Spatial and temporal factors influencing northern pike fry density estimates

Nate Stott
Aquatic Biology Program
Bemidji State University

The Tamarac River in northern Minnesota is an important spawning site for northern pike (*Esox lucius*) in the Red Lake system. However, little is known about fry production in the river. This study investigates migration densities and spatial and temporal factors influencing northern pike fry density estimates. Northern pike fry were collected with drift nets between 28 May and 4 June 2014. Thirty northern pike fry were randomly selected to have total length measured from each sample. Northern pike fry were observed in the first sample day. Northern pike fry density maxima occurred on 29 May at midnight (3.81 fish/m³), by 4 June fry migration had nearly subsided. Multiple regression modeling with Program R was implemented to investigate the relationship between fish density and abiotic factors. Akaike's Information Criterion was used to select the best supported model. There was enough evidence to suggest time of day ($p < 0.001$, $F = 64.09$), date ($p < 0.001$, $F = 113.64$) and location within the river ($p < 0.001$, $F = 11.96$) were significant factors affecting northern pike fry density within the Tamarac River. The average length of northern pike fry increased 1.12 mm (1.05-1.20 95% CI) per day throughout the study ($p < 0.001$, $R^2 = 0.46$, df = 939).

Faculty advisor: Dr. Andrew W. Hafs

Introduction

Northern pike (*Esox lucius*) are a commonly targeted game fish in Minnesota as well as a staple food source for many people. These fish can reach very large sizes with the Minnesota state record being 20.75 kg (MNDNR 2015a). While these large northern pike are considered by many to be a prized game fish, small northern pike are often seen as undesirable. Large northern pike are often subject to exploitation. This has led to populations with smaller average sizes. Subsequently causing northern pike to become a less prized game fish (Pierce 2012). Currently the Minnesota Department of Natural Resources (MNDNR) has implemented a slot limit in many Minnesota lakes to help promote the growth of trophy fish while continuing to allow selective harvest of smaller northern pike (MNDNR 2015a).

Red Lake and its tributaries are considered by many people to be a world class walleye (*Sander vitreus*) fishery. In addition to the prosperous walleye population, Red Lake is also known to hold numerous trophy northern pike. The MNDNR in conjunction with Red Lake DNR have implemented a conservation plan that allows a harvest of three northern pike. A slot limit is in place where all fish between 660 and 1118 mm must be immediately released. Only one of the three fish harvested can be over 1118 mm (MNDNR 2015b).

With a maximum depth of 5.5 m, Red Lake provides abundant quality habitat with littoral zone dominating the topography of the lake. The abundant littoral habitat and numerous tributaries are optimal for northern pike growth and reproduction (Inskip 1982). Adult northern pike often move up rivers immediately after ice out to find suitable spawning locations such as flooded marshes or pools (Inskip 1982).

In Minnesota, male northern pike can reach sexual maturity anywhere from 1 to 2 years or when they reach a length of 300 mm. Female northern pike often take longer to mature, usually between 2 and 3 years, or when they reach 330 mm (Pierce 2012). Northern pike spawn shortly after ice out when water temperatures reach 8 °C. Cold weather, strong winds, or heavy rain can stop or delay spawning. Prolonged delays of spawning can cause a resorption of eggs. By the time water temperature reaches 13 °C, the majority of mature females have completed spawning (Inskip 1982).

High spring water levels during spawning followed by a slow decline throughout incubation, promote the strongest year class strength of northern pike (Johnson 1957). Small northern pike females (399 mm) typically lay around 7,000 eggs while large females have been observed to lay upwards of 200,000 eggs (Frost and Kipling 1967). If northern pike eggs have satisfactory incubation conditions, the observed hatch rate of eggs can be upwards of 60 to 90 percent (Pierce 2012). Some examples of satisfactory conditions are; water temperatures between 12 and 19 °C and good water quality without extensive siltation (Adelman 1969). The length of the incubation period for northern pike eggs is highly dependent on water temperature. In natural spawning sites eggs can hatch anywhere from 10 to 31 days after fertilization (Pierce 2012). Northern pike have been observed to undergo a staging period where fry grow before migration downstream occurs. This takes approximately 16 days (Franklin and Smith 1963).

The total length of northern pike fry is typically between 6.5 and 8.0 mm at the time of hatch (Pierce 2012). In a Lake Michigan tributary, the average length of northern pike was observed to increase at a rate of 1.3 mm per day for the first 85 days after the hatch (Carbine 1942). However, growth rates of northern pike can be highly variable. In a study conducted on Lake Michigan, young of year northern pike were collected in October ranging from 8.3 cm to 44.6 cm (Carbine 1944). It could be possible that this variation in fish growth rates begins at a very early age.

Northern pike are opportunistic feeders. Fish with the most available food often have the highest growth rates (Inskip 1982). Cannibalism and predation can also have huge influences on northern pike growth and mortality during their first few weeks of life (Hunt 1951). As much as 13.3% of northern pike fry diets has be attributed to cannibalism (Hunt 1951).

The objectives of this study are: (1) to investigate the effect spatial and temporal variables have on northern pike fry density estimates (2) estimate the total larval production in the Tamarac River (3) determine a relationship between the length of northern pike fry and the date of collection.

Methods

The Tamarac River is a common spawning site for northern pike. It flows into the western portion of Upper Red Lake. Northern pike fry were collected by setting 750 µm drift nets at noon and midnight each day for one hour between 28 May and 4 June 2014. The study site was located at 48°09'17.7"N, 94°29'19.5"W. Five 30 by 40 cm drift nets were set during each collection event. Three nets were placed in the center to sample vertically in the water column. Their depths ranging from the top of the shallow net at the surface to the bottom of the deepest net at a depth of 1 m. The other two nets were at the shoreline and 25% stream width at the water surface. Nets were set in this order to collect for three locations both vertically and horizontally in the water column (Figure 1). Drift samples were stored in jars and preserved with 90% ethanol.

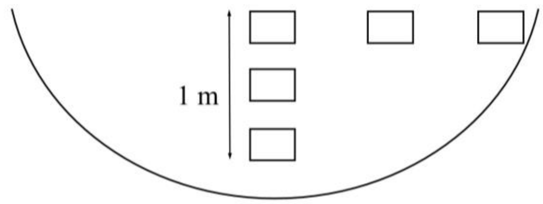

Figure 1.−A graphic representation of the locations and depths drift nets were set within the water column.

Thirty northern pike fry were randomly selected from each sample. If fewer than 30 fish were present all fish were measured. Their total lengths were measured to the nearest hundredth of a millimeter using a micrometer and a dissecting scope. Linear regression in Program R (R core team 2015) was used to test for a significant difference in average length in relation to date of collection.

All remaining northern pike fry were counted from each sample. Total counts were then divided by the volume of water that passed through the net to estimate the fry density (D) per cubic meter of water (fry/m^3). The volume of water was calculated by averaging the water velocity before and after the net was set and then multiplying average velocity by the total set time as well as the net dimensions.

To estimate the total northern pike fry production, a mean fish density (M) was calculated for each day. The mean fish density was then multiplied by the total discharge (m^3/s) in the top 1 m of the stream. Discharge (Q) at any time was estimated using the relationship between staff gauge (S) and discharge ($Q = 0.038 \cdot S - 8.48$, $R^2 = 0.991$, $p = 0.003$). To account for the difference in the total stream discharge and the discharge in the top meter, a ratio (R) was developed between the total cross sectional area above and below the 1 m cut off. Total daily production estimates (P) were then estimated using the equation $P = (M \cdot R \cdot Q \cdot t)$ where t is the total time (sec) in one day. The sum of all daily production estimates (P) was the estimated total fry production in the Tamarac during the study duration.

A multiple regression model was created using Program R (R core team 2015) in order to investigate a relation between northern pike fry density and four independent variables. The variables that were used in the models were; time (midnight or noon), location (center, 25% width, and shore), date and depth. All possible variable combinations were tested. Selection of the best supported model was based on Akaike's Information Criterion (AIC, Akaike 1973). Northern pike densities were transformed by a Box-Cox power transformation (Venebles and Ripley 2002) as well as a scalar transformation in order to improve normality.

Results

A total of 5,489 northern pike fry were collected during the course of the study. Fry densities for individual samples ranged from 0.0 to 3.81 fry/m³ with the maximum occurring at midnight on 29-May. Drift samples that had no northern pike fry present were frequent toward the end of the sampling period (Figure 2). An estimated 2,225,000 (696,000-3,750,000 95% CI) northern pike fry migrated down the river during the collection period.

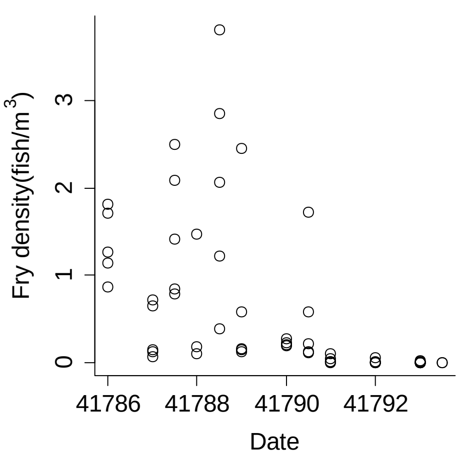

Figure 2.−Northern pike fry densities for every net during the collection period. Dates are represented in the 1900 date system. The spaces between the dates represents midnight sets while the date represents noon sets.

Of the 15 multiple regression models tested, the model predicting fry density that included date, location and time was best supported (AIC = -34.78, Table 1, Figure 3). The next best supported model contained all variables (AIC = -31.20). Because the ΔAIC score was greater than 2, a selection of a best supported model could be made (Arnold 2010). These results suggest date ($p < 0.01$, $F = 113.64$, df = 52), time ($F = 64.09$, df = 52, $p < 0.01$) and location ($p < 0.01$, $F = 11.96$, df = 52) were significantly influencing northern pike fry density estimates in the Tamarac River. The samples at the end of the collection period had lower density estimates than at the beginning (Figure 2). Midnight samples yielded higher density estimates than the noon counterparts (Figure 4). Both the 25 % width and the shoreline samples produced larger density estimates than center nets (Figure 5).

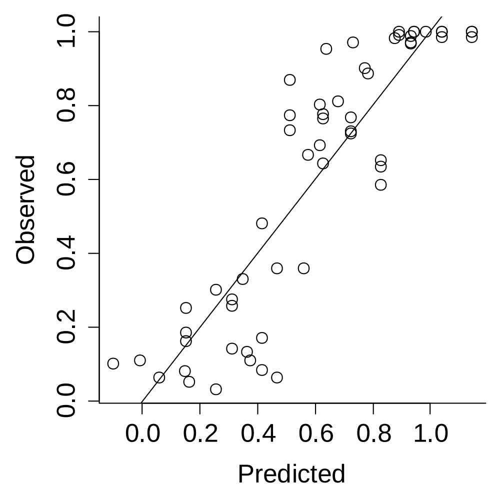

Figure 3.−Observed values in comparison to the values calculated by the best supported regression model (Density (fry/m^3) = Date + Location + Time).

Table 1: A list of all regression models tested along with corresponding AIC and RMSE values. The y variable is Northern pike fry density (fry/m^3).

Model	AIC
~Date + Location +Time	-34.78
~Date + Depth + Location + Time	-31.20
~Date + Time + Depth,	-23.08
~Date + Time	-17.75
~Date + Location	-10.66
~Date + Depth+ Location	-6.81
~Date + Depth	-2.66
~Date	-0.17
~Location + Time	29.26
~Time	32.95
~Depth + Location + Time	33.00
~Depth + Time	33.17
~Location	45.71
~1	47.55
~Depth	48.73
~Depth + Location	49.61

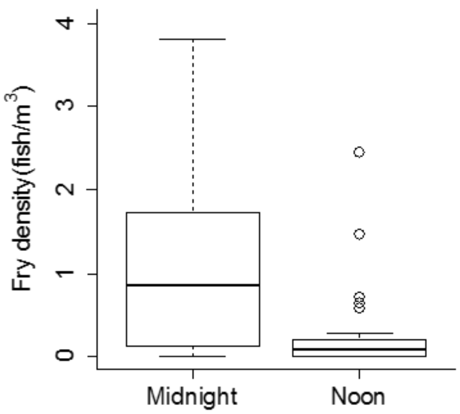

Figure 4.− A comparison of median fish densities (thick black bars) for both midnight and noon drift.

A total of 959 pike fry total lengths were measured throughout the study. The smallest average length occurred on 27 May (16.17 mm, 12.14-20.20 95% CI) at midnight. The largest average length occurred on 4 June (31.76 mm, 25.50-37.83 95% CI) at noon. The average length of northern pike was observed to increase at a rate of 1.12 mm (1.05-1.20 95% CI) per day throughout the study ($p < 0.01$, $R^2 = 0.46$, Figure 6).

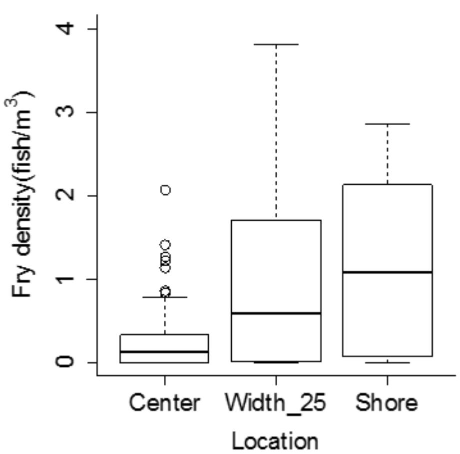

Figure 5.− A comparison of median fry densities (thick black bars) of the nets placed at the center, 25% width and shoreline.

Discussion

An estimate of 2,225,000 northern pike fry migrated down the Tamarac River during the collection period. This estimate provides evidence to suggest there is a solid base of natural reproduction within this system. High densities of northern pike often cause reduced growth rates and a smaller average size of adult fish (Pierce 2012). Thus, stocking the river or lake for northern pike could be expensive, ineffective and possibly detrimental to the size structure of northern pike in Upper Red Lake. Additional information on fry production resulting from northern pike that spawn within the lake is necessary for affirmation. Therefore, future studies on Upper Red Lake northern pike production should include estimating fry production within the lake itself.

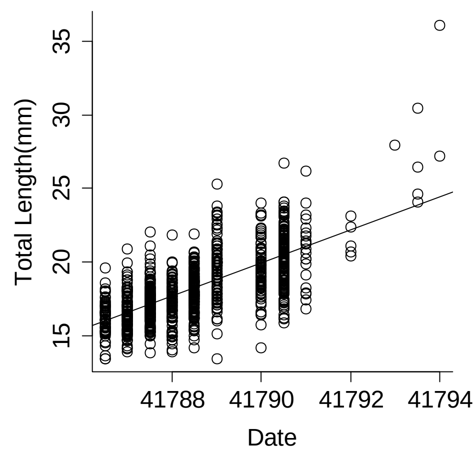

Figure 6.−Total length (mm) of larval fish for each day. Dates are in 1900 date system. Linear regression equation; Total Length = 1.083(Date)-4.525e+04.

By having northern pike fry with lengths greater than 8 mm in the first sample, there is evidence to suggest that the start of the migration was missed. This infers that the estimate of total fry production is low. Only the peak and the tail were collected. Fry densities appeared to have a normal distribution. Therefore we can extrapolate and estimate how many could have been missed. In doing this, an estimated additional 800,000 northern pike fry migrated down river before sampling occurred. Extrapolation, however, has a large amount uncertainty therefore this estimate should be used with caution.

May and June had unusually high water levels with exceedingly low dissolved oxygen levels (< 3.5 mg/L) due to the anoxic conditions of the surrounding flooded wetlands. Northern pike are more tolerant to low dissolved oxygen than many other temperate species (Inskip 1982), therefore, mortality rates could have been low in comparison to other species observed. Low water levels could lead to less fry production as fewer flooded marshes would become available to spawning fish. However, lower water levels could result in increased dissolved oxygen concentration due to minimized water contact with the anoxic soils in the surrounding wetlands. When oxygen saturation reaches 40% egg hatch rates have been shown to increase substantially (Gulidov 1969). Therefore, an increase in dissolved oxygen concentrations could potentially produce higher hatch rates. Future research conducted in the Tamarac River should consider the effect that water levels have on fry production estimates.

The higher concentrations of pike fry occurring at night could suggest that diurnal migration occurs. One possible explanation is that fry are moving up in the water column to take advantage of the stronger current and thus migrate longer distances throughout the night when low light levels hinder visual predators from preying on fry. Northern pike fry could potentially move up in the water column to feed at night as zooplankton exhibit these same behaviors (Lampert 1989). Although, feeding alone seems to be an unlikely cause because white sucker (*Catostomus commersonii*) fry were present in higher numbers during the day (N=449) than at night (N=121) in the samples as well. Northern pike fry were observed to have white suckers in their mouths throughout the study suggesting gape limitations were not occurring. An additional possible causation could be that during daylight hours northern pike fry are able to detect and avoid the nets. Thus, accounting for the lower densities during the day and increased error. We are unaware of any previous research that has been conducted to support or disprove this potential causation.

Northern pike fry were observed in higher concentrations in both the 25% width and the shoreline nets. Northern pike could potentially be avoiding the fast waters of the thalweg. The faster water could inhibit northern pike’s ability to feed. Caudal fins at the time of sampling were not well developed, therefore, movement needed for prey capture could potentially be reduced. With the fish unable to capture prey or maintain position in the water column they would be unable to acquire enough energy to maintain growth. Increased vegetation near the shoreline was observed, although not measured. Northern pike fry could be using this vegetation for predator avoidance.

The change in the average length of larval northern pike is likely related to the growth rate of northern pike in this system. The change in average length of northern pike (1.08 mm) was approximately 0.2 mm less than 1.3 mm per day observed by Carbine (1942). Inskip (1982) suggests pike fry will migrate from the spawning area when fry reach 15 mm. By using the regression equation for growth from this study it is estimated only 7 days were needed for growth to the 15 mm mark. Which would give us an approximate mean hatch date of 21 May.

If a future study is conducted, nets should be set at an earlier date in order to sample the entire migration period. To better approximate the northern pike fry estimates, additional nets should be placed across the stream. The two deeper nets in the center should be eliminated as the increase effort would have little to no effect on the confidence of production estimates. Additional time intervals should be put in place to give a better representation on northern pike fry activity throughout the day.

References

Adelman, I.R. 1969. Survival and growth of northern pike (*Esox lucius*) in relation to water quality. Doctoral dissertation. University of Minnesota, St. Paul.

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 267–281 in B. N. Petrov and F. Csaki. Second international symposium on information theory. Akademiai Kiado, Budapest, Hungary.

Arnold, T.W. 2010. Uninformative parameters and model selection using Akaike's information criterion. The Journal of Wildlife Management 74:1175-1178.

Carbine W.F. 1942. Observations on the life history of the northern pike, *Esox lucius*, in Houghton Lake, Michigan. Transactions of the American Fisheries Society 71:149-164.

Carbine, W.F. 1944. Growth potential of the northern pike (*Esox lucius*). Papers of the Michigan Academy of Science, Arts and Letters 30:205-220.

Franklin, D.R. and L.L. Smith. 1963. Early life history of the northern pike, *Esox lucius*, with special reference to the factors influencing the numerical strength of year classes. Transactions of the American Fisheries Society 92:91-110.

Frost, W.E. and C. Kipling. 1967. A study of reproduction, early life, weight-length relationship and growth of pike, *Esox lucius*. Journal of Animal Ecology 36:651-693.

Gulidov, M.V. 1969. Embryonic development of the pike, *Esox lucius*, when incubated under different oxygen conditions. Problems of Ichthyology 9:841-851.

Hunt B.P. and W.F. Carbine. 1951. Food of young pike, *Esox Lucius*, and associated fishes in Peterson's ditches, Houghton Lake, Michigan. Transactions of the American Fisheries Society 80:67-83.

Inskip, P.D. 1982. Habitat suitability index models: northern pike. U.S. Department of Interior. Fish and Wildlife Service. FWS/OBS-82/10.17. 40 pp.

Lampert, W. 1989. The adaptive significance of diel vertical migration of zooplankton. Functional Ecology 3:21-27.

MNDNR (Minnesota Department of Natural Resources) 2015a. Lake Finder. http://www.dnr.state.mn.us/lakefind/showreport.html?downum=04003501. Accessed October 2015.

MNDNR (Minnesota Department of Natural Resources) 2015b. State records. http://www.dnr.state.mn.us/fishing/staterecords.html. Accessed October 2015.

Pierce, R.B. 2012. Northern pike; ecology, conservation and management history. State of Minnesota Department of Natural Resources. ISBN 978-0-8166-7954-6.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Venables, W.N. and B.D. Ripley. 2002. Modern applied statistics with S. Fourth Edition. Springer, New York.