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**ADULT WALLEYE ABUNDANCE AND SUBSEQUENT FRY PRODUCTION IN  
THE TAMARAC RIVER, MN**

by

**Phillip Oswald**

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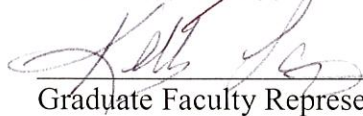
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## **ADULT WALLEYE ABUNDANCE AND SUBSEQUENT FRY PRODUCTION IN THE TAMARAC RIVER, MN**

Walleye reproductive success is of critical interest for the Red Lakes as this system is maintained entirely by natural reproduction and supports robust commercial and recreational fisheries. The Tamarac River, a major tributary to the Red Lakes, hosts a substantial Walleye spawning migration annually. The river drains the largest peat bog in the lower 48 states and thus experiences low dissolved oxygen at times. It is largely unknown how the potential anoxic bog water affects Walleye reproductive success each year and subsequent year class strength. Fyke nets were set from 2014-2018 to assess the relative abundance of adult Walleye spawning in the river with mean peak CPUE ranging from 10 – 288 fish/net. Additionally, in 2017, a Jolly-Seber abundance estimator was used to assess the magnitude of the spawning migration. A total of 13 capture-recapture sampling events resulted in the capture of 9,648 spawning Walleye. Sampling occurred throughout the spawning migration with peak abundance estimated at 268,877 (76,952-460,802 95% CI) Walleye, or about 6.5% of the Red Lakes' Walleye population. It is estimated that 86,040, or 7.9% of the females present in the Red Lakes spawned in the Tamarac River in 2017. Larval drift nets were set later to assess the success of Walleye reproduction in the Tamarac River. Mean peak larval Walleye densities ranged from 0.03 – 0.86 fish/m<sup>3</sup> throughout sampling years. Total fry output from the Tamarac River in 2017 was estimated at 277,462 (95% CI = 273,040-281,884) larval Walleye, or 0.3% of the wild fry estimate of the Red Lakes. Dissolved oxygen ranged from 2.95 – 10.8 mg/L and discharge ranged from -0.32 - 14.80 m<sup>3</sup>/s. Reproductive activity in the Tamarac River may vary annually due to these changing stream characteristics, however remains important to the health of the Red Lakes' Walleye population.

## INTRODUCTION

Walleye *Sander vitreus* are native to Minnesota and popular among anglers year-round. The Red Lakes' Walleye fishery is economically important, creating opportunities for recreational and commercial fisheries. Over 418,000 Walleye have been harvested each year from the Red Lakes since 2014 (Brown and Kennedy 2018). Overfishing led to a collapse of the Walleye population in the late 1990s resulting in densities as low as 0.67 fish/acre in 1996 (MNDNR unpublished data). Walleye populations recovered after a harvest moratorium and short-term recovery stocking efforts (Brown and Kennedy 2018). The population peaked at record levels of Walleye abundance in 2011 with 77.11 fish/acre (MNDNR unpublished data) but has since receded to 28.2 fish/acre in 2017 (MNDNR unpublished data) and remains completely supported by natural reproduction (Brown and Kennedy 2018).

The Tamarac River, a major tributary to the Red Lakes, hosts Walleye spawning migrations annually. A historic egg take operation was conducted on the Tamarac River prior to the collapse of the Walleye population to provide supplemental stocking to other Minnesota lakes. Graham et al. (2017) suggests the Tamarac River could support approximately 106,000 adult females with the amount of suitable substrate available. The Minnesota Department of Natural Resources (MNDNR) conducts an electrofishing survey during the migration to estimate the relative abundance of spawning fish, but the magnitude of the migration is unknown. Fyke netting has also occurred in addition to electrofishing since 2014 to assess the relative abundance of Walleye during the full migration. An abundance estimate of Walleye migrating up the river would allow

managers to know what proportion of fish from the Red Lakes use the Tamarac River to spawn, indicating the river's importance to year class strength.

Annual fluctuations in water level likely influence water quality of the Tamarac River, which may influence Walleye year class strength of the Red Lakes. Big Bog State Recreation Area is located in northern Minnesota adjacent to Upper Red Lake and the Tamarac River. It is largely unknown how input from the bog influences water quality of the Tamarac River given the bog's proximity. Bog groundwater is typically anoxic leading to dissolved oxygen levels around 3.0 mg/L in connected surface water (Winter et al. 2002). Mixing of the hypoxic bog water with river water can affect dissolved oxygen levels in those systems (Winter et al. 2002). Graham (2016) found elevated water levels and low dissolved oxygen concentrations in the Tamarac River in 2014, a high-water year, which suggests high discharge from the bog leads to hypoxic conditions in the river. Further investigation of the interaction between water level, discharge, and dissolved oxygen would strengthen a relationship that is currently lacking. Additionally, Walleye reproductive success in the Tamarac River and the potential impacts of low dissolved oxygen in the river remains largely unexplored.

Population dynamics and year class strength are best understood through examining reproductive success (Johnston et al. 1995). A common practice for estimating success of reproduction in lotic systems is the collection of larval fishes using drift nets (e.g., Franzin and Harbicht 1992; Johnston et al. 1995; Oesmann 2003; Dustin and Jacobson 2003). Survival of larval and juvenile fishes is generally lower, and more variable compared to other life stages (Mion et al. 1998). Walleye recruitment varies greatly among years and depends largely on survival during their first year of life

(Chalupinicki et al. 2011). Critical periods for larval fishes vary from year to year at different stages of life development, and results in survival or mortality (Treasurer 1978). Studying reproduction events through the collection of larval fishes is critical to explain these fluctuations (Treasurer 1978).

Reproductive success of Walleye and potential recruitment are known to be influenced by biotic and abiotic factors occurring during egg development and the larval stage (Rutherford et al. 2016). Aspects of water quality, including dissolved oxygen (Bozek et al. 2011), have been shown to affect Walleye reproductive success. Dissolved oxygen levels above 5.0 mg/L generally result in high egg survival (McMahon et al. 1984) while dissolved oxygen concentrations lower than 2.5 mg/L have resulted in 100% embryo and larval mortality (Siefert and Spoor 1974). Stream characteristics such as discharge can also influence reproductive success. Mion et al. (1998) found high stream discharge can result in high larval mortality because suspended solids in rivers can cause physical harm to newly hatched fish or sweep them downstream too quickly. Studying reproductive events under varied environmental conditions aids managers in understanding variability in annual reproductive success.

The objectives of this study were 1) to estimate the abundance of Walleye spawning in the Tamarac River, 2) estimate total fry output of the Tamarac River to the Red Lakes, 3) establish a relationship between discharge, dissolved oxygen and larval Walleye density, and 4) establish a relationship between stage height, discharge, and dissolved oxygen. Successful completion of these objectives should allow managers to a better understand the relative importance of recruitment from the Tamarac River is to the Red Lakes' Walleye population.

## **METHODS**

### *Study site*

The Red Lakes is the largest body of water by surface area fully contained within Minnesota borders (116,550 ha) and is under cooperative management between the Red Lake Department of Natural Resources (RLDNR), and the MNDNR. Approximately 97,126 ha of the Red Lakes is under RLDNR jurisdiction, and approximately 19,424 ha is under the jurisdiction of the state of Minnesota. The entire portion of the lake under state jurisdiction is relatively shallow with 19,295 ha being littoral zone (99%; < 4.5 m).

The Tamarac River flows 34.9 km into the northeast corner of Upper Red Lake and drains an area of 815 km<sup>2</sup> (Groshens 2000). The watershed is approximately 35% forested, but the remaining portion is primarily wetlands which includes a portion of the largest peat bog in the lower 48 states (1,295 km<sup>2</sup>, Groshens 2000). Graham et al. (2017) reported 26,398 m<sup>2</sup> (8.4%) of the Tamarac River was comprised of gravel and cobble making it suitable for Walleye spawning. Water depths remain relatively constant throughout the river, measuring around one meter, but increases to approximately three meters closer to the river mouth (Graham et al. 2017). Majority of the riparian zone along the river is comprised of peat bog and rice paddies, but some shoreline is developed downstream along forested shorelines.

### *Stream Characteristics*

Water temperature and dissolved oxygen were recorded using a YSI meter (YSI Incorporated, model 5908) in 2014 and 2015, while data loggers (PME, miniDOT) were used in 2016 and 2017. Data loggers gathered dissolved oxygen and water temperature every 15 minutes and were deployed at two locations; upstream near the presumed

spawning site and at the larval fish collection site. Loggers were deployed shortly after ice out and remained in place until the completion of larval drift netting.

Discharge was recorded at the site of larval drift netting, and data were collected across the full range of observed water levels. Measurements occurred when there was a significant change in water level. Depth and water velocity were recorded every meter across the stream to calculate discharge per meter and was summed across the channel to calculate river discharge. Water velocity was recorded at 60% of the depth using a flow meter (HACH, model FH950). To measure water level, a USGS staff gauge location was used. Water levels were recorded using trail cameras to take pictures of the staff gauge every hour to track changes. Two cameras were used in case one stopped recording, and to validate the other water level reading. A rating curve was developed to show the relationship between stage height and discharge in the Tamarac River (Appendix A). This relationship was used to estimate discharge at varying water levels throughout the study.

#### *Adult Walleye Relative Abundance (CPUE)*

From 2014-2018 the relative abundance of Walleye migrating up the Tamarac River to spawn was estimated using fyke nets. Nets had a 2.5-cm bar-mesh and were fished overnight, every third day in the river from ice out until Walleye catches declined and the migration was presumed near completion. A total of four nets were set per netting event in 2014, six nets in 2015, 2016, 2018, and 10 nets in 2017. Nets were associated with inside and outside bends of the river in an attempt to sample different water velocities which may influence fish movement upriver. fyke nets were set faced downstream with the lead extending to shore at an angle such that fish moving upstream encountered the lead, followed it upstream and were captured.

### *Jolly-Seber Population Estimate*

In 2017, a capture-recapture study, using the Jolly-Seber open population method (Seber (1982)), was done to get daily abundance estimates of Walleye in the Tamarac River during the spawning migration. Fyke nets were the primary gear used to sample Walleye, however, one electrofishing event was also used. Netting effort increased from previous years from 6 nets to 10 nets (Figure 1), with the additional nets set in the upper reaches of the river available to Walleye for spawning activity. Nets were associated with inside and outside bends of the river similar to previous efforts. The four nets with the highest catches from 2014-2016 were set at their original downstream locations, then six more nets were set further upstream, with the last two nets set at the upper reaches available to Walleye spawning and where majority of spawning activity is presumed to take place. A total of 13 sampling events took place throughout the spawning migration. All 10 nets and one electrofishing event were used for marking fish and counting recaptures. Fish were given a batch mark, using unique fin clips and/or punches each sampling day during the study so recaptured fish could be assigned to a specific day. Fish were sexed, observed for pre-existing marks, given a mark, and recorded accordingly. Separate abundance estimates were run to calculate male and female abundance.

Assumptions of this study follow Seber (1982) in that 1) marks are easily identified and not mistaken, 2) all fish within a sample have an equal probability of capture, 3) every marked individual has the same probability of surviving from sample  $i$  to sample  $(i + 1)$ , 4) every fish caught in the  $ith$  sample has the same probability of being returned to the population, and 5) sampling time is negligible in relation to intervals between samples. One potential bias of this study is emigration from the population may



not be permanent. Temporary emigration can lead to overestimates of population size due to a decrease in recapture rate (Kendal et al. 1997). The study site is available to all fish in the Red Lakes, however, movement from the river to the lake during primary sampling times is unknown. For the purpose of this study, emigration is assumed not to take place, because fish are present in the river to spawn, and would presumably remain in the river until that individual fish has spawned.

#### *Larval fish collection*

In order to assess the out-migration of larval Walleyes in the Tamarac River, drift nets were set at a predetermined location (15U 389683 5334513 UTM, Figure 1) downstream of where majority of the spawning is presumed to take place. Water temperature data were used to calculate growing degree-days from the peak of the migration to estimate the presumed hatch dates. Degree-days were calculated by multiplying water temperatures in the range of 7-15 °C by the number of days that are in the temperature range, for example, 15 days of 7 °C = 105 degree-days (McMahon et al. 1984). The number of growing degree-days from egg deposition to larval drift was 150 (Colby et al. 1979). Netting events began prior to the predicted hatch date to ensure the beginning of the drift period was sampled.

Drift nets consisted of a 30x40 cm frame opening with a 150 cm long net (750 µm mesh) and collection jar attached to the cod end. From 2014 – 2016 drift nets were set to cover half of the stream channel. One net was set near to shore as possible where the net was still fully submerged, one net at 25% stream width, and three nets were stacked at the stream center. Additional nets were added in 2017 to provide more coverage of the stream channel to more accurately calculate fry output. One net was set at the shore

location, two nets were stacked at 25% and 75% stream width, and the stream center had four nets stacked on top of each other. Furthermore, both sides of the river were sampled in 2017 to reduce bias that might have resulted from assuming that density was symmetrical, however, only half the stream was sampled one day, and the other half was sampled the next day. Nets were set such that the top of the nets were  $\approx 2$  cm below the surface to allow floating debris to pass over minimizing the potential for back-flushing. Nets were deployed for approximately 60 minutes, and contents in the drift nets were preserved in 95% ethanol and stored for later identification and quantification in the laboratory (Appendix B).

Average water velocity, calculated from velocities taken directly in front of the net at the time of deployment and retrieval, length of time the net was deployed, and the area of the drift net were used to calculate the number of larval fish collected per  $m^3$  sampled. Interpolations, using the “interp” function in the “akima” package in Program R (R Core Team 2014), of water velocity and larval fish densities were developed for each sampling time throughout the drift period (Figure 2). Interpolations described water velocities and larval fish density throughout the entire stream channel, creating values at each cell created by interpolations in the river. Water velocity, larval fish density, and the cell size were all multiplied together to get a number of fish drifting downstream each second and multiplied again by 3,600 to get an hourly drift. This was done for each sampling time throughout the drift period. Hourly outputs, along with the mean between each set of two measured values, were added together to calculate total fry output.

In 2014, drift nets were set every day at noon and midnight, and twice every three days a 12-hour evaluation was conducted. During 12-hour evaluations, nets were set

every 4 hours (0000-1200 hours and 1200-0000 hours) alternating which 12-hour period was sampled such that a continuous 24-hour evaluation did not occur (Graham 2016). No larval drift netting occurred in 2015 due to insufficient discharge in the river. In 2016, nets were set every other day after the presumed hatch date at 1600 hours, sunset, and 2300 hours, to be able to calculate densities at varying light intensities. Sampling in 2017 was focused during overnight hours because no larval Walleye were captured during daytime sampling events in previous years. Nets were set daily every two hours starting at 2000 hours with the last sample at 0800 hours. Drift netting was concluded when larval Walleye density decreased to zero for two full 12-hour overnight cycles. No larval drift netting occurred in 2018 because of low discharge in the Tamarac River.

## **RESULTS**

### *Objective 1 – Jolly Seber Abundance Estimate*

Walleye were first captured on 10 April and efforts concluded 14 days later on 24 April 2017 with a total of 13 sampling events. The abundance for spawning Walleye in the Tamarac River peaked on 20 April 2017 at 268,877 fish (76,952-460,802 95% CI). Daily estimates ranged from 2,921 to 9,582 at the beginning and end of the migration, respectively (Figure 3). At the peak of the Walleye migration, 182,836 males and 86,041 females were estimated to be present in the Tamarac River. The adult Walleye (age 3 and older) population in the Red Lakes was estimated at 8,004,897 Walleye during September 2017 (Brown and Kennedy 2018) while 1,087,908 are mature females (Brown and Kennedy 2018). Based on population estimates of the Red Lakes, only 6.5% of the Red Lakes Walleye were present in the Tamarac River at peak migration, and 7.9% of the mature females (Brown and Kennedy 2018).

### *Adult Walleye Relative Abundance (CPUE)*

Adult Walleye catches varied in all sampling years, likely due to fluctuating discharge and dissolved oxygen levels (Figure 4). A total of 955 Walleye were caught in 2014 with a median CPUE of 21.8 Walleye/net (range= 1.0-251.5 Walleye/net, n=24). Only 284 Walleye were sampled in 2015 with a median catch of 8.1 fish/net (range= 3.6 – 10.8 Walleye/net, n=36), likely due to the reduced flow in the river (median discharge = 0.32 m<sup>3</sup>/sec). An increase in Walleye CPUE occurred in 2016 with 4,170 total Walleye caught and a median catch of 168.8 Walleye/net (range= 78.8 – 288.7 Walleye/net, n=36). A total of 9,648 adult Walleye were sampled in 2017 with a median catch rate of 79.5 Walleye/net (range =17.4-171.8 Walleye/net, n=107). Higher catches in 2016 and 2017 are likely due to the moderate discharge (median = 8.9 – 9.7 m<sup>3</sup>/sec, respectively) and high dissolved oxygen levels (median = 10.8 – 8.14 mg/L, respectively) found in the Tamarac River. Another low water year with low discharge in 2018 led to reduced Walleye catches. A total of 229 Walleye were sampled, with a median catch of 6.6 Walleye/net (range = 5.6-25.8 Walleye/net, n=18). Results from 2018 provide evidence to suggest that Walleye negatively respond to low water levels and low discharge (median = 0.21 m<sup>3</sup>/sec).

### *Objective 2 – Fry output from the Tamarac River*

Wild fry estimates are provided by the MNDNR annually (Brown and Kennedy 2018). Total egg production was calculated by multiplying the spawning stock biomass (769,979 kg of mature females) estimate generated by a gill net selectivity model (Anderson 1998) by 11,250 (the number of eggs/kg of fish). Egg production was multiplied by 0.0022 hatch rate, which was the mean observed hatch rate for the Red

Lakes during recovery efforts (Logsdon 2006). This hatch rate was derived from mark-recapture fry estimates using OTC-marked fish stocked during recovery efforts (Brown and Kennedy 2018) and the projected egg production by the spawning stock biomass. In 2017, it was estimated that 72,844,990 wild fry were produced in the Red Lakes. Results from drift net sampling in this study provide evidence to suggest only 277,462 (95% CI = 273,040-281,884) fry drifted down the Tamarac River in 2017 (Figure 5). This estimate is 0.8% percent of the wild fry estimate of Upper Red Lake, and 0.3% of the wild fry estimated in the Red Lakes.

*Objective 3 – Larval Walleye density relationship to discharge and dissolved oxygen*

Drift net sampling took place each year except for 2015 and 2018 due to insufficient discharge in the river. Larval Walleye were only captured during lowlight hours, with the first Walleye seen around sunset. Only 17 larval Walleye were caught in 2014, with a median density of 0.00 fish/m<sup>3</sup> (range = 0.00 – 0.07 fish/m<sup>3</sup> n=107), likely due to the high discharge and low dissolved oxygen in the river. A total of 1,085 larval Walleye were collected in 2016 with a median density of 0.04 fish/m<sup>3</sup> (range= 0-1.54 fish/m<sup>3</sup>, n=112). Median density in 2017 was 0.06 fish/m<sup>3</sup> (range = 0-3.66 fish/m<sup>3</sup>, n=183) with 2,272 total larval Walleye collected. Highest densities occurred when discharge levels were moderate (8.9 – 9.7 m<sup>3</sup>/sec), and when dissolved oxygen concentrations remained greater than 5 mg/L (Figure 6).

*Objective 4 – Relationship of stage height, discharge, and dissolved oxygen*

The Tamarac River experienced a wide range of water levels during the sampling years. Water levels were highest in 2014 with a median stage height of 1.98 m, and lowest in 2015 at a median stage height of 1.13 m. Two intermediate water level years

followed with median depths of 1.53 m and 1.39 m in 2016 and 2017, respectively. Water levels were very low again in 2018, with a median stage height of 1.19 m. This range in water levels created unique stream characteristics each year with discharge and dissolved oxygen levels varied (Figure 7). Abnormally high water in 2014 led to high discharge throughout the fry drift sampling period. Median discharge in 2014 was 14.80 m<sup>3</sup>/sec (range= 8.91-24.88 m<sup>3</sup>/sec, n=5). High discharge in the river may have caused low dissolved oxygen levels in the Tamarac River. Median dissolved oxygen was 2.95 mg/L (range = 2.13-3.84 mg/L, n=12). A lack of precipitation in 2015 led to very little runoff which resulted in extremely low water levels and almost stagnant water in the river. Median discharge was -0.32 m<sup>3</sup>/sec (range = 0.13-0.62, n=3), likely due to irrigation from the stream pumping to local farms or a wind driven seiche effect from the lake. Median dissolved oxygen in 2015 was 9.8 mg/L (range= 8.85-13.90 mg/L, n=5). With a more typical water level in 2016, dissolved oxygen was high, and discharge was moderate. Median dissolved oxygen concentration was 10.8 mg/L (range = 8.6-11.3 mg/L, n=1,343) with a median discharge of 8.4 m<sup>3</sup>/sec (range= 6.65-13.18 m<sup>3</sup>/sec, n=5). The Tamarac River experienced another intermediate water year in 2017. Median dissolved oxygen concentration was 8.14 mg/L (range = 7.0-8.14 mg/L, n = 1,324) and median discharge was 9.7 m<sup>3</sup>/sec (range = 8.9-11.6 m<sup>3</sup>/sec, n=8). In 2018, the Tamarac River experienced low discharge and high dissolved oxygen concentrations. Median discharge was 1.7 m<sup>3</sup>/sec (range = 1.1-2.1 m<sup>3</sup>/sec, n=5). Low discharge resulted in high dissolved oxygen levels with a median concentration of 9.5 mg/L (range = 8.4-12.7 mg/L, n= 1,152).

## DISCUSSION

This study provides an analysis of Walleye reproduction and larval abundance relative to water chemistry in peatland ecosystems, a subject that has largely been unexplored. Data in this study provides evidence to suggest low dissolved oxygen concentrations in the Tamarac River could be a cause of low Walleye embryo and/or larval survival. There is also evidence to suggest Walleye can successfully reproduce in the Tamarac River when dissolved oxygen concentrations are high. Further, this study provides a better understanding of factors that influence density of larval Walleye and may enable more effective sampling regimens in future studies that evaluate relative reproductive success of this species.

Overall, a small percentage of reproduction activity takes place in the Tamarac River with less than 10% percent of the Walleye population of the Red Lakes spawning in the river. There are many other tributaries to the Red Lakes, however, the Tamarac River historically hosts the largest spawning migration. Adult abundance estimates in 2017 are similar to historical migration numbers in the Tamarac River (MNDNR unpublished data). However, with ample suitable spawning substrate in the lake, it is presumed that majority of the spawning activity takes places in the lake. Some Walleye, however, may spawn in the river, which may serve to maintain genetic diversity in the system. Eggs may develop under different environmental conditions leading to adaptations and genetic diversity. Genetic differences have been recorded in Walleye spawning in tributaries and in the lake. Strange and Stepien (2006) found genetic differences in Walleye spawning in Lake Erie and its tributaries which may be beneficial for the population as a whole. Another explanation for the small amount of activity in the

Tamarac River is spawning site fidelity. Crowe (1962) found Walleyes return to the same spawning areas year after year. This may suggest that Walleye that spawn in the Tamarac River once will repeat and migrate to the river in subsequent years, but if fish spawn in the lake, they will stay in the lake in succeeding seasons. Walleye are not known to make long spawning migrations compared to other species of fish such as Salmonids. Due to the size of the Red Lakes, it is largely unknown if Walleye migrate from long distances to spawn in the Tamarac River. Although, it remains largely unexplored what percent of a lake's population uses tributaries for spawning. This study provides preliminary evidence to suggest a small percent of Walleye spawn in tributary streams.

Over the course of this study the density of larval Walleye at peak drift, average density of Walleye/net on the peak day, varied, likely due to variable stream conditions experienced in the Tamarac River (Appendix C). Mean larval Walleye density at the peak in 2014 was 0.03 fish/m<sup>3</sup> while the dissolved oxygen concentrations were likely lethal with a median concentration 2.95 mg/L. Results from 2014 are consistent with Oseid and Smith (1971) in that dissolved oxygen concentrations less than 3 mg/L reduce hatch rates and negatively impact size at hatch. In 2016 and 2017, dissolved oxygen concentrations were above the threshold of 5 mg/L (McMahon et al 1984) at 10.8 mg/L and 8.4 mg/L respectively, resulting in higher larval Walleye peak density (0.48 fish/m<sup>3</sup> and 0.83 fish/m<sup>3</sup>, respectively).

Positive correlations between spring river discharge and Walleye year class strength have been reported for several rivers (Nelson and Walburg 1977; Spangler et al. 1977). Stream discharge also appeared to influence Walleye reproductive success in the Tamarac River. However, there was not a strictly positive correlation between discharge



and fry drift in the Tamarac River as 2014 had the highest discharge of any sampling year (median = 14.80 m<sup>3</sup>/sec) but the lowest larval density. Results from 2014 are similar to Priegel (1970) who concluded non-adhesive eggs can be dislodged from the substrate if stream flows or wind-generated currents are too high which can lead to eggs being deposited on unsuitable substrates or physically harmed by floating detritus. However, stagnant water, which was seen in 2015 (median discharge = -0.32 m<sup>3</sup>/sec) and similarly in 2018, may also result in poor embryo development as eggs do not receive oxygen or other nutrients (Raabe and Bozek 2014). Priegel (1970) found stream flows and wind-generated currents in spawning areas must be sufficient for adequate circulation of oxygenated water around embryos, which supports the results from 2016 and 2017, with moderate discharge levels of 8.4 m<sup>3</sup>/sec and 9.7 m<sup>3</sup>/sec, respectively, and high larval Walleye density.

It is unknown if Walleye in the Tamarac River are selective to the suitable substrate available to them, which may have resulted in the low number of fry migrating out of the river. Graham et al (2017) found only 8% of the Tamarac River's substrate is suitable for Walleye spawning. Graham et al. (2017) also found approximately 106,000 females can spawn on the suitable substrate in the Tamarac River assuming there are no eggs stacked on each other; however, it is estimated less female Walleye (86,041) migrate up the river to spawn at the peak of migration. However, females spawning outside of the peak may result in over 106,000 and an overcrowding effect on the amount of suitable substrate available. Due to the small amount of suitable substrate available, it is possible there are too many eggs for the amount of substrate resulting in high mortality. Majority of the stream's substrate is silt, sand, or mud (Graham et al. 2017), which has

been known to result in low hatch rates of Walleye (Johnson 1961). Percent survival of embryos is greatly reduced on sand, and survival of eggs deposited on soft muck and detritus is negligible (Johnson 1961; Priegel 1970). Further investigations should be conducted to identify the presence and density of Walleye eggs on suitable substrate in the Tamarac River.

Diel peak in larval Walleye drift is not uniform across studies. Larval Walleye collected in the Tamarac River only occurred during lowlight hours for all sampling years. Drift patterns from the Tamarac River are consistent with Corbett and Powles (1986) where peak collection times of larval Walleye was found to be between 2100 - 0100 hours, whereas Priegel (1970) found peak collection at 1300-1400 hours. An explanation for increased drift during night hours is that Walleye fry are photosensitive until becoming demersal at lengths of 25 to 40 mm (Ney 1978). All larval Walleye collected from the Tamarac River were smaller than 25 mm providing evidence to suggest they were still sensitive to light. Fry were consistently collected at highest densities in the center of the stream approximately 0.5 m deep (Figure 2). Walleye fry actively seek the shelter of dim light during periods of strong light intensities in clear waters (Scherer 1971; Ryder 1977). Although the Tamarac River is relatively stained water, the lack of depth could inhibit the drift of Walleye during high light intensity hours. Darkness may also provide protection from diurnal predators such as Northern Pike as they are visual predators which primarily exhibit daytime activity (Carlander and Cleary 1949; Polyak 1957; Braekevelt 1975; Diana 1980) and are present in the Tamarac River.

This study also provides evidence to suggest elevated water levels in rivers with peatland-associated drainages can result in hypoxic conditions due to anoxic water stored in the bog. Glaser et al. (1981), defines the peatland near Red Lake as a perched bog, resulting in unique water chemistry and nutrient availability. Bogs and wetlands are efficient at absorbing runoff from precipitation (Faulkner and Richardson 1989). Soil in bogs have a high storage capacity but water can flow through the bog when the soil becomes saturated. Water being held in the sponge-like soil, can take on the physical properties of its surroundings, while water with short residence time in the wetland is less likely to take on properties of the peatland soil (Holden et al. 2004). The most significant result of flooding in a peatland system is the isolation of the soil from atmospheric oxygen, creating anaerobic conditions resulting in redox reactions (Holden et al. 2004). Water levels were highest in 2014 (staff gauge reading of 1.98 m) resulting in the lowest dissolved oxygen concentrations of all sampling years (2.95 mg/L). Following years had lower water levels (medians = 1.13, 1.53, 1.39, 1.19) with higher dissolved oxygen levels, giving evidence to suggest that runoff from the bog creates hypoxic conditions in the Tamarac River. These hypoxic conditions appear to have the potential to influence survival of Walleye larvae of the Tamarac River.

Management implications for this study include that the Tamarac River is not of critical importance to the year class strength of the Red Lakes in terms of sheer numbers. A small percentage (6.5%) of adult Walleye use the river for spawning, and a small percentage of total fry (0.3%) in the system are contributed from the Tamarac River. Varying stream characteristics such as discharge and dissolved oxygen may lead to fluctuating reproductive success. This study provides evidence to suggest that low

discharge results in fewer adult Walleye spawning in the river while high and low discharge may result in reduced fry production. Contrarily, this study provides evidence to suggest Walleye can successfully reproduce under ideal conditions of moderate discharges and high dissolved oxygen concentrations. The Tamarac River remains important as it may provide genetic diversity in the Walleye population of the Red Lakes and supplements the lake spawning population. Additionally, this study provides evidence to suggest elevated water levels in rivers with bog-associated drainages can result in hypoxic conditions due to water stored in anoxic bog entering rivers and tributaries.

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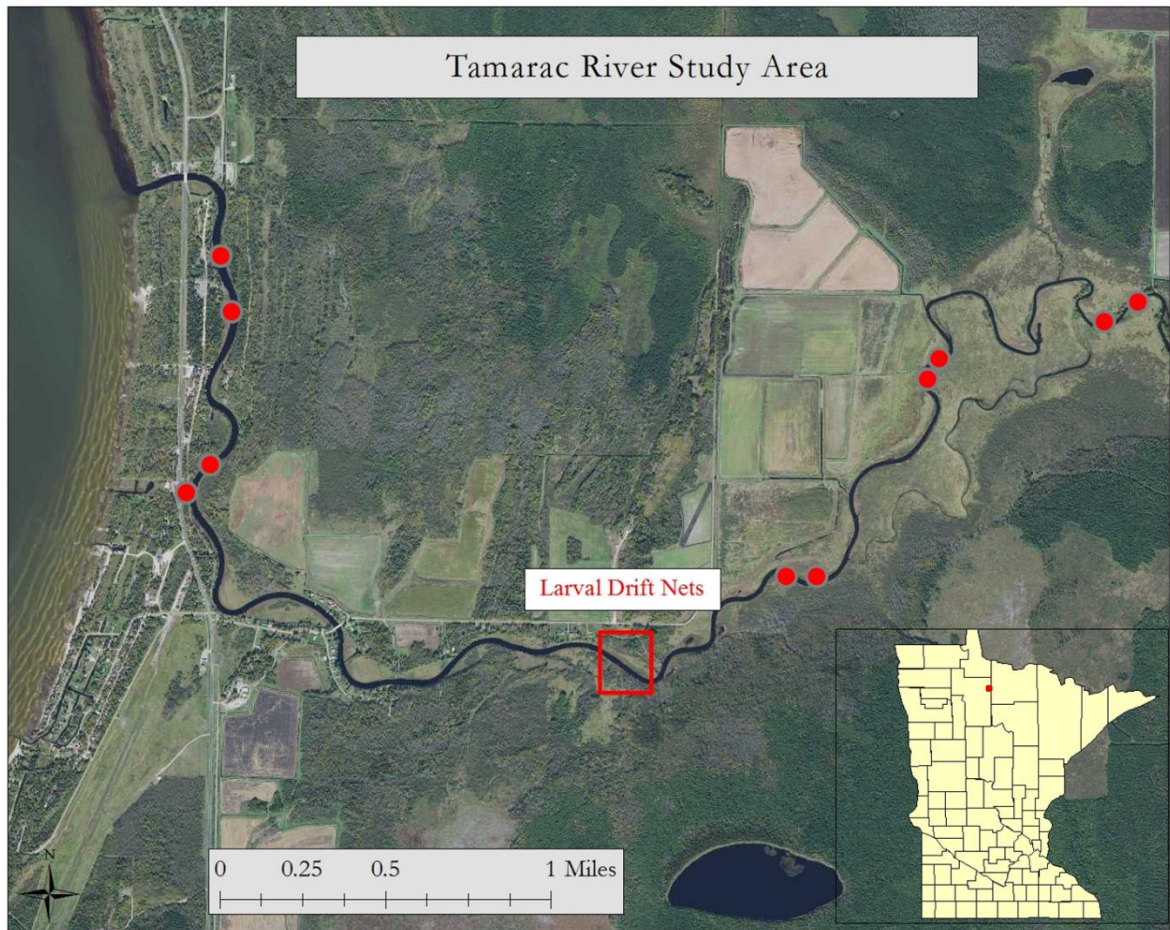
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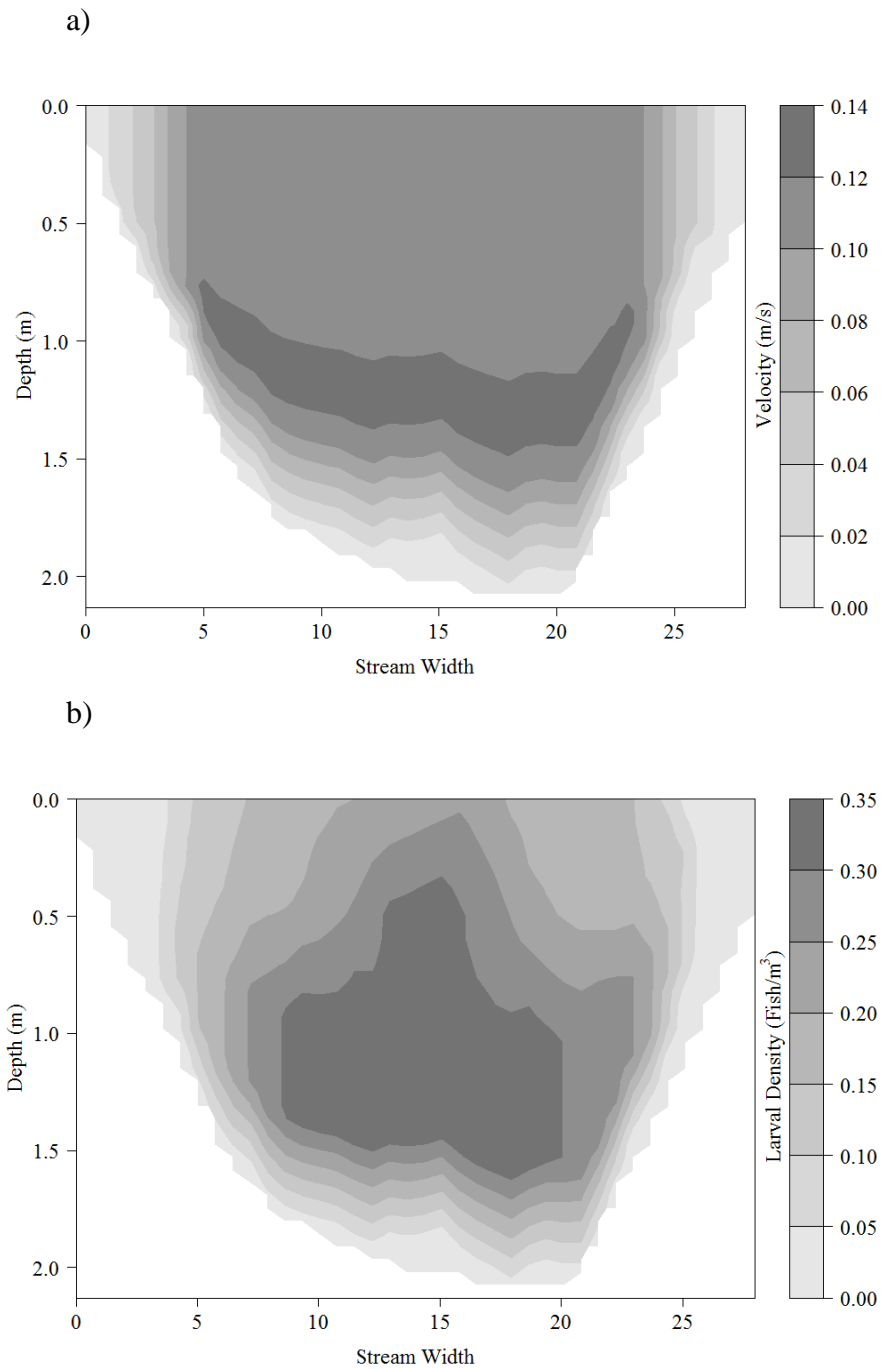
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**Table 1.** Walleye Fyke netting events during the 2017 spawning migration used for Jolly-Seber population estimates. Number of Walleye caught (N), unmarked (U), previously marked (M) and released (R), each day during the spawning migration, along with the generated estimate (E).

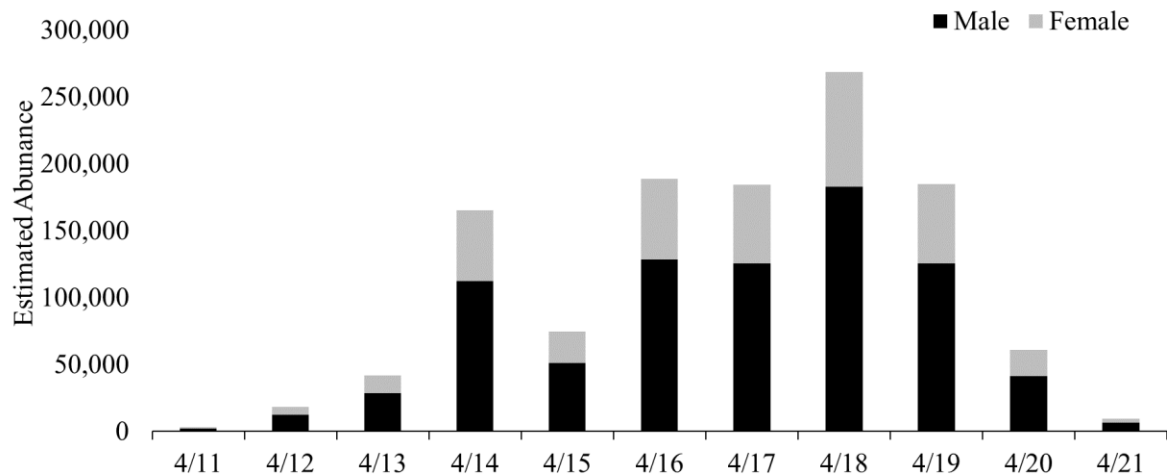
	<b>Day 1</b>	<b>Day 2</b>	<b>Day 3</b>	<b>Day 4</b>	<b>Day 5</b>	<b>Day 6</b>	<b>Day 7</b>	<b>Day 8</b>	<b>Day 9</b>	<b>Day 10</b>	<b>Day 11</b>	<b>Day 12</b>	<b>Day 13</b>
<b>N</b>	533	260	484	958	922	1,374	1,311	930	1,295	550	363	236	139
<b>U</b>	533	212	433	829	831	1,210	1,256	887	1,270	530	599	236	133
<b>M</b>	0	48	51	129	91	164	55	63	25	20	37	14	6
<b>R</b>	533	260	484	958	922	1,374	1,311	930	1,295	550	363	236	139
<b>E</b>	N/A	2,921	18,141	41,934	165,415	74,891	188,792	184,642	268,877	184,853	61,129	9,582	N/A



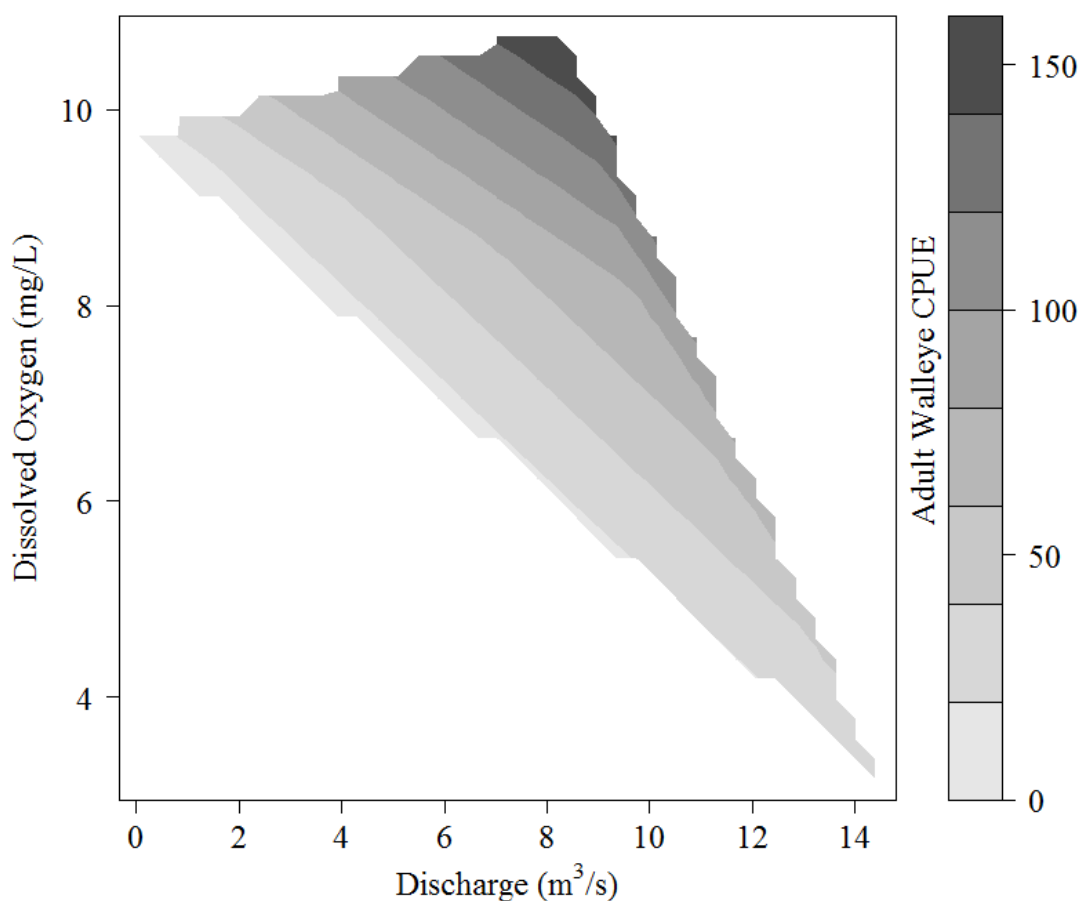
**Figure 1.** An aerial photo of the Tamarac River study area for all sampling years. This stretch of river is 11 river km. There is a beaver dam that could block passage on a given year at far end of the study site. Red dots indicate Fyke net locations in 2017, with the four nets downstream consistent throughout all sampling years, while the red box defines the location where larval drift netting occurred.



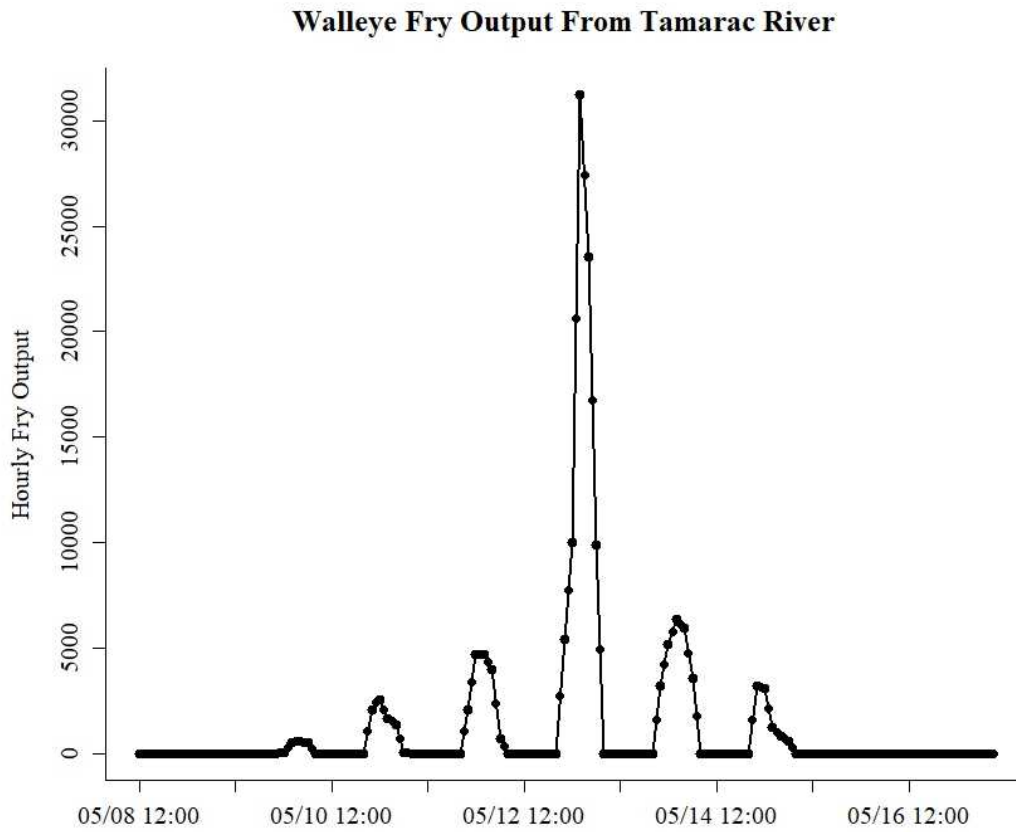
**Figure 2.** Interpolations from 13 May 2017 at 0000 hours showing water velocity (a) and larval Walleye density (b). These interpolations were used in the calculating of fry output from the Tamarac River.



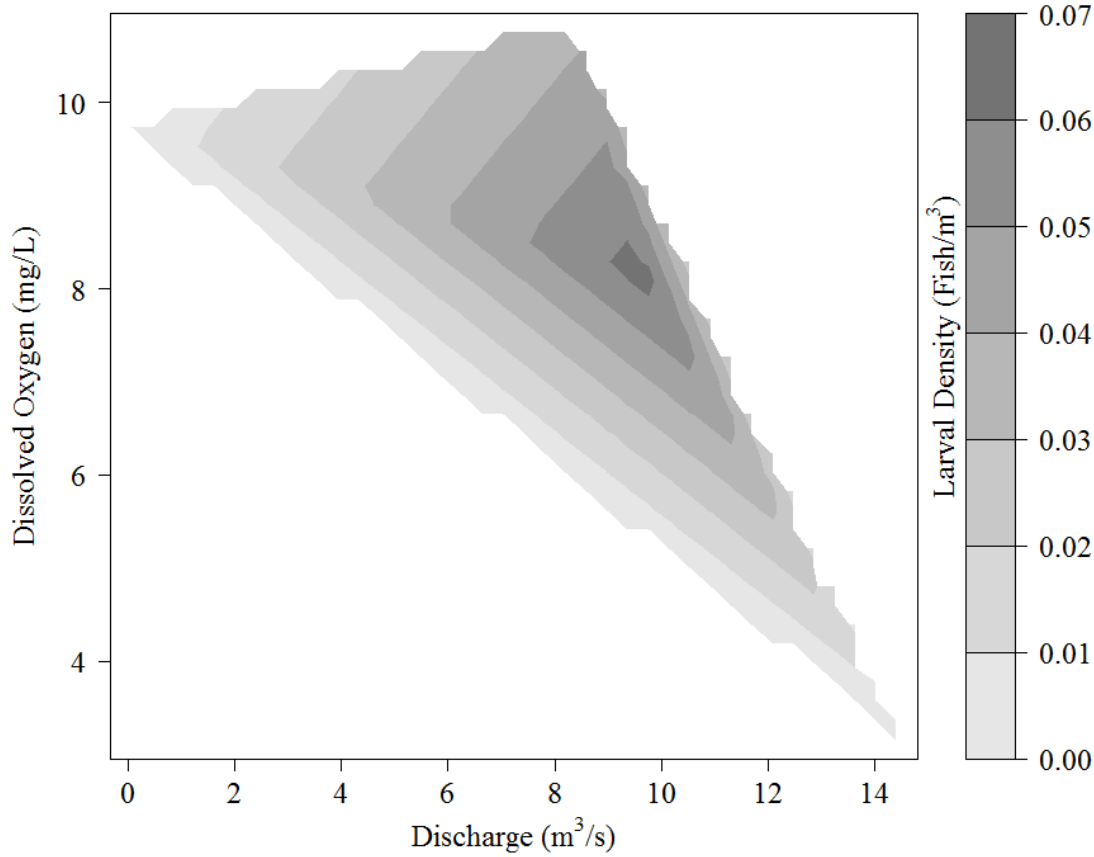
**Figure 3.** Composition of males and females during the 2017 spawning migration in the Tamarac River. Population peaked on 18 April with 268,877 (76,952-460,802 95% CI) estimated spawning Walleye. There was an estimated 182,836 males and 86,041 females in the river at peak migration. Black represents males, and gray represents females.



**Figure 4.** Pooled data from 2014-2018 showing the relationship between median discharge, median dissolved oxygen, and median adult Walleye CPUE (number of Walleye/net). High discharge with low dissolved oxygen occurred in 2014 resulted in lower Walleye catches in the Fyke nets. In 2015, low discharge led to low numbers of adult Walleye. Study years 2016 and 2017 had moderate discharge and dissolved oxygen values resulting in high CPUE of Walleye.

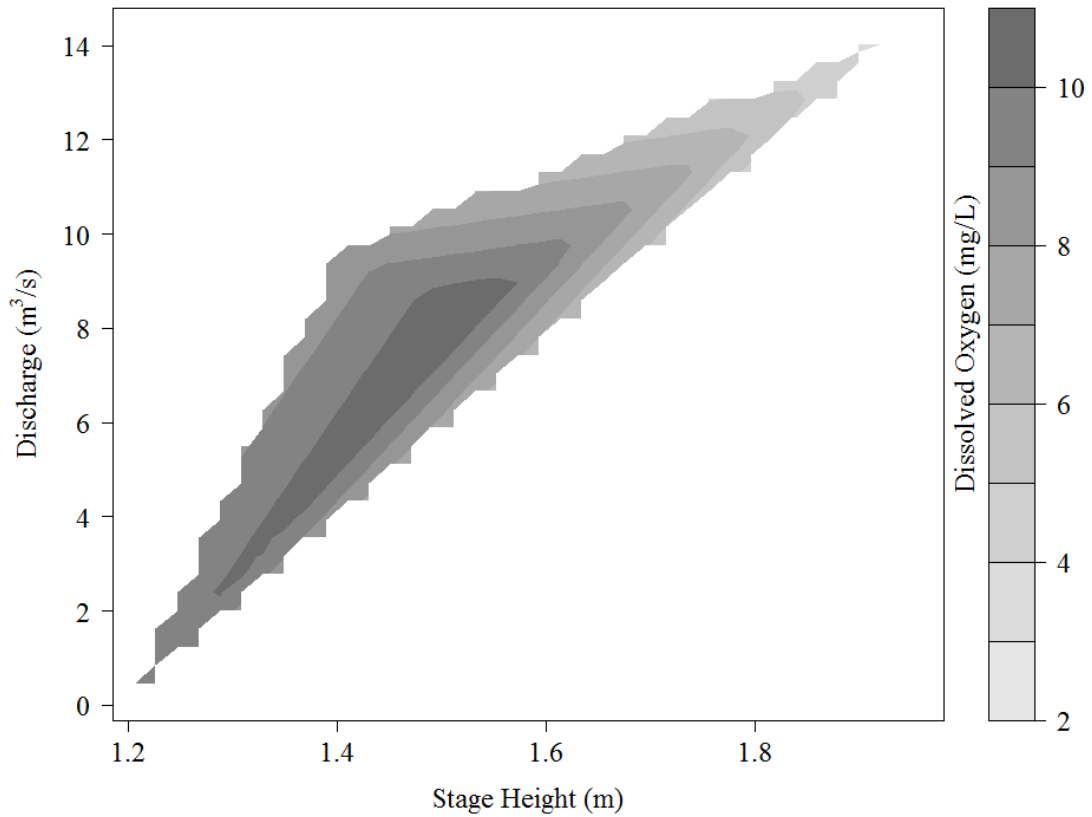


**Figure 5.** Hourly fry output from the Tamarac River in 2017. Peak drift occurred during nighttime hours and peak on 13 May 2017.



**Figure 6.** Pooled data from 2014-2018 showing the relationship between median discharge, median dissolved oxygen, and median larval Walleye density. High discharge with low dissolved oxygen occurred in 2014 resulted in lower Walleye density. Study years 2016 and 2017 had moderate discharge and dissolved oxygen values resulting in high density of larval Walleye.

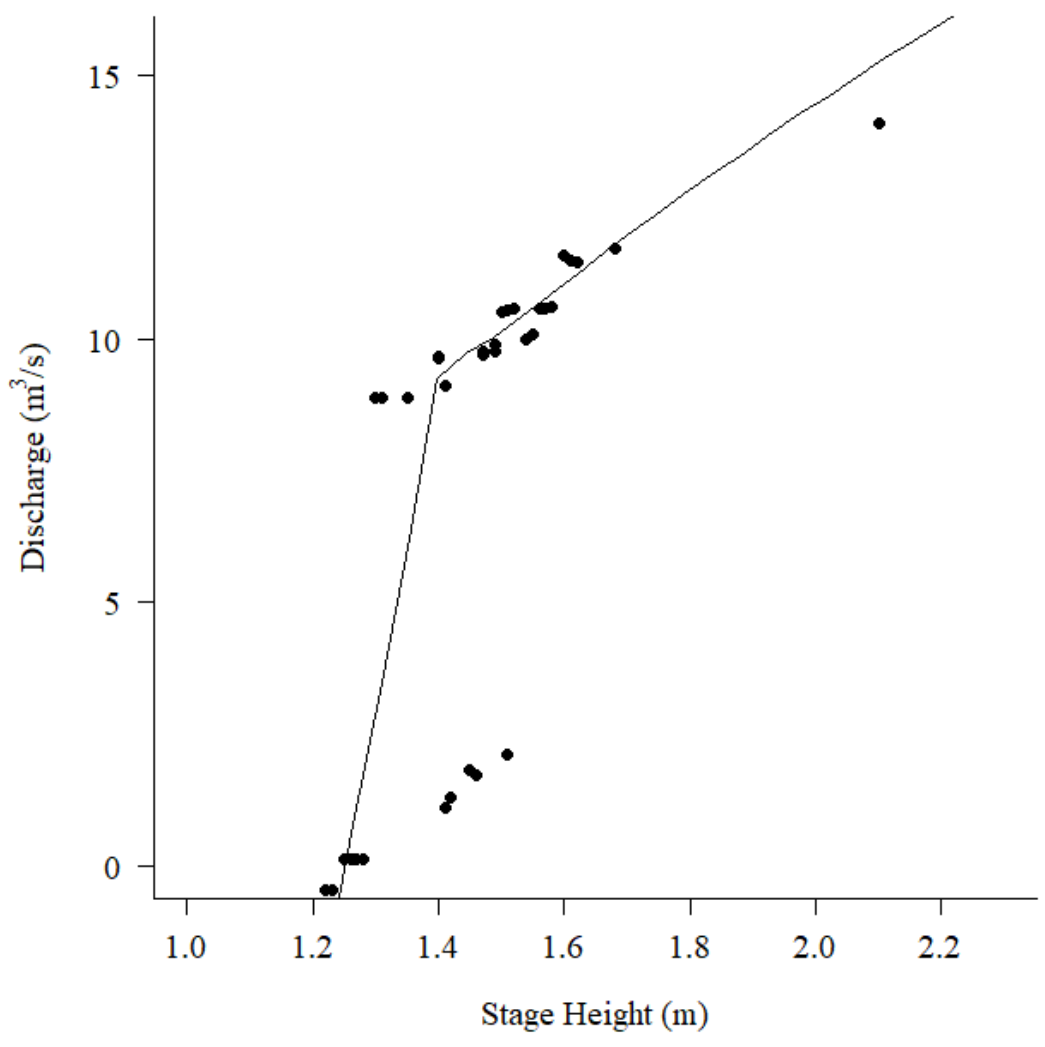




**Figure 7.** Pooled data from 2014-2018 showing the relationship between median stage height, median discharge, and median dissolved oxygen values. Low dissolved oxygen occurred in 2014 with high discharge and high stage height, while 2015 had high dissolved oxygen and low discharge at a low stage height. Study years 2016 and 2017 had moderate values between the two extremes of this study.

**APPENDIX A**

**Stage height and discharge rating curve of the Tamarac River from all from 2014 – 2017. Values with high stage height and high discharge are a result from 2014 while values with low state height and low discharge are from 2015. Values with intermediate stage height and discharge are from 2016 and 2017.**



**APPENDIX B (Pictures of larval fish)**



Larval Northern Pike sampled from the Tamarac River, Minnesota in 2017.



Larval Walleye sampled from the Tamarac River, Minnesota in 2017.



Larval White Sucker sampled from the Tamarac River, Minnesota in 2017.

## APPENDIX C

Mean peak larval Walleye density and mean peak adult Walleye CPUE from 2014 – 2018. Error bars represent standard error.

