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Keynote Speakers

Trophy Muskellunge Populations and Fisheries Can Be Sustainable

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Sustainability of trophy Muskellunge (*Esox masquinongy*) populations and fisheries was examined by using long-term catch data from Muskies Inc. and Muskies Canada, along with 35 years of Muskellunge data and cleithra (2,633) submitted to *The Cleithrum Project*. Muskellunge catch has increased substantially over the past five decades, but harvest has reduced greatly because of increased size limits, in Ontario set on a biological basis using growth potential, and voluntary catch and release promoted by organized, enlightened Muskellunge anglers. Science transfer has been fundamental in encouraging interaction between anglers and fisheries professionals, promoting communications, awareness, and improved management, assessment, and research. The Cleithrum Project exemplifies this interaction, and although fewer samples have been submitted in recent years, they indicate a significant increase in total length and weight of harvested "trophy" samples; this pivotal change occurred in the mid-1990s (mean size – 1979-1994, TL=105.9 cm, TW=9.01 kg; 1995-2013, 119.0 cm, 11.74 kg). Cleithrum Project age data were used to estimate total annual mortality rate of trophy Muskellunge, using a predictive mortality rate-longevity relationship (Hoenig 1983). Total annual mortality rate (A) ranged from 15 to 23%, corresponding to a maximum age of 26 to 16 years. Estimated annual mortality rate of trophy Muskellunge increased only slightly over the past 35-yr period – 13 to 14.8%. Up to the mid-1990s, mortality rate increased, but since then, there has been a substantial decrease. Although angling pressure has increased in recent years, size and mean age of angled harvested trophy Muskellunge have increased substantially (10.2–15.8 yr) with an associated decrease in mortality rate (31.0–21.9%), suggesting an overall increase in mature populations and reproductive potential. Considering instantaneous mortality rate and exploitation, to ensure that trophy Muskellunge and fisheries are sustainable, fish younger than 15 should not be harvested (Z=29%, where F=M) or exposed to additional fishing mortality. Management for large size can have unexpected outcomes because large, older fish are increasingly sensitive to all forms of stress (e.g., VHS mortalities). However, if Muskellunge populations are managed for high reproductive capacity (protecting fish to an old age and large size), they will be more reproductively resilient, producing larger year classes, better-sustaining trophy populations and fisheries – investing in longevity and greater reproductive capacity.

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The Muskies Inc. Lunge Log Database . . . 370,000 Muskies and Growing

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Muskies Inc. is the largest organization in the world dedicated to the conservation of Muskellunge (*Esox masquinongy*) and the enjoyment of muskie fishing. It was formed in 1966 by Gil Hamm to conserve, protect and restore Muskellunge fisheries in North America. One of the most notable accomplishments of Muskies, Inc. relates to the establishment of the Lunge Log database in 1970. The Lunge Log is a standardized voluntary reporting system through which members of Muskies, Inc. register Muskellunge catches, and by doing so participate in an annual Members Only Fishing Contest. The Lunge Log has been a valuable tool used by Muskies, Inc. to promote the practice of catch and release. Details on nearly 370,000 Muskellunge are included in the database. The number of Lunge Log entries has grown from 58 muskies reported in 1970, with 31 percent of the muskies released, to an average of 15,000 muskies reported per year for the past decade with over 99.9 percent of them being released. In the past two years Muskies, Inc. members have reported a total of 541 Muskellunge which were 50 inches or greater and have released 100 percent of those trophy-sized fish. Lunge Log data have been shared with a number of fisheries agencies over the years and the program has been cited in multiple professional publications by fisheries scientists. This presentation will take a closer look at many of the interesting trends which can be found in this 45-year database.

Anglers, Science, and Management

Going Wild: Canada's Path to Sustainable Muskellunge Populations

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Muskies Canada Sport Fishing and Research Inc. strives to ensure sustainable wild Muskellunge (*Esox masquinongy)* populations in Canada. To date, this has involved the promotion of catch-and-practices and mitigating angling mortality through regulations. Muskies Canada proposes that we now begin to focus on natural reproduction as the key to sustainability. This means we must recognize and address concerns about the fragmentation, disruption and loss of essential spawning and nursery habitat. Embracing research with university and government partners, we can better understand Muskellunge breeding migration, ideal spawning site characteristics, site fidelity, and young-of-year (YOY) nursery habitat requirements. This will facilitate better identification of, protection for and, in some cases, restoration of, significant local wetland and shoreline habitat that supports natural reproduction. In addition we must use analysis of Muskellunge age and population dynamics to indicate the appropriate optimum number of breeding cycles that will sustain populations. Any age-based approach may require some adjustment of minimum size limits. This new focus on natural reproduction will lead to a comprehensive review and updating of Muskellunge management strategies, working extensively through partnership and collaboration, to chart the path to future sustainability for Canada's wild Muskellunge populations.

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Ontario's Muskellunge Angler Log Program – 1979-2015

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Since the inception of Muskies Canada in 1978, the Muskies Canada Angler Log Program has been a core initiative of the club and a long term commitment and partnership with the Ontario Ministry of Natural Resources and Forestry (OMNRF) in the management of the Muskellunge (*Esox masquinongy)* fishery in Ontario. A unique aspect of the Log Program is that is an angler diary program rather than a fish reporting program. It tracks not just the fish that are caught but also places an importance on logging for days when no fish are caught. During the past 20 years, over 30,000 logs have been submitted, with over 17,000 muskies reportedly caught. This is the single largest source of Muskellunge data available to provincial fisheries managers. Enhancements to the program have been implemented to facilitate participation. Since 2012, Muskies Canada members have been able to submit logs on-line and access past logs to 1995 (soon to be 1978). At the national level, Muskies Canada Release Awards recognize the achievements of club members and commemorate an individual's Muskellunge milestones through pins and certificates. This presentation will highlight both the perspectives of MCI and OMNRF on the Log Program. Factors that influence angler participation in the program and trends in angler involvement will be discussed. This presentation will examine trends in the Muskellunge fishery, with particular emphasis on key Ontario waterbodies where participation in the program has been highest – Lake St. Clair, St. Lawrence River, Ottawa River, Georgian Bay, Pigeon Lake and the Rideau River – from 1995-2015. A key point of emphasis will be in evaluating the use of the angler diary program to serve as an indicator for the development of fisheries objectives for Ontario's Muskellunge populations.

Characteristics of the Muskellunge (*Esox masquinongy*) Fishery Based on Angler Diaries in the St. Lawrence River, Quebec (Canada).

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Muskellunge (*Esox masquinongy)* declined during the first half of the 20th century in the Quebec portion of the St. Lawrence River. Muskellunge stocking was conducted from 1950 to 1997 in order to support the recreational fishery. The present study aimed to monitor the muskellunge fishery using angler diaries. Fishing effort and success as well as fish length and sex were noted from 2010 to 2013 in five sectors of the St. Lawrence River. A total of 2,619 individuals were captured an angling effort of 12,503 rod hours. Angling success, expressed in terms of captures-per-unit-of-effort, varied between 0.17 and 0.30 muskellunge caught per rod hour, depending on the sector. Based on historical data, size of angled fish increased over the past century. The proportion of catch larger than 44 inches (1125 mm) increased from 19% in 1918-1927 to 53% in 2010-2013. However, the proportion of catch smaller than 35 inches (890 mm) was low in the downstream sectors of

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the river, suggesting a recruitment failure in recent years. The status of muskellunge stocks seems to be globally healthy in the upstream sectors of the St. Lawrence River but remains fragile downstream. In the context of the large scale habitat loss observed during the past decade, studies are needed to measure the genetic structure of the populations and to identify, restore and protect critical spawning, nursery and growth habitats. Angler diaries have proven to be an effective management tool that should be maintained or expanded in the future.

Volunteer Guides as a Novel Source of Data Collection for Riverine Muskellunge Populations in Northwest Wisconsin

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Medium-sized, warmwater rivers in northern Wisconsin hold popular Muskellunge *(Esox masquinongy)* fisheries yet present many challenges to management agencies interested in gathering reliable fisheries data. Access, gear limitations, funding, safety concerns, and timing all contribute to sampling difficulties and inefficiencies. In response, the Wisconsin DNR enrolled private fly fishing guides in a detailed angler diary project to enhance understanding of gamefish populations in rivers, particularly Smallmouth Bass and Muskellunge. This project has been in effect for four fishing seasons totaling over 2,700 documented hours of Muskellunge fishing effort on the Namekagon, Chippewa, and Flambeau rivers. To date, volunteer guides have captured 215 muskies, which greatly exceeds the total number captured in 15 previous years of agency electrofishing surveys. Data generated from volunteer guides comes at a fraction of the cost of traditional surveys and covers a wider spatial and temporal range. Results of this project have enhanced our understanding of size structure and abundance of Muskellunge within and among Wisconsin rivers. This project has also led to insights into water level management of rivers and associated impacts on fishing quality. While there are several challenges to initiating and maintaining these types of angler/agency partnerships, they can be an efficient means to collect relevant Muskellunge population data in uniquely challenging environments, particularly in comparison to traditional fisheries survey methods.

Muskellunge Stock Assessment in Two North-Central Minnesota Lakes Aided by Angler Participation.

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A stock assessment of Muskellunge (*Esox masquinongy)* in two connected north-central Minnesota lakes provided the opportunity to evaluate Muskellunge population characteristics, explore the use of anglers to provide recapture samples for population estimation, and assess the effects of historical stocking on the populations. The Minnesota Department of Natural Resources (MNDNR) sampled Muskellunge using trap nets during spring spawning and anglers provided recapture samples to compare with those obtained from MNDNR electrofishing. Electrofishing sampled smaller fish than trap nets, while the length-frequency distributions of

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fish captured by angling and trap nets were nearly identical. Both recapture methods produced similar estimates and confidence intervals. Six individual fish were captured 2-3 times by anglers within the same fishing season. Although movement between lakes was detected, fish sampled in one of the lakes were significantly older and longer. Post-spawn movements suggested more individuals migrated from the lake characterized as having optimal spawning and nursery habitat to the lake characterized as having preferred summer habitat and prey. A strain of Muskellunge of non-local origin had been stocked in the lakes until 1979 when its use was discontinued because it showed poor size potential. The percentage of non-local ancestry remaining in the populations was 13% in 1995 and 9% in 2012. Higher proportions of non-local ancestry within individuals were associated with decreasing estimates of asymptotic length (L_∞), but the relationship was only significant for males. Our study provided considerable information on population size, age and size structure, fish movement, and ancestry that will assist management of these Muskellunge populations. The use of anglers to provide samples was shown to be a viable alternative or supplement to agency sampling efforts.

The Saint John River Muskellunge Tagging Project, 2006-2015.

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We document the results of a ten year tagging and recapture study on the St. John River, New Brunswick, Canada. Muskellunge (*Esox masquinongy*) gained access to the Saint John River watershed by escapement from a headwater lake in Québec where they had been stocked in the 1970s. In an attempt to document movements and other characteristics of this new species, a tagging study was initiated by members of the Saint John Chapter of Muskies Canada. From 2006 to 2015 (inclusive), a total of 691 angled Muskellunge were marked with individually numbered Floy tags and then released. To date, a total of 68 (9.8%) Muskellunge have been recaptured by angling. Most Muskellunge were observed to establish discrete summer home ranges from which there was little, if any, movement. Transitional movements occurred during the spring and fall associated with spawning and the establishment of summer and winter ranges. Some Muskellunge demonstrated the ability to move long (>10 km) distances both upstream and downstream including passage over/through the Mactaquac dam. The longest movement exceeded 97 km. Growth of colonizing muskellunge was relatively rapid. Future efforts will be directed to obtaining more information from recaptured fish. Information derived from this study indicates the value of citizen science which should prove valuable to local management agencies.

Maintaining Momentum in Ohio's Stocked Muskellunge Fisheries through an Angler Agency Partnership

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Ohio anglers and the Ohio Department of Natural Resources (ODNR) Division of Wildlife maintain a long-standing partnership that originated from a voluntary catch reporting system to promote and sustain high-quality Muskellunge *(Esox masquinongy*) fisheries in reservoirs. An agency initiative during the 1950s to restore quality Muskellunge fishing in Ohio followed decades of habitat degradation that reduced and constrained

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natural populations. Twentieth century construction of on-stream reservoirs for flood control provided opportunities to establish Muskellunge fisheries in selected waters with suitable habitat, abundant prey, and good angler access through put-grow-take stocking. In 1960, less than a decade after reservoir stocking began, the ODNR created a voluntary catch reporting system by forming the Ohio Huskie Muskie Club (OHMC). The club provided a means to recognize angler catches, monitor stocking success, and communicate with anglers through a formal angler-agency relationship. Eventually this relationship expanded to include five Ohio chapters of Muskies, Inc. (MI) as they became established. The unified partnership between these anglers and the agency has facilitated program changes that capitalized on adaptive management, scientific research, and advances in technology. Mutual appreciation of the partnership and shared interests have allowed progress to continue, facilitated by routine angler summits, club commitments to support fish production and research, dedicated agency outreach and an online catch-reporting application, the Ohio Muskie Angler Log. Partnerships like this are essential to ensuring the future of Muskellunge fisheries maintained by annual stocking as fish and wildlife agencies continue to face challenges associated with habitat quality, declining participation in fishing, and funding.

A Management Tool for Biologists and an Online Fishing Resource for Anglers: An Introduction to the Ohio Muskie Angler Log

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Voluntary angler catch reporting has been the principal method for monitoring Muskellunge *(Esox masquinongy)* fisheries in Ohio. From 1960-2007 anglers used mail-based catch cards to report 46,000 Muskellunge catches. This program has not only been vital for collecting robust long-term data on fishery performance and participation, but has served as a focal point for building a strong partnership between the Ohio Department of Natural Resources (ODNR) Division of Wildlife and Muskellunge anglers. While instrumental in building quality Muskellunge fisheries in Ohio, the mail-based program was limited by the lack of catch detail provided, tardiness of catch reporting, and minimal access to the catch data by anglers. Consequently, a new online catch reporting system called the Muskie Angler Log (MAL) was launched in 2008. Designed in collaboration with anglers, the MAL expands on the tradition of providing important fishery data to biologists while serving as a fishing resource to anglers. In addition to reporting their catches, anglers using the MAL can now view, summarize, and download their personal catches, review reservoir-specific stocking and catch histories, and examine recent catch details voluntarily shared by other anglers. Biologists benefit from the MAL by being able to instantaneously track fishery performance and participation. The MAL also provides the opportunity to collect previously unavailable data on fishing effort and catch rates. The MAL shows promise in guiding management strategies, initiating research questions, and further strengthening the angler-agency partnership.

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Integrating Voluntary Angler Catch Reports with Mark-Recapture Data to Model a Muskellunge Fishery in Clear Fork Reservoir, Ohio

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Voluntary angler catch reports can be a valuable tool for monitoring fisheries. In Ohio, these reports have been integral for monitoring long-term trends in Muskellunge *(Esox masquinongy*) fisheries. The integration of angler catch data into mark-recapture methods has been increasingly advocated as a means of improving estimates of fish population metrics. A mark-recapture study was conducted to evaluate population demographics of Muskellunge during 1981–2006 in 1,033-acre Clear Fork Reservoir, Ohio. Each spring, adult Muskellunge (≥588mm) were collected and tagged using trap nets. Anglers reported catches of tagged Muskellunge (resightings) between tagging events. A total of 4,744 Muskellunge were tagged and 2,399 (50.6%) were recaptured in trap nets. Anglers reported catching 995 tagged Muskellunge (20.1%) from within the reservoir. Recaptures and angler resightings were analyzed using a joint mark-recapture, tag-resighting, and tag-recovery model (Barker model) within program MARK. Mean estimates of Muskellunge annual survival was 0.59 (SD, 0.21) for males and 0.71 (SD, 0.23) for females for the study period. Emigration was constant over time with any given Muskellunge having a 0.13 probability of emigrating annually, which was consistent with expectations based on surveys below the dam. The probability of Muskellunge being caught by anglers varied across years, but factors influencing vulnerability was unclear. The model tended to underestimate catch and release rates based on estimates derived from all angler catch reports, yet the trends toward higher release rates over the course study were generally consistent. Voluntary angler catch reports provided the data necessary to make valuable inferences on the fishery that would not otherwise be available using only traditional mark-recapture modelling.

Assessment of a Riverine Muskellunge Population in Minnesota

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The 65 km reach of the Mississippi River from Brainerd downstream to Little Falls supports a genetically distinct naturally reproducing Muskellunge *(Esox masquinongy*) population. The Minnesota Department of Natural Resources (MNDNR) initiated an evaluation of the Muskellunge population and habitat in this section of the Mississippi in 2013 through 2015. Muskellunge were captured by electrofishing and cooperating volunteer anglers. Bathymetric and habitat maps of the study reach were created with down- and side-looking sonar. Muskellunge made seasonal movements from generally shallower dispersed summer habitats and congregated at deeper overwintering areas in the late fall. Trained cooperating anglers provided over one-half of the captures and angled fish were slightly larger than those captured by electrofishing. Estimated population size (0.34 fish/ac) and length distribution were similar to other regional Muskellunge fisheries. Genetic evaluation of captured Muskellunge indicated that over 20% of individuals were from a stocked fish brood-source (Leech Lake strain), which has been stocked directly upstream of the study reach since 2006. Integrating

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data collected from cooperating anglers provided a valuable source of fish recaptures as well as an independent measure of population statistics.

Muskellunge Habitat

Spawning Habitat for Muskellunge Is Far More Variable Than We Ever Expected – Even 2 Years Ago.

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Muskellunge *(Esox masquinongy)* have been studied for quite some time due to their unique nature, large adult size, and importance to sport fishing. One of the main limitations to current Muskellunge distributions is the loss of spawning habitat due to encroachment by human development. Human alterations of littoral habitat, along with changes in water levels due to dams and diversions, have resulted in dramatic declines in Muskellunge throughout their range. Early studies focusing on the habitat characteristics selected by spawning Muskellunge showed that they often selected back bay areas with soft substrates and some emergent and submergent vegetation. As we have continued to evaluate spawning site selection for Muskellunge in a wider variety of habitats, we have found that they select a wide variety of sites, including sandy and rocky substrates and open shoreline as well as back bays. Often the site selected was determined by the lack of their preferred habitat characteristics in a given lake or river, but at the same time these fish do reproduce successfully in this less than optimal habitat. Recent work has also shown some degree of differentiation between sites selected by Great Lakes or northern strains of Muskellunge. This presentation will review studies on spawning habitat done in the north central region of the US, and relate them to the type of habitat available as well as to human alteration.

Fine-Scale Features of Muskellunge Spawning Grounds in Georgian Bay

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Loss and degradation of spawning habitat has been identified as a major stressor in the widespread decline of Muskellunge *(Esox masquinongy)* populations. Protection of spawning habitat has therefore been designated a management priority, and research is needed to permit efficient identification of these areas. One avenue of research is to model spawning habitat based largely on the characteristics of "spawning sites", locations where a confirmed spawning event has occurred; however, use and characterization of the more general "spawning grounds" remains comparatively unexplored. We analyzed radio telemetry data collected from three regions of Georgian Bay (from southeastern to northern Georgian Bay) to determine if adult muskies have predictable fine-scale movement patterns when using their spawning grounds. 49 individuals were tracked for up to three years during the spawning seasons of 2012-2015. Both males and females exhibited staging behaviour during the spawning season and appeared to travel along areas with moderate slopes (between 1° and 10°). Females staged further offshore in deeper waters (max depth: 1.7-2.9m), and were consistently more mobile than males; by comparison, males staged in shallower waters (max depth: 1.3-2.6 m) towards the offshore edges of coastal wetlands, and waited at access points for females to move inshore to spawn. In all three regions of Georgian Bay, we found adult Muskellunge staging in water deeper than what has been typically defined as spawning

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sites (>1.5 m), and then make brief forays into shallower areas to spawn. We suggest that deeper areas and moderately sloping areas used as travel corridors are important components of spawning grounds that need to be protected in addition to the typically shallow wetland areas where Muskellunge actually spawn.

Index of Nursery Habitat Suitability for Muskellunge in Georgian Bay, Lake Huron

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To support Georgian Bay's self-sustaining Muskellunge (*Esox masquinongy*) fisheries, we developed two Index of Nursery Habitat Suitability (INHS) models that can be used to identify and monitor the quality of Muskellunge nursery habitats in coastal wetlands. The INHS models were based on habitat features found in wetlands with young-of-the-year (YOY) Muskellunge identified at two large embayments in northern Georgian Bay. One INHS model had 5 variables that included relative abundance of Yellow Perch (*Perca flavescens*), relative abundance of Cyprinids, residual fish species richness, the wetland's substrate slope and a metric related to macrophyte abundance. The other INHS model included only three variables from the 5-variable INHS, omitting information on macrophyte and fish species richness. When they were applied to an independent dataset, both INHS models successfully tracked deterioration in nursery suitability after 15 years of sustained low water levels in Georgian Bay, but the 5-variable INHS had higher overall accuracy and showed stronger discrimination between sites with and without YOY. We applied the 3-variable model to classify coastal wetlands in other regions of Georgian Bay and obtained a false negative rate <13%. We also obtained a higher false-positive rate with the 3-variable model compared with the 5-variable model (54% vs 31%) because it required a lower threshold to indicate suitability (0.6 versus 0.70, respectively). These INHS models should allow managers to screen for suitable nursery habitat near current spawning sites across Georgian Bay, and allow managers to predict how changes in water-level regimes might affect the suitability of spatially explicit wetland units.

Effects of Water Level and Substrate Slope on Availability of Suitable Habitat for Young-of-the-Year Muskellunge in Georgian Bay

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Georgian Bay, Lake Huron currently supports a self-sustaining Muskellunge (*Esox masquinongy)* fishery but recruitment failure has been suspected in a sub-population in southeastern Georgian Bay (SEGB) due to the apparent absence of young-of-the-year (YOY) Muskellunge at historic nursery sites. We have previously attributed the disappearance of the YOY to the negative effects of a decade of sustained low water levels, since YOY Muskellunge had been found in the historic sites when mean summer water levels were 176.80 m asl, but could no longer be found in 2012, when mean summer water levels had dropped to 176.03 m asl. The presence of YOY Muskellunge in wetlands of northern Georgian Bay (NGB) during 2012, however, cast doubt on the validity of this water-level effect. Here, we hypothesize that habitat available to YOY is dependent on water level and the local near-shore bathymetry of each region, and predict that differences between SEGB and NGB with respect to presence of YOY in 2012 could be due to differences in site geomorphology. To test this hypothesis, we built a digital elevation model (DEM) for both regions and calculated the slope and amount of core

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nursery area (CNA; area delineated by shore to the 1-m contour in the wetland unit) for 20 historic nursery sites in SEGB and 17 confirmed nursery sites in NGB using both 1981 and 2012 water-level conditions. The mean slope of the CNA for NGB sites was 8.35° in 1981 and during lower water levels in 2012, it became reduced to a mean of 6.78° (paired t-test, $p < 0.001$); by comparison, the mean slope for SEGB sites was considerably shallower and remained statistically similar, dropping from a mean of 0.94° in 1981 to 0.73° in 2012 (paired t-test, $p = 0.497$). Under current low water levels, CNA in SEGB increased significantly from a mean of 1.73ha in 1981 to 2.5ha in 2012 (Wilcoxon Signed Rank, $p = 0.003$), while that in NGB also increased significantly from 0.11ha in 1981 to 0.15ha in 2012 (Wilcoxon Signed Rank, $p < 0.001$). Since both regions experience the same water level regimes, differences in habitat quality between regions may be related to the consistently steeper near-shore slope that makes northern wetlands less susceptible to fluctuations in water levels than southern wetland with shallower slopes. On average, the shoreline in SEGB migrated 20m lakeward between 1981 and 2012, while the 1-m depth contour migrated 50m. By comparison, the shoreline in NGB migrated only 10m while the 1-m depth contour migrated 22m over that same time. Therefore, the absence of YOY during the 2012 survey in SEGB was likely the interaction between sustained water levels and shallow slopes exposed by the low water levels that affected the suitability of YOY Muskellunge habitat.

Habitat Use by age-0 Muskellunge in the Upper Niagara River, New York

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Studies of fine-scale habitat use by age-0 Muskellunge (*Esox masquinongy*) are uncommon and those that have been conducted have relied on targeted, non-random sampling designs, which may bias study results. We used a random sampling design to sample age-0 Muskellunge and shallow water (<1.3 m) habitat features in the upper Niagara River, New York during late July through early September 2013-2015. Comparisons of habitat features between sites where Muskellunge were present and absent, and Firth logistic regression were used to identify important characteristics of Muskellunge nursery locations. A total of 15 age-0 Muskellunge were collected at 11 of 297 sites. Wild Celery (*Vallisneria americana*) was the dominant aquatic vegetation, and sand and mud were the dominant substrate sizes at locations were age-0 Muskellunge were collected. The probability of age-0 Muskellunge presence was positively related to the proportion of the water column occupied by aquatic vegetation. Despite sampling nearly 300 sites, the small number of age-0 Muskellunge collected limited the types of analyses that could be performed. However, our results provide evidence that shallow water areas with abundant Wild Celery should be conserved or restored to provide rearing habitat for Muskellunge in the upper Niagara River. In future studies, sample sizes of age-0 Muskellunge may be increased, while maintaining a probability sampling design, by randomly sampling within predefined areas that contain habitat features identified at sites where Muskellunge were present in this study.

Spring Flow Variability Associated With Muskellunge Recruitment on the Upper James River, VA

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Muskellunge *(Esox masquinongy*) fingerlings were stocked most years on the Upper James River from 1972 through 2010. Significant increases in relative abundance were detected beginning in the early 2000s. Annual

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increases in age – 0 Muskellunge catch-per-unit-effort (CPUE), even during no stocking years, led biologists to cancel the stocking program in 2010. Since cancellation, total Muskellunge CPUE has continued to increase exponentially, while age- 0 has remained variable. We analyzed long-term water quality and river discharge datasets (2000 to current) for the upper James River in an effort to explain the expanding Muskellunge population. We used a combination of regression techniques to identify abiotic variables associated with year-class strength. Spring discharge fluctuation (ft^3/s) (Range of mean monthly flow March –June) had a significant positive relationship with fall YOY CPUE. Further analysis of catch curve residuals vs. range in spring flows for respective year classes also showed a significant positive relationship. Slope of spring-mean-monthly flows had a significant negative relationship with fall YOY CPUE, suggesting that a declining trend in monthly flows was more important for Muskellunge recruitment. Conductivity also had a significant positive relationship with YOY CPUE, which suggest that productivity during cascading spring flow regimes is greater than years with stable or increasing spring flow regimes, which may further increase YOY survival. Years with flows highest in March followed by cascading declines through June produced the strongest Muskellunge year classes on the Upper James River, Virginia.

Evaluating Spawning Habitat and Natural Recruitment of Great Lakes Spotted Muskellunge in Green Bay, Lake Michigan

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The identification, protection, and restoration of critical spawning habitat for Muskellunge (*Esox masquinongy)* in Green Bay of Lake Michigan are vital steps for re-establishing a self-sustaining population. This study was designed to locate spawning habitat and document the extent of natural reproduction across three study areas in Green Bay (Menominee River, Fox River, and lower Green Bay). Radio transmitters were inserted into the oviduct of mature female Muskellunge prior to spawning and expelled transmitters were later located using radio telemetry to identify spawning sites. Between 2009 and 2010, twenty-six of thirty-seven (70%) implanted transmitters were located as having been deposited at spawning sites. Using these identified spawning locations, habitat selection was estimated for key environmental variables, and a spatial model was built to predict Muskellunge spawning habitat in the Menominee River. Menominee River Muskellunge showed a significant preference for spawning in areas with low to moderate bottom slopes (0-3%), moderate vegetative coverage (35-70%), where woody debris was present, and substrates containing low to moderate levels of silt (5-30%). Utilizing these identified habitat preferences, Maxent modeling proved to be the most effective tool at predicting limited areas as potential spawning locations and correctly classifying most of the identified spawning sites. Comparisons of habitat characteristics identified in modeling as preferred Muskellunge spawning habitat showed differences in availability of preferred spawning habitat between the Menominee River, Fox River, and lower Green Bay, with minimal suitable habitat present in the Fox River and lower Green Bay. In the future, habitat preferences and model results could be used by resource managers to locate suitable locations for stocking Muskellunge, guide designations of critical habitat to protect current spawning habitat, as well as identify areas and guidelines for rehabilitation projects to enhance Muskellunge spawning success in Green Bay.

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Muskellunge Population Dynamics

St. Lawrence River Muskellunge and Effects of Invasive Species and VHSV: Population Indicators and Potential Effects of Emerging Viral Variants

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Long-term research sheds light on how the St. Lawrence River Muskellunge *(Esox masquinongy)* has responded to widespread adult Muskellunge mortalities observed from 2005-2008. Disease outbreaks (VHSV), invasive species, prey community shifts, and habitat change are recently identified stressors that potentially affect Muskellunge recruitment. Survival studies in the early 1990s conducted with experimental larval muskellunge releases in comparison to wild fish provide a useful baseline for population demographics in nursery habitats in the region. This approach is now being replicated to compare contemporary and historical population demographics to examine young-of-year (YOY) survival and effects of environmental change. VHSV status and changes in the virus itself (62 known variants) are also being examined with monitoring of prevalence in spawning sites and through use of laboratory challenge tests (survival) of YOY Muskellunge of different genetic strains exposed to past and present forms of the virus. The future of natural recruitment in a changing environment will be explored and discussed using research results from a variety of ongoing studies as well as updates from long-term population and habitat monitoring.

Die-Off of Muskellunge (*Esox masquinongy*) in the Upper St. Lawrence River Caused by Viral Haemorrhagic Septicaemia, 2005–2008: Impacts and Consequences

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A catastrophic die-off occurred in the prized Muskellunge (*Esox masquinongy*) population of the Canadian and U.S. waters of the 1,000 Islands section of the upper St. Lawrence River in 2005 to 2008. Fish collections and regular river travel particularly in Canadian waters provided 103 dead muskellunge (66 CAN, 37 US) primarily mid-May to mid-June 2005 (74%) and a similar time in 2006 (15%), 2007 (9%) and 2008 (3%). Some dying fish were observed, but most had died earlier, possibly late winter or early spring. Detailed necropsies of 63 Canadian samples indicated all were mature; most (90%) had not spawned. In 2005, rapidly rising temperature was the suspected primary cause. However, temperature changes that year were no more extreme than some in the past three decades; viral haemorrhagic septicaemia (VHS) was subsequently confirmed as the cause. Dead fish were large and old: 60% females and 40% males; mean TL 129 and 109 cm; WT 15.6 and 9.3 kg; age 17.0 and 17.2 years. Both sexes were older, slower growing, and had smaller ultimate size than Muskellunge angled

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before die-off. Ovaries of older fish were underdeveloped; fecundity peaked in the 12–18 age range. Individuals that died in 2006 and 2007 were faster growing in years just prior to the mortality than those that died in 2005; mortality was higher in slower-growing individuals, possibly influenced by maturity and temperature. Anglers reported increased handling stress just before and during the mortality, and 2003–2007 Muskies Canada creel logs confirmed a 49% decline in catches of larger mature individuals (October–December). Comparative data indicated that VHS probably killed half the mature population; management actions were taken – size limits were increased (48 to 54 in [122 to 137 cm]) to protect the remaining spawning stock and its reproductive capacity.

A Modeling Evaluation of Multiple Threats to Lake St. Clair Muskellunge

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The current Lake St. Clair Great Lakes Muskellunge (*Esox masquinongy*) (LSCM) fishery is entirely self-sustaining and dominated by a catch and release ethic. Catch rates of LSCM are among the highest of any waterbody, and "trophy fish" are relatively commonplace. The proximity of Lake St Clair (LSC) to a large number of potential new Muskellunge anglers, interest in a winter spear fishery among some anglers, and warming temperatures associated with climate change pose potential risks to the quality of this fishery. We developed an age-structured equilibrium yield model to predict the likely effects of changes in size and harvest limits, increased angling effort, establishment of a winter spearing season, or warming temperatures on open-water catch rates of three size classes of LSCM (All fish, Legal fish > 42", Trophy fish > 50"). Our modeling indicated that changes in regulations in the LSCM fishery were unlikely to make substantial changes to catch rates of Muskellunge of any size class. Similarly, the current high rate of voluntary release would largely buffer catch rates of all size classes of LSCM from substantial negative effects due to foreseeable levels of increased fishing effort. Our simulation of a winter spearing fishery indicated that only high levels of spearing effort and harvest would negatively affect open-water catch rates to a degree that would likely be objectionable to anglers. In contrast to effects of potential changes to the fishery, the predicted catch rates of legal and trophy-sized fish were highly sensitive to modeled reductions in growth due, a possible outcome of climate warming. While our model predicts the LSCM fishery to be fairly insensitive to changes in regulations and substantial changes in angling effort and spearing harvest, possible effects of warming, which are difficult for fisheries managers to mitigate, could be significant. In addition to insight into the LSCM fishery, the development of our simulation model revealed important knowledge gaps including recruitment dynamics, abundance estimates, diet composition and delayed mortality from catch and release angling.

Effect of Stocking and Biotic and Abiotic Factors on Muskellunge Recruitment in Northern Wisconsin Lakes

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The Muskellunge (*Esox masquinongy)* is an important recreational fish species in North America. Some populations of Muskellunge are in decline despite a reduction in harvest by anglers (due largely to a growing catch-and-release ethic). Our objectives were to determine if Muskellunge recruitment was influenced by stocking, biotic factors, and abiotic factors in northern Wisconsin lakes. To address our first objective, we compared parameters of Ricker stock-recruit models from stocked and non-stocked lakes to determine whether stocking enhanced Muskellunge abundance. Density dependence of recruitment rates did not differ significantly between stocked and non-stocked lakes, but the recruitment rate was significantly higher in stocked lakes than in non-stocked lakes. This finding confirmed that Muskellunge stocking significantly increased recruitment in Wisconsin lakes, so we recommend that stocking continue in order to supplement Muskellunge populations with low natural recruitment. To address our second objective, we tested biotic and abiotic variables in stock-recruit models as possible explanatory variables for Muskellunge recruitment in Wisconsin lakes. Adult stock density, stocked Muskellunge density, average spring temperature, spring temperature variation, and age-0 Walleye (*Sander vitreus)* abundance explained significant Muskellunge recruitment variation. Our findings indicate that Muskellunge recruitment is regulated by a mix of stocking, as well as abiotic and biotic environmental factors in northern Wisconsin lakes.

Electrofishing Catchability of Juvenile Muskellunge in Northern Wisconsin Lakes

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To assess the effectiveness of Muskellunge (*Esox masquinongy*) stocking, biologists conduct electrofishing surveys in fall to estimate catch per effort (CPE) and relative contribution of stocked fish. Inherent assumptions of this sampling are that wild and stocked fish have equal probability of capture and that changes in CPE reflect changes in actual abundance. However, capture rates of age-0 Muskellunge tend to be low for both wild and stocked fish, making it difficult to determine if electrofishing catch is a meaningful predictor of actual abundance. The goal of our study was to determine the effectiveness of electrofishing for capturing individual age-0 Muskellunge by determining locations of stocked fish released into two lakes in northern Wisconsin. All stocked fish received a fin clip and at least 40 fish per lake were inserted with radio transmitters. All fish were released at a single boat ramp on each lake, which followed standard Wisconsin Department of Natural Resources (DNR) protocols. Stocked Muskellunge with transmitters were tracked weekly for one month after release. Fish were also sampled weekly using standard Wisconsin DNR electrofishing methods that included a single boat following single line transect around the shoreline of each lake. Comparing known locations of radio-tagged fish to the area sampled by the electrofishing boat revealed that most of the sampling effort was expended outside the area where stocked fish were located. Our initial results suggest that the majority of hatchery fish remained in the vicinity of the release location, with fish moving a max distance of 0.4 – 0.7 km on average away from the release location within four weeks of being stocked. Based on these results, biologists

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will be able to improve sampling protocols to evaluate Muskellunge stocking success by stratifying sampling effort so that more time is spent sampling where the fish are located.

Muskellunge Population Responses to Angler Catch and Release Practices in Escanaba Lake, WI, 1987 – 2015.

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The Muskellunge (*Esox masquinongy)* fishery in Escanaba Lake (Vilas Co., WI) has been unregulated (no closed season, no bag limit, no size limit) since 1946. A significant change in muskellunge angler behavior was documented in Escanaba Lake during the mid-1990s; muskellunge angler behavior switched from harvest-oriented (1946 – early-1990s) to almost exclusively voluntary catch and release (C & R) (mid-1990s – present). In response to this angler behavior transition, muskellunge population demographics changed. Prior to the shift in angler behavior, the muskellunge population exhibited characteristics of an exploited fishery (e.g., low adult size structure, high recruitment). After the shift to C & R angling, the muskellunge population exhibited characteristics of a relatively unexploited fishery (e.g., high adult size structure, low recruitment). The relatively recent practice of C & R angling for Muskellunge is a behavior that is well documented throughout North America. Therefore, well established Muskellunge populations will likely exhibit characteristics of lightly exploited fisheries across their North American range over time. Fisheries managers need to account for these changes in angler behavior and associated population responses, and adjust management strategies accordingly. In particular, stocking rates and length-based regulations need to be evaluated to test whether they are commensurate with current population dynamics and management goals.

Effects of Consumption-Oriented Versus Trophy-Oriented Fisheries on Muskellunge Population Size Structure in Northern Wisconsin

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To determine if a consumption-oriented fishery was compatible with a trophy-oriented fishery for a common species, we modeled effects of a consumption-oriented spearing fishery and trophy-oriented angling fishery on Muskellunge *(Esox masquinongy)* population size structure in northern Wisconsin. An individual-based simulation model was used to quantify the effect of harvest mortality (ranges of spearing and angling fishery mortality) on Muskellunge population size structure (small-, medium-, and large-bodied populations).

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Muskellunge population size structure declined as angling mortality increased. For small-, medium-, and large-bodied populations subjected to a range of angling mortality and regulated by a range of minimum-length limits, numbers of trophy Muskellunge declined by an average of 49.6% (range = 14.3─100%). At observed levels of angling mortality, numbers of trophy length Muskellunge declined by 16.9% (range = 0.0─100%). Muskellunge population size structure declined as angling and spearing mortality increased. For small-, medium-, and large-bodied populations subjected to ranges of both angling and spearing and regulated by a range of minimum length limits, numbers of trophy Muskellunge declined by an average of 85.4% (range = 60.5─100%). At observed levels of angling and spearing mortality, numbers of trophy Muskellunge declined by an average of 28.0% (range = 4.5─100%). We conclude that current levels of spearing harvest are compatible with trophy objectives for the angling fishery, but that increased spearing harvest may not be compatible with trophy objectives for the angling fishery.

Haters Gonna Hate (*Esox* edition): User-group Conflicts and Vigilante Justice in the Age of Social Media

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Animosity is common between specialized angler groups, and Esocids particularly engender polarized views. The New River (Virginia, USA) hosts a renowned fishery for Smallmouth Bass (*Micropterus dolomieu)*. Introduction of Muskellunge (*Esox masquinongy)* initially did little to change ecological or fishery dynamics. Muskellunge (muskie) stocking was intermittent, natural reproduction and population biomass were low, and harvest regulations were liberal. Muskie presence was tolerated by bass anglers, and their occasional capture even considered notable. Improved stocking strategies coupled with harvest restrictions led to a trophy muskie fishery. Highly specialized anglers now target muskies, and bycatch in other fisheries is common though often unappreciated. Bass catch and size structure waxes and wanes, partially in response to flow-related variations in recruitment. But bass anglers have become increasingly vociferous against muskies, and vitriol is spread through social media. The management agency is vilified for 'destroying bass fishing,' and reports abound of some anglers illegally killing muskies. We are re-evaluating biomass, size structure, and diet for muskies and bass. Increases in muskie standing stock may mean more bass are consumed, but the effects of increased predation may be indistinguishable from the effects of increasing bass-angling pressure. We are modeling alterative regulatory strategies to identify approaches palatable to most anglers. A concerted outreach effort is needed to make fisheries data and decisions transparent, to increase public support, and counter social-media vitriol that worsens in an information vacuum.

Can They Play Nicely? Creating and Managing A Two-Predator System

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The management of fisheries that include multiple predatory sport fish species can be difficult, from both the perspectives of ecological balance and competing angler interests. Such complications certainly exist for the Muskellunge (*Esox masquinongy)* and Smallmouth Bass (*Micropterus dolomieu)* fisheries of the New River, Virginia. The Virginia Department of Game and Inland Fisheries (VDGIF) introduced Muskellunge in the 1960s, and the population has since developed into a premier, state-renowned fishery. Circa 2006, the VDGIF changed Muskellunge management to spur this development and promote a self-sustaining, trophy fishery. Concurrently, Smallmouth Bass anglers voiced concern over possible increases in predatory interaction between Muskellunge and Smallmouth Bass and the effects their interaction might have on the quality of the bass fishery. We evaluated the population demographics and food habits of the current Muskellunge population. We found several ontogenetic shifts in Muskellunge diet, but consumption of Smallmouth Bass overall and within size classes was very little. We also found an increase in the CPUE, biomass/ha, and size structure of Muskellunge, since the VDGIF changed Muskellunge management. Using this information, we simulated interactions between the populations under different management regimes. Our study indicates the New River can support premier fisheries for both Smallmouth Bass and Muskellunge. Similar results are emerging from studies conducted on other Virginia rivers, and we feel intensive Muskellunge management can successfully add new fishing opportunities in Virginia while preserving other popular fisheries.

Muskellunge Biology, Ecology, and Life History

Feeding Habitats and Diet of the Muskellunge (*Esox masquinongy*): A Review

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This review was prompted by concerns that the predatory habits of Muskellunge *(Esox masquinongy*) could have negative impacts on other popular sport fishes such as bass *(Micropterus spp.),* Walleye *(Sander vitreus),* trout and salmon. Muskellunge are known to be opportunistic predators with a highly diverse diet. Generally, the size of prey items increases as the size of the fish increases. Larger Muskellunge also seem to prefer one large meal over several smaller meals. In studies examined, Yellow Perch (*Perca flavescens*), catostomids and shad were consistently important in Muskellunge diets. There was little evidence to indicate that Muskellunge predation had any significant impact on resident Walleye or bass populations where they co-existed. Due to the fact that habits seldom overlap, only limited information was available on the predatory impact of Muskellunge on salmonids. The greatest impact of Muskellunge seems to be related to the size of waterbody and the composition of the resident fish community. Larger waterbodies and those having a diverse forage fish community are relatively unaffected by the presence of muskellunge. The presence and abundance of soft-rayed fish species likely reduces the predatory impact on other resident sport fish species. More research is recommended to determine the potential impact of Muskellunge on salmonids and species at risk.

Tiger Muskellunge Diet and Effect on Target Prey Species in Curlew Lake, Washington

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Evaluations of tiger muskellunge (*Esox masquinongy x E. lucius)* diet, growth and condition, as well as their effect on the target forage Northern Pikeminnow (*Ptychocheilus oregonensis)* population, were conducted in Curlew Lake (Ferry County), Washington from 2001 to 2006. Tiger muskellunge were stocked annually into Curlew Lake, beginning in 1998, with the intent of reducing an overabundant Northern Pikeminnow population and creating a unique trophy fishery. Historically, Curlew Lake has provided excellent fishing opportunity for stocked Rainbow Trout (*Oncorhynchus mykiss)*, as well as abundant naturally reproducing Largemouth Bass (*Micropterus salmoides)* and Smallmouth Bass (*M. dolomieu)*. The quality of trout fishing, however, had declined throughout the 1990's, commensurate with anecdotal observations of increased numbers of Northern Pikeminnow in the sport catch. To monitor changes in the fish community following tiger muskellunge introduction, Curlew Lake was sampled annually in spring and fall with standardized boat electrofishing, gillnetting and fyke netting surveys. Additionally, the lake was sampled by boat electrofishing monthly from spring through fall to collect tiger muskellunge diet samples via gastric lavage. Rainbow Trout and Northern Pikeminnow were found to be the most important prey species overall. Diet varied seasonally, with Rainbow Trout being the most important prey in the spring, while Northern Pikeminnow was most important in the summer and fall periods. The relative abundance of Northern Pikeminnow in Curlew Lake declined significantly over the duration of the study. The high proportion of Northern Pikeminnow observed in the tiger muskellunge diet analysis indicates that the reduction can be attributed to the introduction of tiger muskellunge to the fish community. Angling opportunities for Rainbow Trout have improved and tiger muskellunge now offer a trophy fishery with fish reaching 50 inches and larger. Several tiger muskellunge tournaments are held annually on Curlew Lake. Fishery managers consider this introduction a great success.

Seasonal Movements of Muskellunge in North Bend Lake, West Virginia.

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North Fork Hughes River, West Virginia, is a native Muskellunge (*Esox masquinongy*) stream and is impounded by North Bend Lake, a 12.4-km long, 123-ha impoundment that serves as an important brood source for the West Virginia Division of Natural Resources. Muskellunge movement was monitored from 26 March 2010 through 2 January 2014 to monitor seasonal movements and to verify muskellunge migration through the outlet structure of the dam. Twenty-four fish were collected using pulsed DC boat-mounted electrofishing equipment and surgically implanted with acoustic transmitters. Six submersible data loggers were stationed throughout the lake. Data logger data were downloaded monthly throughout the study, resulting in 1,256,046 detections of implanted fish. Seasonal movement of marked fish was consistent during the four years of the study. Most fish moved throughout the entire length of the lake, and seven implanted fish left the lake through the outlet structure of the dam. Fish occupied the upper half of North Bend Lake in spring, and spent the summer and winter in the lower half of the lake. Fish occupied the lower lake in early and late fall, but exhibited a collective movement to the upper lake in October. Based on their upstream movements in early spring, Muskellunge appeared to use the upper areas of the lake for spawning purposes. Knowledge of seasonal movements of muskellunge in North Bend Lake, particularly in spring, will enhance future broodstock collection efforts. Dam escapement by Muskellunge may have a significant effect on fisheries in small impoundments, and should be considered in Muskellunge management plans in similar systems.

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West Virginia Muskellunge: Findings from Recent Telemetry Studies

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Muskellunge (*Esox masquinongy*) are native to West Virginia in the Ohio River drainage, including the Ohio, Hughes, Little Kanawha, and Elk Rivers, Middle Island Creek, and the Kanawha River downstream of Kanawha Falls. Other Muskellunge fisheries historically developed by stocking include the Kanawha River drainage upstream of Kanawha Falls (New, Greenbrier, Bluestone, Gauley, Meadow Rivers), the Potomac River drainage (Potomac, Shenandoah Rivers), and the Monongahela drainage (West Fork, Buchannon, Tygart Valley Rivers), and several large reservoirs (Stonewall Jackson, Stonecoal, Burnsville, Bluestone lakes). Stocking still occurs in most of these fisheries. Natural reproduction is present in all native and several introduced waters. Since 2010, the West Virginia Division of Natural Resources (WVDNR) has implanted Muskellunge with acoustic transmitters and monitored their movements in three different waterbodies. These studies have focused on determining seasonal movement patterns and identifying spawning areas in waters used as broodstock sources for hatchery production. In North Bend Lake, a small impoundment of the Hughes River, 24 fish were tagged and monitored from March 2010 through January 2014. This study documented significant passage by adult muskellunge through a dam, and collective upstream movements in spring and fall. In an ongoing study in the London Pool of the Kanawha River, a 12-mile study area, 24 fish have been tagged since April 2013. Adult Muskellunge in the Kanawha are able to pass downstream and upstream through an actively operating lock structure, exhibit a collective upstream movement to Kanawha Falls in spring, and, in other seasons, occupy concentrated areas of available habitat. In an ongoing study in the New River between Sandstone Falls and Hawks Nest Dam, a 47-mile study area, 9 fish have been tagged since April 2014. Despite a large study area, tagged fish in this system have not exhibited significant upstream or downstream movements from tagging locations. Seasonal movement patterns gleaned from these studies will serve as valuable management tools for the West Virginia Department of Natural Resources and will help guide efforts by active musky angler groups statewide.

Movement of Muskellunge in the St. Croix River System

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Proposals to install fish barriers in Minnesota's large rivers near the Twin Cities to prevent upstream expansion of Silver Carp **(***Hypophthalmichthys molitrix),* Bighead Carp *(Hypophthalmichthys nobilis),* Grass Carp (*Ctenopharyngodon idella),* and Black Carp *(Mylopharyngodon piceus)* , prompted a study to evaluate movement of riverine fish throughout this system. A stationary acoustic receiver network was deployed in the Minnesota, Mississippi, and St. Croix rivers in 2013 to determine fish passage through the lock and dam system, and to study movements and habitat preferences for several fish species. Muskies, Inc. donated 10 acoustic transmitters equipped with temperature and pressure sensors (to measure depth) to be implanted into Muskellunge (*Esox masquinongy*) in the St. Croix River, a popular Muskellunge fishery. Six of the 10 transmitters were implanted in November, 2014. Four of the six Muskellunge traveled at least 10 river miles, two of which traveled into the Mississippi River. One Muskellunge passed Lock & Dam #3 in Red Wing, Minnesota, into Pool 4 of the Mississippi River, and later returned to the St. Croix River. All six of the Muskellunge with transmitters had recorded depths of over 30 feet, five recorded depths exceeding 40 feet. Although the results are preliminary, our study shows that placing a barrier at the mouth of the St. Croix River could constrict Muskellunge movement between the St. Croix and Mississippi rivers. Therefore, any barrier constructed to prevent upstream expansion of Silver Carp, Bighead Carp, Grass Carp, and Black Carp should be tested on Muskellunge.

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A Field Portable Non-Lethal Muskellunge Tissue Sampling Device for the Analysis of Harmful Environmental Contaminants

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As top predators, the health of a muskellunge population can be directly linked to the health of the supporting ecosystem and food chain. Due to bioaccumulation and biomagnification effectively concentrating environmental contaminates, such as pesticides, in the tissues of top predators the muskellunge is an ideal candidate for monitoring programs aimed at identifying environmental pollutants with adverse effects on the health and stability of water based ecosystems. As muskellunge populations in many regions are dwindling, due to loss of habitat and the environmental pressures associated with pollution, non-lethal and minimally-invasive sampling techniques are required in order to ensure adequate sample collection, while limiting the impact on the tested individual muskellunge. Solid phase microextraction (SPME) fulfills both of these requirements due to the miniature nature of the sampling technology. As SPME is a diffusion based sampling technology, the sampler introduced by a hypodermic needle, simply needs to be exposed to the fish tissue which will allow compounds contained within the tissue to then be extracted by the device. The geometry of the technology is designed such as to only remove a relatively small portion of the compounds present in the tissue, and therefore not disturb the system under study. Once a predetermined sampling period has elapsed, normally in the order of minutes, the device can be removed from the muskellunge and transported to a laboratory for analysis.

Described herein, is a field-portable kit which will allow anglers with basic training to perform non-lethal and minimally-invasive muskellunge tissue sampling. The sampler itself has been designed to facilitate the safe and proper application of the SPME technology in an easy to use format. Traditionally, SPME has been applied to muskellunge tissue sampling in a difficult to use fashion that required specialized training. Though the kit itself is a new development, the traditional application of SPME has already been applied to samplings on Lake St.Clair, as well as the Ottawa River where the plasticizers diethyl, butyl and propyl phthalates were detected among other compounds of interest.

Genetics

A review of Muskellunge population genetics: implications for management and research directions

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At the original International Musky Symposium held in 1984, it was recognized that management agencies need policies for the sustainable management of native Muskellunge *(Esox masquinongy)* stocks and their genetic suitability. Identified research needs included documenting existing genetic diversity and evaluating effects of management on diversity. In this review, we summarize research over the past three decades that has addressed these needs and provided additional genetic information useful to managers. We then suggest future research directions to fill information gaps and benefit from advances in genetic technologies. Genetic data support the existence of three major regional stocks in the upper Mississippi River, Great Lakes, and Ohio River drainages, all of which derived from a Mississippian glacial refuge population. Each of these major lineages exhibits substructure, with numerous genetically distinct subgroups, influenced by geographic proximity, history and habitat connectivity. When traits such as growth, maximum size, survival and food consumption have been compared among strains stocked into common environments, researchers have usually found differences partly attributable to genetics. Genetic evaluations of ancestry in relation to stocking have revealed a wide range of outcomes, from substantial mixing of strains to no apparent contribution to resident populations. Genetic principles and data have led to state-wide stocking guidelines developed to conserve within- and among-population genetic variation and avoid artificial selection in broodstock practices. Molecular data have also been used to estimate genetic effective population size of a wild population and as individual tags for mark-recapture estimates of abundance. Future research needs include a range-wide assessment of population genetic structure, including how stocking has affected structure of wild populations, resolution of the role of reproductive versus natal site homing in individuals returning to spawning sites, and application of genomic techniques that can move us toward an understanding of the genetic basis for differences in performance or adaptive traits.

Genetic Insights into Wild Muskellunge Populations in Ontario

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Genetic information has provided valuable insights into the history, biology and behaviour of Muskellunge (*Esox masquinongy*) populations, and is being used to inform practical management questions in Ontario and across the species range. All Muskellunge alive today seem to be descended from a single Ice Age (Wisconsinan) ancestral source, although contemporary populations can exhibit substantial genetic differences at regional and local scales. Analysis of stock structure and gene flow in Ontario waters has shown that Muskellunge populations in Georgian Bay are limited to local habitats, with very little straying and/or strong site fidelity. Populations in connected inland waters (Ottawa and Rideau Rivers and the Kawartha Lakes) show contrasting patterns of spatial structure: muskellunge in the upper and lower Ottawa River are recognizably distinct from each other and from those in the Rideau River, whereas Muskellunge in the Kawartha Lakes show very little structure or spatial pattern. Despite widespread historical stocking, wild populations show little evidence of genetic contributions from supplemental stocking, although stocking for introductions (new populations) has been successful. The resultant genetic information is helping to inform management of Muskellunge populations in Ontario by identifying and mapping stock structure and habitat use, as well as for assessing ongoing rehabilitation efforts in Lake Huron and Lake Simcoe.

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Population Genomics of Muskellunge (*Esox masquinongy*) in the St. Lawrence River and the Inland Waters of Québec (Canada): Impact of 47 years of Stocking and Management Implications of a Trophy Fishery

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Muskellunge *(Esox masquinongy)* management has benefited from genetic insights through most of its natural range, but such information is lacking in Québec (Canada) known to support one of the best trophy fishery in North America. Moreover, there have been no population genomics studies performed thus far for Muskellunge with next-generation (NGS) sequencing techniques that allow covering genome-wide variation and analyzing both neutral and adaptive genetic polymorphisms. This study applies NGS population genomics to document Muskellunge genetic population structure and identify appropriate spatial scales for fishery management and conservation genomics in Québec. We address three major questions: (i) how is genetic diversity distributed through the system, (ii) which environmental, phenotypic and evolutionary factors influence the contemporary genetic structure, and (iii) to what extent past stockings have affected local integrity of native populations. Sampling sites were chosen in order to represent the species' natural range throughout Québec and sites of primary interest to the sport fishery. We also included samples from New York and Ontario comprising the upper St. Lawrence River and four known source populations used for historical stocking, as well as a Québec lake that was never influenced by stocking. The entire project aims to document genetic variability based on single nucleotide polymorphisms (SNPs) defined by Genotyping by Sequencing (GBS) among 863 Muskellunge from 19 different sites (n=20-93). Here, we will present and interpret initial results of this large-scale effort. We expect to link our findings with previous work conducted in Ontario, New York and elsewhere towards a unified effort to optimise Muskellunge management.

Muskellunge Genetic Integrity and Structure in the Great Lakes: Implications for Propagation Programs

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Muskellunge (*Esox masquinongy*) have experienced considerable population declines and several extirpations in and around the Great Lakes. While few populations have persisted relatively unchanged, others have benefited from restoration efforts, and others still have yet to be restored. Additionally, historic and contemporary stocking of Great Lakes and non-Great Lakes strain Muskellunge poses a threat to the genetic integrity of remaining populations. Therefore, a broader understanding of the degree of current genetic differentiation among all major Great Lakes populations, including those existing in key tributaries is needed. Our goal was to describe the genetic diversity within and differentiation among all major Great Lakes area populations and to determine the extent of introgression that has resulted from past Muskellunge stocking efforts. Thirteen microsatellite loci were used to characterize genetic diversity and structure of more than1,800 Muskellunge from 42 locations throughout the Great Lakes and associated inland drainages. Bayesian and maximum likelihood results suggest discrete genetic structure both east/west and inland-Great Lakes proper, including significant fine-scale structure at various locations throughout the Great Lakes. Genetic diversity, molecular variance, and other genetic measures were used to identify reasonable genetic management units (stocks) and potential brood sources for these various stocks.

Evaluation of Survival and Growth Differences of Geographically Distinct Stocks of Muskellunge Introduced into Three Midwestern Reservoirs

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Muskellunge *(Esox masquinongy)* are broadly distributed across the Midwestern and Eastern United States. Post-glacial geographic isolation into major river drainages has resulted in genetic variation due to adaptation to regional environmental conditions. Muskellunge management programs often rely on stocking to create and maintain lake and reservoir populations. In many instances, a local stocking source is unavailable or the appropriate source is unclear. Genetic differences among stocks of Muskellunge may influence survival and growth when introduced into novel environments. Consequently, selecting an appropriate source can be difficult and possibly critical to the future success of Muskellunge stocking programs. We examined differences in survival and growth among Muskellunge stocks from the Ohio (OH) and Upper Mississippi (MISS) River drainages and a mixed-origin Illinois (IL) broodstock population in three Illinois reservoirs over 9 years using mark-recapture data. Program MARK was used to estimate apparent survival among lakes and stocks for six-month intervals from fall age-0 stocking through maturity. Survival during the first six months was typically low but varied among lakes and stocks. Apparent survival estimates past 6 months post-stocking were higher and also varied among lakes and stocks, and declined after age-3. Upper Mississippi River drainage stock Muskellunge often had the lowest survival and IL the highest throughout the study, depending on lake and age. In addition to the effects of lake and stock, survival during the first 6 months post-stocking

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increased with cohort length at stocking and declined with increasing water temperature at stocking and increasing growing degree days during the first winter. Despite some differences in apparent survival estimates among stocks, lake- and sex-stratified length-at-age growth estimates were generally similar. Our findings suggest that survival differences among stocks occur and that stock selection can influence the survival of stocked Muskellunge and subsequent contribution to the fishery.

Water wolves and tigers: testing for directional hybridization and introgression between Northern Pike (*Esox lucius*) and Muskellunge (*Esox masquinongy*)

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Tiger muskellunge (*E. masquinongy* x *E. lucius*) are commonly stocked in the United States, but not in Canada. Much research has been done on the culturing and stocking of these fish however, there has been little research done on natural hybrids, or the genetics of tiger muskellunge. Hybridization and introgression occur within and among different taxa and can have both positive and negative impacts. Hybridization can lead to speciation events and can also be used for genetic rescue, but introgression has the potential to cause extinction of populations when hybrids repeatedly backcross with the parental species. Studies on hybridization utilize species specific markers because unique differences between species allows for more reliable and accurate detection of hybrids. In this study, the cytochrome *b* region of mitochondrial DNA (mtDNA) was sequenced from 80 tiger muskellunge from various lakes in Ontario as well as hatcheries and lakes in New York, Wisconsin, and Minnesota. This was done to determine whether tiger muskellunge had Muskellunge *(Esox masquinongy)* or Northern Pike (*Esox lucius)* mtDNA. Since mtDNA is maternally inherited, the data allowed the directionality of hybridization to be determined. Tiger muskellunge, were genotyped using 20 nuclear microsatellite loci to confirm hybridization, and to test for introgression. Muskellunge and Northern Pike have historically faced population declines, and information on hybridization between these two species may help to understand population declines, especially if introgression is occurring. Anthropogenic effects such as habitat fragmentation are known to increase the rate of hybridization in species, and if there is evidence of introgression it may suggest the need for management actions in order to protect genetically distinct populations of both Muskellunge and Northern Pike.

Muskellunge Assessment Techniques

Using Long-term Mark-Recapture Data to Assess Muskellunge Population Characteristics: Application to Two Illinois Reservoirs

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Understanding factors influencing growth and mortality is important for management of fish populations.

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Estimates of growth and morality typically use length-at-age data, which often necessitates sacrificing fish to obtain accurate age, and is undesirable for trophy fishes such as Muskellunge *(Esox masquinongy)*. Length-at-age data in Muskellunge are often derived from cleithra from mounted fish; however, obtaining these structures can be difficult, especially with increased minimum length limits. Previous research indicates long-term mark-recapture history (coupled with length data) can be used to estimate growth and mortality in fishes. In this way, we examined growth and mortality using >12 years of mark-recapture data of Muskellunge from two Illinois reservoirs (Kinkaid Lake and North Spring Lake). von Bertalanffy growth estimates by sex, lake, and tag type (PIT and T-bar) were obtained using a novel modification of Fabens growth model. Mortality was calculated using both age- and length- based methods and Program MARK. Fabens von Bertalanffy growth estimates of L-INF and K differed significantly between lakes and by sex, with Kinkaid Lake fish growing faster and attaining larger sizes than fish from North Spring Lake. Growth estimates by tag type did not differ significantly in males, but did in females. Annual mortality estimates differed significantly between lakes using multiple methods, with a higher annual mortality estimated for North Spring Lake fish (30-45%) compared to Kinkaid Lake fish (15-30%). Our results suggest that population characteristics differed between these lakes, and these methods may be applicable to other Muskellunge populations where long-term mark-recapture data are available.

A Comparison of Muskellunge Weight Estimation Equations to a Modified Length-Girth Technique

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Accurate estimates of weight for large individuals are of utmost importance for trophy fisheries. Substantial variation exists among models developed to estimate the weight of Muskellunge *(Esox masquinongy),* especially for the largest individuals. The objective of this paper was to develop an improved Muskellunge weight model via the inclusion of more predictor variables and to review and compare that model to the most commonly used Muskellunge weight models. Over 500 adult Muskellunge were captured, anesthetized, and measured during spring brood stock collections from natural lakes in Iowa between 2012 and 2015. In general, total length alone explained much of the variation (≥ 93%) in weight and this was particularly true for smaller Muskellunge (25.6-39.9 in). For large Muskellunge (≥ 40 in), the inclusion of both girth measurements substantially improved model r2-values. Overall, the inclusion of girth measurements for all Muskellunge sizes improved model accuracy. When comparing the five most popular Muskellunge weight models to observed Muskellunge weight obtained in this study, no two models consistently provided similar weight estimates across the five size categories examined and only one had similar estimates to the three variable model presented in this paper. These stark differences in weight estimates for a single species via several popular models strengthen the need for a more robust measure of Muskellunge weight by the inclusion of more body measurement variables. The models provided in this paper allow managers to fine tune weight estimates for Muskellunge if desired.

The Birth of a Muskie Lake: A Strategy for Assessing Survival, Age and Growth

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I measured age, growth and emigration for a new population of Muskellunge *(Esox masquinongy)* stocked in Lake Neshonoc, a 743 acre reservoir in La Crosse County, Wisconsin. I developed a strategy for marking and recapturing fish in order to assess a new Muskellunge population. 4,738 Muskellunge fingerling and 116 adult muskellunge were stocked from 2006 through 2015 in order to create a fishery. Each fish was either batch or

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individually marked. From 2007 to 2015, I handled and PIT (Passive Internal Transponder) tagged 388 fish. 90.2 % were subsequently recaptured in the lake proper, 9.8 % were downstream of the impoundment. Growth varied greatly for fish recaptured in the lake and those that escaped. Ages of fish were 0 to 9. Findings of this work will help determine if differences in size at stocking and fish stock origin influences growth and survival in stocked Muskellunge populations. In addition, it may lead to advancements in marking methods and stocking strategies.

Understanding Muskellunge Growth Using PIT-tag Recapture data in Lakes in Northwestern Wisconsin

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The use of passive integrated transponder (PIT) tags allows managers to obtain incremental length measurements for estimating fish growth for species like Muskellunge (*Esox masquinongy)* without having to sacrifice fish to obtain traditional size at age information from hard boney structures. In Wisconsin, the majority of PIT-tagged Muskellunge growth information comes from individuals of unknown age. A lack of muskellunge age information can be a major limitation when assessing certain dynamic rate functions, but fortunately managers are still able to evaluate and compare fish growth using incremental length data. The purpose of this study was to evaluate growth of PIT-tagged Muskellunge and demonstrate some useful methods for evaluating Muskellunge growth in the absence of age data. Growth data was derived from 476 PIT-tag recapture events occurring in 14 Northwestern Wisconsin lakes during fyke net, electrofishing, and volunteer angling surveys from 2006 to 2015. We estimated relative incremental growth rates [$(\Delta$ TL/$TL_{Initial})$ / Δ years] by sex, waterbody, and size class for each lake. We also estimated ultimate length or L_{Inf} for each population using Ford-Walford graphical methods. Female incremental growth rates showed substantial inter-lake variation at the 20-30" size class and gradually less inter-lake growth variation at the 30-40" and 40-50" size classes. Male incremental growth rates showed a similar inter-lake growth pattern at the 20-30" and 30-40"size classes, but no data were available to describe growth patterns at the 40-50" size class. Ford-Walford plots estimated female L_{Inf} = 44.8 ± 1.9" (± 1 SE; n= 80) and male L_{Inf} = 38.4 ± 0.8" (n=159) for all lakes. Female L_{Inf} varied from 28.6-45.4" among lakes, whereas male L_{Inf} varied 36.2-40.4". Overall, the ultimate lengths for female and male muskellunge were comparable to those in other Wisconsin growth studies. Some L_{Inf} estimates for individual lakes were likely biased, due to low sample sizes and inadequate representation of fish size structure. Nonetheless, ultimate lengths revealed insights about Muskellunge growth potential in Northwestern Wisconsin lakes without the sacrifice of fish to obtain unbiased age data. Additionally, information on incremental growth rates provided a more detailed perspective about the amount of growth occurring at different size classes among populations.

Assessment of Leech Lake Strain Musky Stocking in Lake Wissota, WI

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Lake Wissota is a 6,148 acre impoundment of the Chippewa River located in west central Wisconsin that has a "Trophy" (Class A1) Muskellunge (*Esox masquinongy*) fishery which is maintained largely through stocking

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Upper Chippewa River strain Muskellunge. In the early 2000s, with the dramatic improvement in Minnesota's Muskellunge fishery, a few private organizations lobbied the Wisconsin Department of Natural Resources to shift the genetic strain of musky stocked in Wisconsin to a strain found in many Minnesota lakes – the Leech Lake strain (LLS) - with the aim of improving the quality of Wisconsin's Muskellunge fishery, in terms of size-structure and reproduction. A study was developed to evaluate the potential impacts of stocking LLS musky in Wisconsin; Lake Wissota was selected as one of the study lakes for this project. The First Wisconsin Chapter of Muskies Inc., initiated the shift in genetic strain, so they purchased the LLS Muskellunge for stocking in Lake Wissota. Lake Wissota received LLS muskies from nine stocking events between 2005 and 2015, where a total of 7,717 fall fingerlings and 1,057 yearlings were stocked. Prior to stocking, a fin was removed from each fish to identify future recaptures of LLS Muskellunge. From 2006-2015, four extensive fishery surveys were conducted on Lake Wissota, capturing 876 Muskellunge. In the 2006 survey, 18 yearling LLS Muskellunge were captured; however, in subsequent surveys, no fin-clipped Muskellunge were captured. From these preliminary results, it appears that LLS Muskellunge have not survived in Lake Wissota, assuming clipped fins have not regenerated and these fish are vulnerable to WDNR fisheries surveys. In order to determine whether LLS Muskellunge have regenerated clipped fins, a genetic analysis will be conducted from tissue samples taken from musky captured in the 2015 and 2016 fisheries surveys. This planned research will conclusively determine the origin of captured Muskellunge and will allow detection of any past natural reproduction of LLS Muskellunge or introgression with upper Chippewa River strain fish in Lake Wissota.

A General Assessment of a Southern Riverine Muskellunge (*Esox masquinongy*) Population

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Biologists began stocking Muskellunge *(Esox masquinongy)* in the Shenandoah River systems in the mid 1960's. Very little sampling was completed specifically targeting general Muskellunge population parameters. The Shenandoah River Muskellunge Research Project began in 2009 to determine contribution of stocked Muskellunge, percentage of natural reproduction, individual growth, movement, and general population data. Sampling took place in the months of February and March using three electrofishing boats in tandem. Muskellunge age three and greater were considered fully recruited to the sampling gear. Coded Wire Tags (CWT) were used to mark fingerling and advanced fingerling Muskellunge stocked into the South Fork and Main Stem Shenandoah rivers. All Muskellunge collected during spring sampling (2009-2015) were double marked with a passive integrated transponder tag (PIT) and visual implant alpha tag (VIA). In 2014 & 2015, pelvic fin rays were collected on all fish for age verification. Known-age (CWT) fish verified 100% reader accuracy through age four, 88% through age five using pelvic fin rays in 2014. Throughout the duration of the project, 61 CWT fish were collected. Thirty four percent of Muskellunge (< 7 years old) from the 2014 sample contained CWT stocked Muskellunge. Both stocked and wild fish contribute to the population. Of the 55 PIT tagged Muskellunge recaptured, 9.1% showed significant movement. Catch rates (CPUE) ranged from 1.0 – 2.2 fish per hour. Current findings will direct future Muskellunge management in the Shenandoah River watershed.

Population Estimate of Adult Muskellunge in Lake Bemidji

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Muskellunge *(Esox masquinongy)* are native to the Upper Mississippi River watershed but were considered extirpated from Lake Bemidji and connected waters prior to restoration efforts that began in 1978. Efforts to re-establish Muskellunge intensified through the 1980s with consistent, alternate-year fingerling stocking that continues to present day. Length and age frequency data from Muskellunge assessments conducted in 1998 and 2013 portray an aging population. For example, only one fish greater than 48 inches in length was captured in 1998 whereas 34 fish exceeded this length in 2013. Overall mean lengths of fish captured in these two assessments were 39.4 and 45.3 inches, respectively. As expected, older fish are achieving maximum growth potential with the largest females now exceeding 55 inches in length. However, despite consistent fingerling stocking few fish less than 40 inches were captured in 2013. Eighty nine percent of fish captured during the 1998 assessment was younger than age 11; whereas these age classes comprised only 7% of the 2013 sample. Given the length and age distribution of the population in 2013, it appears that recruitment to the mature population has declined. Whether this is due to increased mortality of juvenile fish or delayed sexual maturity is uncertain. Mark-recapture population estimates for the sexually-mature population were attempted during both assessments using large-frame trap nets (marking effort) and boat electrofishing (recapture effort) during the spawning period. The 1998 effort was unsuccessful recapturing only a single fish. Although a sufficient number of fish were recaptured to generate a population estimate in 2013, there was concern that model assumptions were violated due to sex-specific fish behavior. Thus, efforts were made to generate two additional estimates using angler diaries and a follow-up electrofishing assessment in 2014. Point estimates for our three population estimates of the Lake Bemidji sexually mature Muskellunge population during the 2013 spawning period ranged from 320 to 603 individuals (0.04 to 0.08 fish/surface acre).

Regional Management Approaches

130 Years of Muskellunge Management on Chautauqua Lake

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Chautauqua Lake is one of New York's top Muskellunge *(Esox masquinongy*) waters and has supported the state's Muskellunge hatchery system since 1888. The early fishery was characterized by commercial harvest and high recreational harvest. When Muskellunge numbers declined in the late 1800's a propagation program was instituted. The first permanent Muskellunge hatchery was established on Chautauqua Lake in 1889. Early hatchery operations focused on stocking large numbers of Muskellunge fry. By the early 1930's pond rearing fingerlings was tested and established. A new hatchery was constructed in 1950 that emphasized, and expanded, pond rearing. In the 1980's the hatchery system shifted away from pond rearing and focused its efforts toward rearing Muskellunge fingerlings inside hatchery raceways. Extensive field studies of the relative survival of pond reared vs hatchery reared fingerlings indicated pond rearing produced substantially higher survival rates. Ultimately, rearing fingerlings in the hatchery was discontinued and pond rearing was brought back on line. The current stocking policy, for Chautauqua Lake, is 13,000 pond reared fingerlings each year. A variety of regulations have been implemented in addition to stocking changes. Regulations focused on season dates, minimum size limits, bag limits and special licenses. Regulations on the harvest of Muskellunge have become stricter over the years and are currently 40" minimum size with a bag limit of one fish per day. In addition to

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strict regulations a catch and release ethic has evolved among Muskellunge anglers and the fishery is now dominated by catch and release.

Ontario's Approach to the Management of Muskellunge

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Muskellunge *(Esox masquinongy)* are present in more than 400 lakes and rivers in Ontario, representing an estimated 22% of Muskellunge populations in North America and 30% of the naturally-reproducing populations on the continent. The Ontario Ministry of Natural Resources and Forestry (OMNRF) are leaders in the management of this species. The current angling regulations for Muskellunge are grounded in the research associated with the Cleithrum Project. Five standards for minimum size limits based on the growth potential of the populations, in concert with considerable changes to voluntary catch and release practices have resulted in Muskellunge populations that are thriving and providing world-class fisheries. This presentation will provide an overview of Ontario's Muskellunge management with some discussion of current and future management challenges.

Managing and Monitoring Muskellunge Populations in Eastern Georgian Bay and the North Channel of Lake Huron- A Twenty Year Retrospective

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The nearshore waters of eastern Georgian Bay and the North Channel of Lake Huron support the largest contiguous distribution of Muskellunge *(Esox masquinongy)* populations in the Great Lakes. Prior to 1996 very little was known about the population characteristics of this species yet the area was perceived by ardent anglers as supporting a 'World Class' fishery. Since 1996, over 25 targeted spring Muskellunge spawning surveys at ten different locations have been conducted in the area using live-capture trap-nets. Incidentally captured spawning Muskellunge from additional spring surveys targeting other fish species have also contributed to the over 1000 individuals that have been biologically sampled and affixed with external identification tags. Subsequent recaptures of close to 300 tagged fish, 17% from assessment nets and 10% from angler reported catches, have provided insights into movement patterns and growth characteristics that have distinct gender based differences. Several locations have been sampled in multiple years, however, changes in annual temporal and spatial coverage likely contribute to variable catch rates making it difficult to discern trends in abundance over time. In addition to acquiring basic information on biological attributes and distribution of spawning adults these surveys have resulted in collaborations with other government agencies and academia. These collaborations have revealed the substantial spatial genetic structure and diversity of these populations, the homing behaviour of adults, the strong association between spawning and nursery habitat and negative impacts of low lake levels and shoreline development on recruitment. Collectively these efforts have contributed to a greater understanding of Muskellunge in this unique area of the Great Lakes.

Managing Muskellunge in MN: Deliberate Steps to Better Fishing in the Next Two Decades

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Minnesota boasts 115 water bodies managed for Muskellunge *(Esox masquinongy)* with 44 of these being stocked as part of ongoing management. Although widely recognized as a destination for Muskellunge anglers, much remains to be learned about the efficacy of Muskellunge stocking. Generally, past practice has been an individual lake, experimental approach to deriving optimal stocking densities and frequencies, within broad guidelines. In 2015, MN DNR Fisheries developed well-defined rates and frequencies, and stocking priorities which will provide a basis for determining optimal stocking rates and frequencies for Muskellunge management in Minnesota waters. These new management protocols provide replication of multiple stocking strategies and will ensure long-term consistency that will aid in evaluation of management actions. Consistency over the next two decades and extensive use of PIT tags in newly established fisheries will position Minnesota to better understand and more effectively manage these important fisheries.

Trends in Muskellunge Fishing Tournaments in a North Central Wisconsin County

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Muskellunge *(Esox masquinongy)* fishing tournaments are very popular among anglers. Throughout the 1990's and early 2000's Muskellunge tournaments in Lincoln County in North Central Wisconsin grew in popularity. Muskellunge tournaments in Lincoln County peaked in 2007 and have since declined. There we no Muskellunge fishing tournaments in Lincoln County in 2014 and 2015 for the first time since at least 1994 when tournaments in Wisconsin first required a permit.

From 1995 through 2015, 56 Muskellunge tournaments were analyzed. These 56 tournaments included 3,578 anglers fishing 674 tournament hours for a combined total of over 1.5 million angler-hours. A total of 276 34-inch and larger Muskellunge were registered during these tournaments. On average, it took 5,604 angler-hours for tournament anglers to register a Muskellunge, which equates to 4.9 muskellunge registered per tournament or one Muskellunge for every 13.0 tournament anglers. Average length of Muskellunge registered was 39.8 inches. There was about a four-inch difference in average length of registered Muskellunge between tournaments that registered fish over 34 inches (38.8" average) and those that only registered Muskellunge over 40 inches (43.0"). Mean length of registered Muskellunge increased over the years from about 38 inches in the early 2000's to about 39 inches in the early 2010's. From 1995 to 2013, a subset of the 40-inch and larger Muskellunge registered, showed no increase in the average length. Mean length of 40-inch and larger fish registered remained stable through the years at about 43 inches.

Netting surveys on both Lake Mohawksin and Rice Reservoir have indicated that the Muskellunge populations have decreased, though not statistically significantly, over time from the early 2000's to the late 2000's and early 2010's. Over these same time periods, size quality has increased on both bodies of water, both in terms of netting surveys and tournament angler catches. The decrease in population size seems not to have affected tournament angler catches as their catch rates have increased over time and both netting survey and angler catches show an increase in Muskellunge size quality.

One tournament which took place from 1995-2004 consisted of 2 days and 15 or 16 hours of tournament fishing. All the other tournaments were one-day events and averaged 10.0 hours of fishing over all of the 19 years studied. Trends in the number of Muskellunge tournaments and average number of anglers per

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tournament showed an increase from 1995 to a peak in 2007 and a steady decline since 2010. Similar trends in muskellunge tournament numbers were seen at the statewide level also: a decreasing trend from 1994-99, an increasing trend from 1999-2007, and then another decreasing trend from 2007-15. Downward trends in Muskellunge tournaments and tournament anglers since 2010 has occurred despite increases in tournament catch rates and the average size of registered muskellunge which may signify that "muskie angler burnout" or "muskie tournament saturation" has occurred. Continuing to follow trends in Wisconsin Muskellunge tournaments may show that tournament numbers and participation may run in streaks.

Managing Muskie on the Fringe: An Examination of Nebraska's Efforts to Provide Quality Fishing Outside the Native Range

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The popularity of Muskellunge *(Esox masquinongy)* has led them to be introduced outside of their native range. The state of Nebraska first introduced Muskellunge in 1958 and has intermittently tried to establish populations via introductory and supplementary stocking over the past 50 years. In an effort to provide more clarity to the performance of Muskellunge on the western edge of their native range, we will examine the stocking and sampling database available from the Nebraska Game and Parks Commission. Specifically, we will: 1). explore the stocking history of Muskellunge in Nebraska, 2). develop a statewide muskellunge growth model, 3). compare relative weight of Muskellunge in different water bodies, and 4). discuss historic and current management intended to maintain muskellunge sportfishing opportunities. The database will highlight the distribution of over 113,000 Muskellunge fingerlings since 1995 and share population dynamics associated with sampled fish. Finally, we will reflect on lessons from historic management efforts and how this knowledge will assist with future allocations of available Muskellunge fingerlings.

Muskellunge in Eastern South Dakota

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The South Dakota Muskellunge (*Esox masquinongy)* program began in 1975 when Muskellunge were introduced into Amsden Dam (95 ha). Amsden Dam was the only South Dakota Muskellunge fishery until the 2000s when five additional waters were added; Lynn (648 ha), West 81 (554 ha), North Island (101 ha), Sinai (486 ha) and Middle Lynn (425 ha). Program goals are to maintain low-density populations that can diversify fishing opportunities and provide anglers with a chance to catch a trophy-sized fish. Current management includes a 1,016-mm minimum length limit and stocking. Fingerling Muskellunge are received from Spirit Lake Fish Hatchery (Iowa DNR) in early July and reared in 0.2-ha, lined ponds covered with netting at Blue Dog State Fish Hatchery. These ponds are stocked during mid-May with adult Fathead Minnows (*Pimephales promelas)* (1.8 kg/pond) that spawn and produce large numbers of small minnows. Additional minnows (1,700 to 2,350 kg/ha) are provided throughout the summer depending upon Muskellunge stocking density which varies from 5,000 to 15,000 Muskellunge per ha. Ponds are harvested during September and Muskellunge survival has met or exceeded 75% since 2011 with total length (TL) ranging from 230 to 320 mm. Lake stocking rates are variable because they are dependent of the number of fingerling surviving in ponds until September. Sampling adult Muskellunge has proven difficult, but recent use of large trap nets (1.5 x 1.8 m

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frames, 30.5 m leads) in the spring has improved our ability to sample adult fish. All sampled Muskellunge are measured for TL, weighed and PIT tagged. Population estimates have been completed at Amsden Dam, Lynn and West 81 and estimates have ranged from 0.10 fish/ha to 0.47 fish/ha. Long-term population monitoring will include sampling in the spring with large trap nets and using mark-recapture techniques to estimate population abundance. Anecdotal information indicates that anglers are catching Muskellunge from all waters and interest in Muskellunge fishing in eastern South Dakota has increased. Future research needs include evaluating stocking success, obtaining age and growth information and measuring angler use.

Muskellunge Propagation and Stocking

Realized Effects of Implementing a Genetic Broodstock Management Plan for Muskellunge in Wisconsin.

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In 2006, the Wisconsin Department of Natural Resources' Muskellunge (*Esox masquinongy)* propagation program underwent a series of revisions aimed at conserving genetic diversity. Changes were made primarily to ensure natural Muskellunge diversity was represented in brood fish and crossing and rearing strategies were refined to minimize changes in genetic diversity throughout propagation. To evaluate these revisions, we determined if the new protocols resulted in improved genetic integrity between brood fish and offspring. In 2012, allele frequencies at GTH were similar between brood stock and fry ($\chi^2 = 11.87$, df = 28, $P = 0.99$), pooled fingerlings ($\chi^2 = 8.398$, df = 28, $P = 1.00$), and all individual fingerling ponds ($P > 0.05$). Conversely, allele frequencies at AOH differed between brood stock and pooled fingerlings ($\chi^2 = 44.58$, df = 28, $P = 0.02$) and between four of five rearing ponds ($P \leq 0.01$). However, in 2012, ≥ 95% of all rare alleles observed in the brood stock were conserved in the pooled fingerlings at both hatcheries. Similar results were observed in 2013. Allele frequencies were similar between GTH brood stock and all subsequent life stage comparisons ($P > 0.05$). Allele frequencies within the 2013 AOH production were similar between brood stock and fry ($\chi^2 = 35.34$, df = 28, $P = 0.16$) but differed significantly between brood stock and pooled fingerlings ($\chi^2 = 86.95$, df = 28, $P \leq 0.01$) and between brood stock and all four rearing ponds ($P \leq 0.01$). During 2013, less than 95% of the rare alleles present in the GTH brood stock were conserved in the progeny. Conversely, AOH conserved > 95% of rare alleles in 2013. Overall, the expected genetic results predicted by the prescribed changes to the propagation program were apparent and further adherence to suggested spawning ratios and egg-take procedures will help ensure genetic diversity goals are met.

Paternity Analysis of Pooled-Milt Spawning Practices for Muskellunge Broodstocks

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The current practice of Minnesota Department of Natural Resources biologists collecting Muskellunge *(Esox masquinongy)* gametes for hatchery rearing is to pool sperm from multiple males before fertilizing eggs of a

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single female. The reasons for using multiple males include providing sufficient milt volume and increasing genotypic diversity; the reasons for pooling milt include concerns about infertile males and practicality in the lakeside setting where wild adults are spawned. To provide sufficient males, some may be reused by cribbing and re-stripping males or by preserving sperm. Using microsatellite DNA loci, I assessed paternity of fry from 22 lots each derived from one female and 2-6 males. I used chi-squared tests to determine if males contributed equally and if new and reused males contributed proportionally to their presence in each lot. Males had significantly different numbers of offspring in 16 of 22 lots ($P < 0.05$). A new male had the highest number of offspring in each of the 15 lots that mixed new and reused males, but not all new males had more offspring than all reused males. Combined, new males contributed significantly more than expected in 9 of 15 lots, and in only one lot did reused males exceed expectations (but $P > 0.05$). Although reusing males clearly had an effect on their contribution, males also had significantly different numbers of offspring in 4 of 7 lots with all new or reused males. Because this was an assessment of current practices and not experimentally controlled, I could not determine what combination of unequal milt volume, unequal sperm count, and sperm competition accounted for the unequal offspring contributions. Regardless of the cause, changes in protocols could be considered to reduce disparities in offspring numbers among males, and thus enhance the maintenance of genetic diversity in Muskellunge brood stocks.

Growth, Condition, and Short-term Survival of Age-0 Muskellunge Reared Using Two Different Techniques

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Muskellunge (*Esox masquinongy)* are commonly reared on natural prey in hatcheries. However, this method is expensive and introduces biosecurity risks. Formulated feeds (pellets) are now being used by some agencies, however concerns exist regarding the size and post-stocking survival of pellet-reared Muskellunge compared to those reared on natural prey. Our objectives were to (1) determine if growth and condition differed between pre-stocking age-0 Muskellunge reared solely on natural prey (minnow only; MO) with those reared intensively on pellets and finished extensively on minnows (minnow finished; MF) and (2) determine relative survival of stocked Muskellunge reared using the two different techniques. During 2013 and 2014, fingerling Muskellunge (N≈6,000/treatment/year) were reared, marked, and stocked into 23 lakes throughout Wisconsin. Average condition was higher for MO fish (K= 0.581; 0.587) compared to MF fish (K= 0.532; 0.495), during 2013 and 2014 respectively. Minnow only fish were significantly larger (both length and weight) at stocking than MF fish both years ($P<0.001$ in all tests). Nighttime boat electrofishing catch rates were used to asses short-term (2-6 weeks) post-stocking survival. Capture rates were higher for MO fish (10.0%; 7.1%) compared to MF fish (7.3%; 4.4%) during 2013 and 2014 respectively, however, a large number of fish were captured from both treatments. This could suggest that survival was higher for MO fish. However, formulated feeds may be a viable method if the cost to rear more individuals, to offset reduced survival, is less than the cost to rear fish on natural prey and hatcheries have available rearing space.

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An Overview of the Lake Simcoe Muskellunge Restoration Project

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The Muskellunge (*Esox masquinongy*) is native to Lake Simcoe, Ontario and supported a commercial fishery and sport fishery in the late 1800's and early 1900's, respectively. After significant overharvest, habitat loss and ecological change, the Lake Simcoe population of Muskellunge was significantly reduced by the 1930's. The sport fishery in both Lake Simcoe and Lake Couchiching was closed in 2005. Feasibility and habitat inventory studies determined that restoration of the Lake Simcoe Muskellunge population is a realistic management objective. The goal of the Lake Simcoe Muskellunge Restoration Project is to restore a self-sustaining Muskellunge population to Lake Simcoe through a long-term restoration project including habitat enhancement, effectiveness monitoring and stocking efforts. Recent rehabilitation efforts focused on targeting critical spawning/nursery areas and will benefit nearshore and tributary fish communities, with additional benefits to water quality. Many challenges are identified, including choosing enhancement sites, future habitat protection, logistical concerns of a large inland lake, biological risk, and defining program success. However, these challenges can be addressed with support from the strong partnerships and significant funding commitments that have guided this long-term restoration project to date.

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Poster Session

Influence of Habitat Additions on Survival, Growth, and Condition of Extensively-Reared Muskellunge

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The influence of natural littoral structures such as coarse woody material (CWM) on fish populations is well documented. In general, CWM and other natural littoral structures have been associated with increased growth, survival, and production of a variety of fishes. Because increased growth, survival, and production are often goals of propagation facilities, fish population responses to structural habitat observed in natural settings have prompted production facility managers to consider integration of structural habitat in the extensive fish rearing process, which generally occurs in earthen or lined ponds devoid of structure. Therefore, our objective was to determine the influence of CWM-analogue addition on fish population characteristics in an extensive fish production setting. Specifically, we compared relative survival, growth, and body condition of age-1 Great Lakes spotted muskellunge (*Esox masquinongy)* between rearing ponds with and without CWM-analogue additions. Survival, growth, and body condition varied across ponds and treatments, but were qualitatively greater in ponds with habitat additions compared to those without. For ponds with habitat additions, mean relative survival was 78%, mean size at stocking was 366 mm TL, and mean relative condition factor was 1.03. For ponds without habitat additions, mean relative survival was 73%, mean size at stocking was 355 mm TL, and mean relative condition factor was 0.97. Although results are preliminary and only represent a single year of data collection, our findings suggest that habitat additions may be a viable strategy in terms of meeting goals of increased growth, survival, and production in a fish propagation context.

Lake Monona Paired Comparison of Leech Lake and Chippewa River Strain Muskellunge

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There has been a consistent debate about genetic strains of Muskellunge, (*Esox masquinongy),* having differential performance, specifically growth rates and ultimate size. The Capital City Chapter of Muskies Inc. and the Wisconsin Department of Natural Resources (WDNR) began a paired comparison of Leech Lake (LL) strain and Chippewa River (CR) strain Muskellunge in 2006. The goal of the project was to assess the ultimate size of the two strains of fish and increase the number of Muskellunge greater than 50" in Lake Monona. 500 fish with Passive Integrated Transponder (PIT) tags of each strain were stocked in Lake Monona, Dane County Wisconsin in each year of the study. Only 63 LL fish were stocked in 2006 and no LL fish were stocked in 2010. In 2013, Wisconsin River strain (WR) was stocked instead of CR. To date a 4,616 CR, 3824 LL and 497 WR large fingerling Muskellunge have been stocked. During the study additional CR fingerlings that were not PIT tagged were also stocked. Two netting assessments have occurred since the beginning of the study. One survey was completed in 2011 and 2012, and another begun in 2015 which will be completed in 2016. The

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WDNR standard protocol for Muskellunge assessment is two consecutive years of early spring fyke netting to capture pre-spawn and spawning adults. Annual spring electrofishing also occurs on Lake Monona and connected lakes Waubesa and Wingra. To date there have been 78 known age recaptures of PIT tagged muskies during DNR netting and electrofishing surveys. The Capital City Chapter of Muskies Inc. have purchased PIT tag readers and distributed them to club members. Through 2015 they have reported 97 recaptures of known age PIT tagged Muskellunge. This presentation will compare the performance as evaluated by length at age and survival of the LL and CR strains of fish. It is too early to compare the ultimate size achieved by the two strains. Several factors other than genetic strain may also play a role in some of the performance including time of stocking and size at stocking.

Predicting Abundance of Adult Muskellunge in Northern Wisconsin Lakes

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Most Wisconsin Muskellunge (*Esox masquinongy)* populations occur within the Ceded Territory of northern Wisconsin, where mixed fisheries consisting of a recreational hook-and-line fishery and a tribal spearing fishery occur. Safe harvest levels for each population are based on estimates of adult Muskellunge abundance. Estimates of adult Muskellunge abundance used to establish safe harvest levels are obtained from mark-recapture surveys that are conducted on a few lakes over a two year interval. These estimates are considered valid estimates of abundance for up to two years after the initial marking of fish. If a recent population estimate is not available for an individual lake, a linear regression model is used to predict adult abundance from lake surface area using existing population estimates from all lakes. A similar approach is used to predict abundance of walleyes (*Sander vitreus*), but the amount of variation in adult abundance that is explained by lake surface area is much higher for Walleyes than for Muskellunge. Therefore, the objective of our study is to determine if alternative models can be used to explain greater variation in the abundance of adult Muskellunge within northern Wisconsin lakes than the current linear model that relies solely on lake surface area as a predictor variable.

Long-Term Changes in Wisconsin's Muskellunge Fishery

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Wisconsin's Muskellunge (*Esox masquinongy)* populations provide an important recreational and tribal fishery. My objective was to examine long-term changes in the fishery through time, relative to our overall management goals of sustaining viable Muskellunge populations and providing a trophy fishery. I compiled the number and lengths of Muskellunge from several data sets and computed indices of population abundance and size-structure, angling statistics, and estimates of exploitation for Wisconsin lakes from 1980 to 2014. All available evidence suggests that restrictive fishing regulations, combined with voluntary release of legal-sized Muskellunge, has reduced harvest to very low levels, resulting in an ongoing improvement in size-structure of Wisconsin Muskellunge populations, compared with the 1980s. Abundance of Muskellunge has remained relatively unchanged through time, while angler success has improved by some measures (e.g., catch of

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Muskellunge by contest participants) but has remained relatively unchanged by others (e.g., catch rates from access-point creel surveys). Although specific waters may still occasionally experience relatively high harvest levels, low abundance, poor size-structure and/or low angler success, overall, the status of today's Muskellunge fishery in Wisconsin is strong relative to the 1980s and the overall goals of sustaining viable populations and providing trophy fishing are being met.

Effects of a 40-inch Minimum Length Limit on Muskellunge in Wisconsin Lakes

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Relatively high minimum length limits are commonly imposed on Muskellunge (*Esox masquinongy)* fisheries in order to protect adults to full maturity and provide trophy fishing opportunities. Evaluations of length-limit effects on Muskellunge populations have been either of relatively short duration (< 10 years) or focused on individual lakes. I evaluated the long-term effects of a 40-inch minimum length limit, imposed on several northern Wisconsin lakes, and compared the results to several reference lakes that remained at the statewide minimum length limit of 32 and then 34 inches. Ten or more years after its implementation, I found no evidence of changes in adult Muskellunge density as a result of the 40-inch minimum length limit. However, I observed significant improvements in PSD-40 in the 40-inch minimum lakes, relative to the reference lakes. Even at relatively low levels of angler harvest, a 40-inch minimum length limit had a positive influence on the size-structure of Muskellunge in northern Wisconsin lakes. I also found a significant negative relationship between PSD-40 and density among lakes, indicating that intra-specific interactions may influence size-structure, even in this relatively low density fish. Long-lived, low-density species such as muskellunge should be monitored over extended time periods in order to document responses to management actions.

Development of a cooperative relationship with the Wisconsin Department of Resources (WDNR) for the purpose of side by side research of differential species of Muskellunge Stocking.

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A local fishing club, Capital City Muskies Inc. has developed a cooperative relationship with the Wisconsin Department of Resources (WDNR). This relationship has allowed the club to fundraise, purchase and stock Leech Lake Strain and Chippewa strain Muskellunge *(Esox masquinongy)* and assist in data collection for a matched comparison study of Leech Lake and Chippewa Strain Muskellunge in Lake Monona, Wisconsin. This poster will outline the process of fundraising, purchasing, stocking and collecting data to assist the WDNR study of differential Muskellunge species stocking.
Fundraising was generated primarily through monetary donations from club members and procurement of grant monies. Leech lake Muskellunge were purchased in Minnesota from a private fish farm. Approximately, 500 Leech Lake and 500 Chippewa strain Muskellunge were inserted with Passive Integrated Transponder (PIT) tags and stocked in various shallow bays on Lake Monona, Wisconsin for the last ten years. Data was collected by both the WDNR through netting in the spring and through PIT tag scanner "hits" by local anglers.

Brood Source Identification and the Effects of Supplementation on Muskellunge in the Great Lakes

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Current Muskellunge (*Esox masquinongy*) management in Great Lakes States and Provinces call for stocking Muskellunge native to the Great Lakes to re-establish sustainable populations that have previously experienced population declines or extirpation. Accordingly, native Great Lakes Muskellunge brood sources must be identified or established to meet that need. Managers who seek to develop future Muskellunge brood stocks benefit from knowledge of stock structure to better match the origin of hatchery fish to the locations in which they will be stocked. Therefore our objectives were to (1) determine if the genetic structure of non-admixed Great Lakes Muskellunge populations is consistent with a genetic stock model that can be described in terms of genetic stock identification and degree of stock isolation for the identification of potential brood sources, and (2) determine if significant admixture is present in Great Lakes Muskellunge populations consistent with introgression between stocked and resident Great Lakes Muskellunge. Fourteen microsatellite loci were used to characterize genetic diversity and structure of >1,800 Muskellunge from >40 locations throughout the Great Lakes and associated inland drainages. Genetic diversity and molecular variance will be compared within and among various genetic structure models to identify possible influences of historical stocking and, ultimately, potential brood sources for Great Lakes Muskellunge supplementation efforts.

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