 and 2.3. Given that slimy sculpin populations appear to be panmictic, there were also questions about whether slimy sculpin larvae are only benthic, as has been suggested in the literature (Madenjian and Jude 1985), and whether adults move long distances to spawn. Recent work on deepwater sculpin genetics has indicated that this species exhibits low levels of genetic differentiation throughout the Great Lakes (Welsh et al. 2017). In addition, previous studies, if they exist, on other species (e.g., mottled sculpin and fourhorn sculpin) may eventually guide future research on this topic.

Hypothesis 3. *Variables influencing early life history events (egg and fry life stages) have a larger influence on slimy, spoonhead, and deepwater sculpin population dynamics than variables influencing juvenile and adult survival.*

- ***Q3.1*** *How does recruitment differ among sculpin species and lakes, and why?*

- ***Q3.2*** *Does juvenile and adult survival differ among species and lakes? What variables account for these differences?*

- ***Q3.3*** *Why have spoonhead sculpin populations declined in Lake Michigan?*

- ***Q3.4*** *Are contemporary conditions compatible for successful reintroduction of spoonhead sculpin in Lakes Erie and Ontario and for reintroduction of deepwater sculpin in Lake Ontario?*

To study recruitment events, we considered analyzing length distribution data of the smallest age class collected to determine recruitment. Some data for smaller size classes exist already for Lake Ontario, but determining whether animals were age-0 or age-1 was difficult. Comparing age-length data with ages from otoliths is not straightforward, so survival of juveniles and adults cannot be estimated until an appropriate aging structure is identified. In addition, analyses of length-frequency distributions would require knowledge of the minimum size that fully recruits to the gear, as well as whether gears and vessels are sufficiently similar to facilitate comparison of recruitment estimates among lakes or locations. Questions concerning spoonhead sculpin (Q3.3. and Q3.4) are not currently relevant because they are not related to species coexistence, except in Lake Superior, where all three species are abundant. Additionally, deepwater sculpin appear to have recovered in Lake Ontario, making questions regarding reintroduction no longer relevant.

Hypothesis 4. *The decline of amphipods* Diporeia spp. *and the increase of quagga mussels in the profundal zone will affect sculpin species.*

- ***Q4.1*** *Will the change in invertebrate production have a larger effect on slimy sculpin than on deepwater sculpin (the former are more reliant on* Diporeia*)?*

- ***Q4.2*** *In response to* Diporeia *declines, have sculpins shifted to feeding on opossum shrimp in deeper waters than previously observed?*

- ***Q4.3*** *Does the increased complexity of benthic habitat afforded by quagga mussel shells reduce lake trout and burbot predation on sculpins?*

Slimy sculpin select more for *Diporeia* over *Mysis* than deepwater sculpin in Lake Michigan, which indicates that the forced switch to alternate prey sources following *Diporeia* collapse may have a larger negative effect on slimy sculpin than deepwater sculpin in the Great Lakes

(Hondorp et al. 2011). Recent trends of deepwater sculpin increases and continued declines of slimy sculpin in Lake Ontario (Owens and Dittman 2003, Weidel et al. 2017) may potentially support this claim. However, slimy sculpins could be more resilient than expected to feeding pressures because they are generalists.

In addition to *Diporeia* declines and dreissenid mussel invasion, further research on the effects of round goby on sculpin species in the Great Lakes is necessary. An ongoing MS thesis at Michigan State University will address aspects of these issues by analyzing spatiotemporal (depth) relationships between sculpins and round gobies and changes in sculpin condition relative to the timing of round goby and dreissenid mussel invasions and *Diporeia* declines. We also suggest that behavioral studies similar to a previous study on mottled sculpin (Janssen and Jude 2001) should be performed to understand how round gobies interact with other sculpin species. Specific questions of interest include determining whether round gobies negatively affect sculpin within a territory or only when shelter habitat is limiting, and whether physiological condition of sculpin are affected in areas with abundant round goby.

Other ideas/suggestions for this hypothesis:

- Dreissenid mussels may potentially provide habitat for benthic invertebrates and food for sculpins, which could also lead to a decline in chironomids because of a reduction in available habitat for burrowing.
- What are the sculpin-related implications of round goby predation on dreissenid mussels?
- There appears to be evidence that slimy sculpin populations fluctuate on a five-year cycle, in addition to the decline observed from *Diporeia* collapse, in Lake Ontario.

Hypothesis 5. *Live transfer is a feasible option for reintroducing sculpins to Lake Ontario.*

- ***Q5.1*** *What are the logistical challenges of collecting, handling, transporting, and introducing sculpins to new locations?*

- ***Q5.2*** *How does the genetic diversity of the relict population of deepwater sculpin in Lake Ontario compare with that of populations in the upper Great Lakes?*

- ***Q5.3*** *What are the genetic and ecological risks of transplanting deepwater sculpin from upstream populations to downstream populations?*

These questions become less relevant in light of the recent recovery of deepwater sculpin in Lake Ontario (Weidel et al. 2017). However, the group still discussed the feasibility of translocation and culture of sculpin species. Slimy and deepwater sculpin translocation is feasible, though slimy sculpin might need to be cultured, and deepwater sculpin can experience barotrauma. Spoonhead sculpin seem to be the least feasible for live transfer or rearing because of their scarcity.

In addition to live transfer, the group discussed the recovery of deepwater sculpin and decline in abundance of slimy sculpin in Lake Ontario. The group was interested in laying out a conceptual model for the recovery of deepwater sculpin. For example, the group discussed that predation by nonnative alewife on deepwater sculpin larvae could have been one factor in the decline (as evidenced by the movement of alewife into deeper waters). In addition, recent genetic analyses indicate that deepwater sculpin recolonized from the upper Great Lakes (Welsh et al. 2017). Finally, there was discussion that understanding the potential causes of the decline in deepwater sculpin abundance in Lake Ontario would be helpful for understanding population dynamics in the lake, and elsewhere.

Priorities for Future Sculpin Research

Workshop participants created a large list of new topics for future research. Six priorities for sculpin research were discussed in detail and collaborators delegated responsibilities to further develop these ideas. New research topics included: (1) genetics, dispersal, and early-life history; (2) spawning; (3) round goby and sculpin interactions; (4) age, growth, and mortality; (5) diet; and (6) long-term population dynamics and use of long-term datasets. The list of other topics can be found in Appendix 1.

Genetics, Dispersal, and Early-life History

This topic will address issues with taxonomy and identification of sculpin, improve our understanding of sculpin life history characteristics, and contribute to constructing models of sculpin population demographics critical to informing re-establishment efforts.

Genetics

Leaders: Devin Bloom, Peter Euclide, Ellen Marsden

Population genetics work on sculpin species throughout the Great Lakes and Lake Champlain would provide an understanding of population structure. In addition, genetic studies of sculpin may be beneficial in resolving taxonomic confusion. This can be achieved by collecting additional samples with USGS and the University of Vermont (UVM) and evaluating the status of archived samples throughout the region.

Dispersal & Early Life History

Leaders: John Janssen, Mark Vinson, Ed Roseman, Bo Bunnell, Ed Rutherford

Larval sampling and use of ROVs and diving would aid in identifying spawning habitat and ideal settlement habitat for larvae. While slimy sculpin larvae have been previously considered benthic, it is uncertain if they are exclusively benthic. Additionally, an understanding of the differences and similarities between life histories and genetics, making use of both neutral markers and next generation sequencing technologies, is necessary. All of this knowledge would be particularly useful for answering questions related to the hypotheses discussed above.

Spawning

Leaders: Ellen Marsden, Kelly Robinson, and Shea Volkel

In addition to identifying spawning location, identifying timing of spawning is critical to understanding sculpin life history. The first step is to obtain monthly estimates of the gonadosomatic index (GSI) of females regionally. Along with reviewing historical data from Jude (personal communication), a sampling timeline for each lake has been proposed below (Table 2). The sampling timeline was based on observations of mature and spent animals, as well as feasibility of sampling given ice conditions on the lakes and vessel availability? For Lake Michigan, monthly sampling may be possible if funding is received and additional data may potentially be acquired from the FWS Two Rivers commercial fishery. Lab and field experiments to determine timing of and habitat for spawning also would be helpful.

Table 2. GSI Sampling Timeline.

Lake	**Sample Months**
Superior	May – October
Michigan	September, monthly (pending funding)
Huron	Quarterly (April, July, October, December)
Champlain	Monthly, April – November
Ontario	April, July, October

<u>Round Goby and Sculpin Interactions</u>

In addition to concerns with *Diporeia* collapse and dreissenid mussel invasion posed in Zimmerman and Krueger (2009), the recent invasion and spread of round goby could be contributing to sculpin declines in the Great Lakes. Round goby is a highly aggressive species that shares a similar life history to native benthic fishes, such as sculpins (Janssen and Jude 2001). Round goby have also been linked to the decline of native benthic species, including the mottled sculpin (Dubs and Corkum 1996, French and Jude 2001). Therefore, round goby likely are interacting with other cottid species, and the nature of these interactions could negatively affect sculpin. Research efforts are necessary to determine if such interactions occur. For these studies, Lake Champlain may be useful as a comparison lake because it currently lacks round goby. Collection of pre-invasion data would be valuable, as an invasion may occur within a few years.

Spatiotemporal Overlap

Leaders: Bo Bunnell, Darryl Hondorp, Brian Weidel

Substantial evidence of spatiotemporal overlap or segregation between round goby and sculpin would support the hypothesis that these species have the potential to interact. Recent evidence indicates that round goby have been colonizing offshore to depths > 50 m (Schaeffer et al. 2005, Walsh et al. 2007), which may overlap with various sculpin species. Spatiotemporal overlap between round goby and sculpin has already been observed in April, in recent years, in Lake Ontario (B. Weidel, personal observation). Analysis of historic trawl data and ongoing surveys by the USGS in the Great Lakes could be used to determine depth distribution patterns of these sculpins and round goby, as well as any temperature-mediated effects, where data are available. Additionally, efforts by John Janssen will determine round goby migration patterns, including overwintering habitats.

Food and Spawning Habitat Competition

Leaders: Stephen Riley (diet), Darryl Hondorp (spawning habitat)

Competition is one mechanism through which sculpin could be negatively affected by round goby. This could either be through food or habitat competition or both. Sharp declines in *Diporeia* abundance since the 1990s and increased reliance on mysids by sculpins and other fishes may limit prey resources, and round gobies may potentially exacerbate this issue. Slimy sculpins have been reported to have a higher selectivity for *Diporeia* over *Mysis* than deepwater sculpin (Hondorp et al. 2011), so slimy sculpin could be more vulnerable than deepwater sculpin to prey limitation. Diet studies should be performed and synthesized to address this concern. These methods could include isotopes, sulfur from liver tissue, fatty acid content, and evaluating existing CSMI data. In addition, the multiplicative effect of gobies locally depleting small mussels should be evaluated.

A combination of field and laboratory experiments could be used to determine if spawning habitat competition occurs between sculpin species and round goby. Lake assessments should aim to successfully identify spawning habitat for sculpins, which may be investigated in areas with sandy and rocky substrate using SCUBA and ROV methods. Stream experiments could also contribute to understanding interactions between slimy sculpin and round gobies. Laboratory experiments with more sculpin species and round goby would be useful for understanding behavioral interactions between these species.

Cross-lake Comparison

Leader: Kelly Robinson, Shea Volkel, Matt Kornis

A literature review of existing studies that have evaluated sculpin species in lakes with or without round gobies, or with different predator densities, would provide some baseline information for expectations of sculpin-goby interactions in the Great Lakes. This review would encompass peer-reviewed journals and grey literature.

The invasion of round gobies in the Great Lakes occurred around the same time period as dreissenid mussel invasion and *Diporeia* collapse, so it may be difficult to parse out which of these events, if any, are responsible for the observed declines in sculpin abundance in this system. A comparison of relevant unique lake characteristics (e.g., temperature, predator densities) along with detailed evaluation of differences in the timing and magnitude of these ecosystem changes (e.g., differences in round goby densities) relative to declines in sculpin abundance among lakes may reveal distinct patterns under certain conditions.

Predation

Leader: Brian Weidel

Direct predation on juvenile sculpin could provide another mechanism through which round goby may be negatively affecting sculpin. Round goby diet studies could be insightful.

Age, Growth, and Mortality

Leaders: Timothy O'Brien

In addition to spawning and early life history, it is also necessary to study the life histories of juveniles and adults to construct comprehensive models of sculpin population structure and dynamics including growth and mortality estimates. Determining reliable aging structures for these species is a major obstacle to understanding population dynamics. This may be addressed in the upcoming GLFC-sponsored prey fish age estimation workshop (2018–2019). It would likely be more convenient to start with slimy sculpins.

Diet
Leaders: Tim Johnson, Kelly Robinson

Previous and on-going diet studies should be synthesized to explain and summarize sculpin trophic dynamics.

Use of Long-Term Datasets

Leaders: Kelly Robinson, Andrew Muir

The USGS has amassed a long-term trawl survey dataset that could be useful for projects related to understanding sculpin population dynamics, growth, condition, or other topics. The group discussed the potential intended uses of these data, as well as aspects of data archiving and collection practices that will be helpful in the future. For example, the group discussed a protocol of random sampling of 50 fish per trawl for each species for length/weight measurements, which may be later adapted if this sample size is not feasible. In addition, the group thought that the data could be analyzed in order to inform future collection efforts, including spatial resolution and other needs. Overall, this topic was targeted at how to make the most of the long-term dataset already available and how to enhance collection opportunities into the future.

Relevance of Sculpin to Management

In a COSEWIC (2006) report, deepwater sculpin were once listed as a 'Special Concern' species. While the Lake Ontario population that was once considered to be extirpated appears to be recovering in recent years, it is early to predict the future trajectory of this population, and biomass estimates for both slimy and deepwater sculpin have otherwise been declining since the 1990s. Investigation of these declines would offer valuable insight to the GLFC regarding the Re-establishment of Native Deepwater Fishes research theme, especially since sculpin have historically been a substantial portion of demersal fish biomass in the Great Lakes (Bronte et al. 2003, Owens and Dittman 2003, Bunnell et al. 2006, Roseman and Riley 2009). Declines in sculpin abundance and changes in distribution may dramatically shift the ecological structure of these systems.

Because sculpin are an important prey source for lake trout and burbot (*Lota lota*; Van Oosten and Deason 1938, Owens and Bergstedt 1994, Madenjian et al. 2002) and link between benthic and pelagic food webs (Fratt et al. 1997, Madenjian et al. 1998), sculpin population declines may also have cascading effects on higher trophic levels in pelagic systems. For example, declines in sculpin abundance, a preferred prey for siscowet lake trout, could potentially lead lake trout to compete more with Chinook salmon (*Oncorhynchus tshawytscha*) for alewife. Both sculpin species could also be useful in evaluating ecosystem health as both have been used as bioindicators in previous studies. Workshop participants discussed the merits of trying to create more interest from the public about sculpin, as in New York they are seen as a unique and interesting species.

As managers did not participate in the sculpin workshop, the theme leaders should obtain perspectives on the importance of sculpins in Great Lakes fishery management. Questions for managers include: (1) how important are sculpins to lakewide fish community objectives and does that priority vary across lakes; (2) what management levers are available to influence sculpin dynamics; and (3) could managers benefit from greater knowledge on sculpin ecology and life history. The most obvious management levers include adjusting predator-prey ratios through changes in stocking or harvest and re-establishment of sculpin populations through either hatchery rearing or translocation. With the establishment of deepwater sculpins in Lake Ontario, further reintroduction opportunities seem limited. The workshop team will pursue these questions with fishery managers and update this document as management perspectives resolve.

A SUMMARY OF FUTURE RESEARCH UNDER THE RE-ESTABLISHMENT OF NATIVE DEEPWATER FISHES THEME

Based on the presentations and discussions during the workshop, further research on sculpins is imperative to addressing the GLFC’s Re-establishment of Native Deepwater Fishes research theme. Despite the ecological importance of sculpins in freshwater systems, these species have generally been dismissed as bycatch and have been neglected in research and management efforts. In light of recent ecosystem changes in many of the Great Lakes, such as *Diporeia* collapse and invasive species introductions, along with observed declines in sculpin populations in recent years, with the exception of deepwater sculpin in Lake Ontario, it is urgent that we gain a better understanding of sculpin biology and ecology to manage and restore these species. This report outlines a strategic plan to address these issues by identifying specific topics that future research should address.

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APPENDIX 1

Full list of new topics and questions related to sculpin research in the Great Lakes and Lake Champlain

- Spring sampling in Yankee Reef, Lake Huron, yields only very small slimy and deepwater sculpin. Why are there only small individuals at this location? What is the size distribution of these individuals? What is the maximum size and growth? What is the productivity of Yankee Reef?

- Why are slimy sculpin so much smaller in Lake Champlain than in the Great Lakes?

- What causes depressions in the sediment (observed by David Jude in Grand Traverse Bay)? Are they related to sculpin feeding or spawning?

- There should be more research into why (ecologically) and how deepwater sculpin returned to Lake Ontario. There could be other datasets that would provide insight into these questions (e.g., Environment Canada's contaminant program, joint USGS / MNRF / NYSDEC sampling program).

- Are sculpin a more stable prey source for lake trout than alewife, which are prone to boom and bust cycles? An evaluation of this question would require determining the nutritional and energetic value difference among prey species.

- What role do slimy sculpin and round goby play in lake trout diets?
    - There has been a recent explosion of the lake trout population in Lake Champlain, and slimy sculpins are a large part of their diet.
    - We hypothesize that the recent increase in abundance of the deepwater siscowet form of lake trout in Lake Superior was partially influenced by the availability of sculpin species as forage.

- There appears to be a positive relationship between slimy sculpin and lake trout density in Lake Ontario. Are slimy sculpin declining because they are effectively being squeezed out (deepwater sculpin in deeper waters and lake trout in shallower waters)? Was there a bottleneck and loss of diversity in slimy sculpin after the crash of *Diporeia* in Lake Ontario?

- Has the ecological role of sculpins changed over time (prey and diet)? Have round gobies been invading their niche?
    - The time series of data that are available (i.e., trawl survey data from 1970s–present) do not provide a good baseline for sculpin abundance or biomass.
    - Could lake trout diet studies from the 1930s enhance the time series of data about sculpins?

- What would be accomplished with reintroduction at this time, and where, if at all, would reintroduction take place?

- Very little is known about sculpin population dynamics, including:
    - Predation as a potential driver of slimy sculpin dynamics.
    - Early life history bottlenecks.
    - Processes that facilitate diversity (both genetic diversity within species and diversity of species within the lakes).
    - Genetic relationships.

- What other environmental factors might influence sculpin populations, (e.g., dissolved oxygen, sediment contamination)? EPA prey fish monitoring work might provide some data to evaluate this question (Beth Murphy as contact).

- What abiotic variables are required for sculpin spawning. For example, do sculpin need or prefer cavities, wood recruitment, substrate, spawning in the littoral (or litter) zone?

- Are the slimy sculpins found in tributaries to the Great Lakes from the same population as those in the Great Lakes proper? Is there population connectivity or structure between those in tributaries and lakes?

- Additional data needs to fill gaps knowledge:
    - Sampling rocky habitats
    - Where are round gobies going when they migrate offshore in the winter?
    - Better understanding of lake trout consumption of sculpins in Lake Ontario. Data analysis of lake trout diets is underway by scientists at MNRF and USGS.
    - Studies of feeding in early life history stages (see priorities)

- There are remaining questions about the taxonomy of sculpins in the Great Lakes and other regions.

- Do high flow streams act as a refuge for slimy and mottled sculpin from round gobies (e.g., mottled sculpin were found in high velocity waters near the Bluewater Bridge, Lake Huron, but no gobies were present)?

- In freshwater, early feeding of benthic fishes has not been extensively studied. Some suggested methods for acquiring early feeding data are to use modified ROVs with electric shock, benthic sled sampling, and experimenting with different kinds of spawning substrate (e.g., wood).

- Sculpins can be cannibalistic. Could this lead or contribute to juvenile mortality? Could juvenile mortality be observed as a skewed increase in mean length data?