Spring egg mat and larval net tow surveys for Walleye in Hamilton Harbour

Melanie V. Croft-White, Joshua Glasbergen, Paul A. Bzonek, Simon Fernandes, David T. Reddick, Nicole A. Turner, and Jonathan D. Midwood

Fisheries and Oceans Canada
Ontario and Prairie Region
Great Lakes Laboratory for Fisheries and Aquatic Sciences
867 Lakeshore Road
Burlington, ON L7S 1A1

2026

Canadian Manuscript Report of Fisheries and Aquatic Sciences 3310

Fisheries and Oceans Canada · Pêches et Océans Canada

Canada

Canadian Manuscript Report of Fisheries and Aquatic Sciences

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However, no restriction is placed on subject matter, and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Manuscript reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers 1426 - 1550 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Rapport manuscrit canadien des sciences halieutiques et aquatiques

Les rapports manuscrits contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes nationaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. II n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports manuscrits sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques.*

Les rapports manuscrits sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 900 de cette série ont été publiés à titre de Manuscrits (série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme Manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de Rapports manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 sont parus à titre de Rapports manuscrits du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 3310

2026

Spring egg mat and larval net tow surveys for Walleye in Hamilton Harbour

by

Melanie V. Croft-White, Joshua Glasbergen, Paul A. Bzonek, Simon Fernandes, David T. Reddick, Nicole A. Turner, and Jonathan D. Midwood

Fisheries and Oceans Canada
Ontario and Prairie Region
Great Lakes Laboratory for Fisheries and Aquatic Sciences
867 Lakeshore Road
Burlington, ON
L7S 1A1

Cat. No. Fs97-4/3310E-PDF ISBN 978-0-660-79055-8 ISSN 1488-5387

https://doi.org/10.60825/thj0-xm16

Correct citation for this publication:

Croft-White, M.V., Glasbergen. J., Bzonek, P.A., Fernandes, S., Reddick, D.T., Turner, N.A., and Midwood, J.D. 2026. Spring egg mat and larval net tow surveys for Walleye in Hamilton Harbour. Can. Manuscr. Rep. Fish. Aquat. Sci. 3310: vii + 29 p. https://doi.org/10.60825/thj0-xm16

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Croft-White, M.V., Glasbergen. J., Bzonek, P.A., Fernandes, S., Reddick, D.T., Turner, N.A., and Midwood, J.D. 2026. Spring egg mat and larval net tow surveys for Walleye in Hamilton Harbour. Can. Manuscr. Rep. Fish. Aquat. Sci. 3310: vii + 29 p. https://doi.org/10.60825/thj0-xm16

The re-establishment of a self-sustaining Walleye (*Sander vitreus*) population is a key goal for fish population recovery in Hamilton Harbour, a designated Area of Concern. Historically, Walleye spawned in the harbour, but overexploitation and habitat degradation led to their decline by the 1970s. Recent stocking efforts have resulted in strong adult year classes and observed spawning activity in nearshore areas. This study assessed Walleye egg deposition and larval recruitment across spatially distinct harbour locations. Egg mats were deployed at six locations in April, and larval net tows were conducted at 10 locations in May 2024. Eggs were detected at five of six sites, with the highest deposition at the Southeast location. Sediment accumulation within the egg mats varied spatially and was highest in exposed eastern sites, potentially impacting egg survival. Despite confirmed egg presence and sampling during hatching windows predicted from temperature models, no larval Walleye were captured in net tows. The findings highlight the importance of substrate and sediment dynamics in spawning success and suggest that although Walleye are spawning in potentially suitable habitats, a recruitment bottleneck exists between egg and larval stages. This research contributes to understanding the ecological barriers to natural Walleye recruitment in Hamilton Harbour and informs future restoration strategies.

RÉSUMÉ

Croft-White, M.V., Glasbergen. J., Bzonek, P.A., Fernandes, S., Reddick, D.T., Turner, N.A., and Midwood, J.D. 2026. Spring egg mat and larval net tow surveys for Walleye in Hamilton Harbour. Can. Manuscr. Rep. Fish. Aquat. Sci. 3310: vii + 29 p. https://doi.org/10.60825/thj0-xm16

La réintroduction d’une population autosuffisante de doré jaune (*Sander vitreus*) constitue un objectif clé du rétablissement de la population de poissons dans le port de Hamilton, un secteur jugé préoccupant. Dans le passé, le doré jaune frayait dans le port, mais la surexploitation et la dégradation de l’habitat ont mené à son déclin dans les années 1970. Les récents efforts d’ensemencement ont donné lieu à de fortes classes d’âge adultes et à des activités de fraie observées dans les zones littorales. Cette étude a permis d’évaluer la ponte et le recrutement des larves de doré jaune dans des emplacements portuaires distincts sur le plan spatial. Des tapis d’œufs ont été déployés à six endroits en avril, et des relevés de larves par traits de filet ont été effectués à 10 endroits en mai 2024. Des œufs ont été détectés à cinq des six sites, le dépôt le plus élevé ayant été observé au site du sud-est. L’accumulation de sédiments dans les tapis d’œufs variait sur le plan spatial et était la plus élevée dans les sites exposés de l’est, ce qui pourrait avoir une incidence sur la survie des œufs. Malgré la présence confirmée d’œufs et de l’échantillonnage effectué pendant les périodes d’éclosion prévues grâce à des modèles de température, aucune larve de doré jaune n’a été capturée dans les traits de filet. Les résultats mettent en évidence l’importance de la dynamique du substrat et des sédiments dans le succès de la fraie et indiquent que, bien que le doré jaune fraye dans des habitats potentiellement convenables, il existe un goulot d’étranglement du recrutement entre le stade de l’œuf et le stade larvaire. Cette recherche contribue à la compréhension des obstacles écologiques au recrutement naturel du doré jaune dans le port de Hamilton et oriente les futures stratégies de restauration.

INTRODUCTION

The re-establishment of a self-sustaining Walleye (*Sander vitreus*) population is a key objective for supporting the recovery of fish populations in the Hamilton Harbour Area of Concern (HHRAP 2003). Healthy populations of top predators, such as Walleye, can provide top-down control on fish communities (Bowlby and Hoyle 2017). While Walleye were historically known to spawn in tributaries of the harbour (Dymond et al. 1929; Goodyear et al. 1982), overexploitation and habitat degradation drastically reduced population sizes, and by the 1970s, there was no evidence of tributary spawning (Whillans 1977). Initial stocking of adults in the 1990s had limited success, but stocking of summer fingerlings, particularly in 2012, 2016, and 2018, led to the establishment of strong adult year classes (OMNR 2020). Following 2016, summer fingerlings have been stocked into the harbour in alternating years, with swim-up fry also stocked when available (OMNR 2025). Despite the successful establishment of these stocked individuals and documented evidence of spawning activity in nearshore areas within the harbour, to date, there has been no evidence of natural recruitment across the system (Midwood et al. 2026).

The general ecology of Walleye, including their spawning habitat requirements and recruitment limitations, has been well studied throughout their range (Barton 2011; Raabe et al. 2020; Krabbenhoft et al. 2023). A recent review of Walleye recruitment limitations in lentic systems identified multiple factors that are likely relevant to Hamilton Harbour, including: sedimentation, wind and currents, water clarity, predation, and starvation, among others (Krabbenhoft et al. 2023). Several studies have been conducted on the stocked Walleye in Hamilton Harbour to explore their seasonal habitat association (Larocque et al. 2024a), movement within and outside of the harbour (Brooks et al. 2019; Larocque et al. 2024b), response to upwellings of hypoxia hypolimnetic waters (Brooks et al. 2022; Brooks et al. 2025), and behaviour within a known spawning shoal (Midwood et al. 2025). These works have found that Walleye typically move out of the system in the late summer and return in the winter or early spring to spawn. Further, ripe and milting individuals have been captured in the spring along Hamilton Harbour shorelines (OMNR 2017), proximate to suitable spawning substrates (i.e., cobble, gravel; Roseman et al. 2002; Raabe and Bozek 2012). In a spatially-limited study of spawning behaviour and egg deposition (detections from 11 Walleye in 2018, 13 Walleye in 2019), acoustically tagged Walleye in Hamilton Harbour were found to display spawning behaviour (i.e., station holding, low rates of movement at night), and several of these locations were correlated with high deposition of eggs, with peak deposition in mid-April when water temperatures were approximately 7 °C (Midwood et al. 2025).

Given that Walleye exhibit spawning behaviour in Hamilton Harbour, identifying their preferred spawning habitat is advantageous. Raabe and Bozek (2012) developed models to predict the probability of Walleye egg deposition based on physical habitat conditions. These models informed a habitat survey completed in 2021, which identified multiple suitable spawning locations across the harbour (J.D. Midwood, unpublished data). Furthermore, egg deposition by stocked Walleye was confirmed at one location along the southeastern shore of Hamilton Harbour in 2019 (Midwood et al. 2025). We expect Walleye are spawning beyond this single observed location, as adult Walleye have been captured during the spawning period at multiple locations within the system (OMNR 2017). Our objectives were to assess the spatial extent of Walleye spawning, the habitat quality of spawning sites, and spawning success (i.e., evidence of larval recruitment) across the Hamilton Harbour Area of Concern. These objectives were addressed by: 1) sampling egg deposition and habitat parameters at spatially distinct harbour locations; 2) determining spawning-site quality by associating sedimentation and habitat parameters with egg deposition rates, 3) evaluating the predictive power of Raabe and Bozek (2012) models by correlating egg deposition rates with predicted probability of egg deposition, and 4) assessing spawning success by sampling surface waters for swim-up larvae. Such a multi-faceted assessment contributes to the evaluation of natural recruitment success and limitations experienced by stocked Walleye in the Hamilton Harbour Area of Concern.

METHODS

EGGS AND HABITAT

To assess Walleye egg deposition throughout Hamilton Harbour, six egg deposition study locations were selected to reflect a gradient of spawning habitat conditions observed during habitat surveys in 2021 (i.e., a variety of substrate types, fetch, shoreline type; J.D. Midwood, unpublished data). Sets of three egg mats (20 cm x 40 cm hog hair air filter, clipped to a steel plate) were deployed at each location between April 4-24, 2024 (Figure 1). Mats were deployed in the water for 5-6 nights (marked with a rope and a float) before being swapped out. On April 10, 15, 19, and 24, deployed mats were collected, and new mats were deployed. During egg mat deployment and redeployment, environmental parameters were recorded, including water depth, distance to shore, as well as basic water quality information collected using a YSI EXO2 multiprobe (i.e., water temperature (°C), pH, dissolved oxygen (mg/L), conductivity (µS/s), and turbidity (NTU)). Trends in these water quality parameters among locations and sampling events were plotted and visually interpreted. Substrate type was recorded only during initial egg mat deployment (see sediment section below for details). Retrieved egg mats were transported in plastic bags, rinsed with a standard garden hose jet style nozzle for approximately two minutes, and all materials were retained and filtered through a wire mesh colander (0.5 mm pore size). Material collected in the colander and on the egg mats was manually processed in the lab. Walleye eggs (1.5-2.0 mm diameter, and visible) were separated from the colander contents and mats using forceps and were counted. The egg deposition rate was calculated as the number of eggs per the number of nights the mat was deployed. Accumulated sediment that passed through the colander was retained from one of the three replicates per location per retrieval day for sediment analysis (see sediment section below).

As noted, habitat surveys were completed at all locations in 2021 and included measurement of substrate composition, shoreline type, slope, and fetch, among other parameters necessary to allow the application of two models to predict the probability of egg deposition (Raabe and Bozek 2012). The first model was based solely on the proportion of gravel substrate and the second included the distance to shore, water depth, and proportions of gravel, cobble, and rubble (see Table 1 in Raabe and Bozek 2012 for model coefficients). We plotted the log-transformed mean total count of eggs at each individual egg mat location against the mean predicted probability of deposition to investigate whether these models would be applicable in Hamilton Harbour. A linear model was applied to provide an indication of overall fit.

A temperature logger (Onset Hobo Pro v2) was attached to the central egg mat at each location and left in place until June 30, 2024, when they were recovered and downloaded. Water temperature data for each location were plotted, and Pearson correlation values among locations were calculated. An equation to predict Walleye egg development based on mean daily water temperature (eq. 2 in Jones et al. 2003) was applied daily, for two egg mat deployment dates (April 10 and 24, 2024). This model predicted the percent development of eggs, and when 100% development was reached, the eggs were assumed to have hatched and individuals would be available for capture by surface net tows within 1 day of hatching, given documented swim-up behaviour (Corazza and Nickum 1981 in Bozek et al. 2011). Application of this model provided a potential period when larval Walleye may be detectable in the system – a useful measure for *post-hoc* evaluation of the larval surface net tow survey detailed below.

SEDIMENT

Sedimentation of fine particles (organics, sand, silt) was assessed qualitatively and quantitatively across collection intervals and egg collection locations. Due to the loss of the total sample weight data records, the total sediment accumulation on the egg mats could not be quantified and was instead categorized by visually comparing photos of the egg mats. Categories included: low (mat partially covered in sediment, <25%), moderate (mat cover of 25-75%), and high (mat almost entirely covered in sediment, >75%; Figure 2).

Quantitative analysis of sedimentation consisted of calculating the proportion of organic materials in a sediment sample using loss on ignition and partitioning the remaining inorganic sediment sample into sand and silt through sieves. To assess sedimentation at egg deposition sites, the accumulated sediment was retained from egg mats that were retrieved on April 15, 19, and 24, 2024 (April 10, 2024 was excluded due to equipment failure). For one egg mat per location per collection interval, all material and water that passed through the colanders after the egg mats were rinsed were retained in individual 19 L sealed buckets and allowed to settle undisturbed for a minimum of two weeks. The majority of the water was decanted, and the remaining material was placed into an aluminum tray (20 cm x 26 cm x 7 cm) and frozen to -20°C. The trays were covered with Kimwipes and placed in a freeze dryer (Virtis General Purpose Freeze Dryer; pressure = <50mTorr; condenser temperature -50°C) where the temperature was held at -40°C, then slowly brought up to ambient temperature over roughly one week. Drying continued until the sample weight stabilized. Each freeze-dried sample was mixed to ensure homogeneous consistency, then a subsample (1.1 g - 37.2 g) of the material was placed in a pre-weighed aluminum tray (7 cm diameter) and placed overnight in a desiccator (Drykeeper desiccation cabinet; Drierite desiccant) to remove any residual moisture. The dry mass of the sample (g) was recorded before being placed in a muffle furnace (Barnstead Thermolyne 62700 Furnace) at 550°C for 4 hours to burn off any organic materials (Hoogsteen et al 2015). After cooling to room temperature overnight, the sample was placed in the desiccation cabinet. The mass of the remaining inorganic fraction was recorded, and the loss on ignition was calculated based on the change in mass post-burning; this value represents the proportion of organic material. A modified Wentworth scale was used to determine percent sand (0.0625-2.0 mm) and silt (< 0.0625 mm) composition in the inorganic fraction, using sieves that were agitated on a shake table for 15-45 min until separated.

We compared sediment composition among locations with a linear mixed-effects model using the lmer function from the R package lme4, where location was a fixed effect and date was the random effect (Bates et al. 2015)

LARVAE

To assess the presence of Walleye swim-up larvae throughout Hamilton Harbour, ten locations were sampled for swim-up Walleye fry during daylight hours on May 7, 9, 14, and 16, 2024 (Figure 1). Six tows were conducted nearshore and aligned with the egg mat locations, while four offshore tows were conducted to monitor open areas of the harbour (Figure 1). Nearshore tows started roughly 50 m from shore, running parallel to the shoreline. Sampling involved towing three simple plankton nets (50 cm diameter opening; 500 µm mesh; two nets paired on the port side and a single net on the starboard side), with two flow meters (Hydro-Bios Mechanical counter with back run stop – 438 115) at a speed of 2-6 km/hr. Nets were towed in the top 1.0 m of the water column, positioned 6.5 m behind the boat for approximately 10 minutes; a second pass was conducted in the opposite direction for an additional 10 minutes.

Flow meters were used to calculate the total volume of water filtered through the net, where net radius is 0.25 m and the flow meter turns at 0.3 m per revolution, Eq. (1). We calculated the net efficiency, which can vary depending on the density of zooplankton, phytoplankton, or other debris using Eq. (2). The mean volume of water, and mean net efficiency were calculated as the mean from the two flow meters for each date and location.

<u>Eq. 1</u>

$$Volume\ of\ water\ (m^3) = \ flow\ meter\ revolutions\ \times 0.3\ m\ per\ revolution\ \times\ \pi 0.25^2$$

<u>Eq. 2</u>

$$Net\ efficiency\ (\%) = \frac{flow\ meter\ revolutions\ \times 0.3\ m\ per\ revolution}{Transect\ length\ (m)}\ x\ 100$$

Following each 10-minute tow interval, the nets were taken aboard, and the contents were emptied into either a 0.5 L or 1.0 L plastic sealed container and labeled. Additionally, we used a wash bottle to rinse out the contents of the net into the sample container. At each sampling location, basic water quality information was recorded using a YSI EXO2 multiprobe, including: temperature (°C), pH, dissolved oxygen (mg/L), conductivity (µS/cm), and turbidity (NTU) (summarized by site as mean and standard deviation). Transect start and end coordinates, wind direction, and sampling time were also recorded.

Net samples were stored in a fridge (4°C) until processed (< 2 days). If sample jars contained a large quantity of unwanted material (e.g., algae, debris, or zooplankton), the contents of the jars were passed through a series of sieves with a minimum mesh size of 300 µm. Each sieve was then visually inspected for the presence of larval fish. When samples contained small amounts of unwanted material, the whole sample was poured into a glass tray and visually inspected for the presence of larval fish. Any potential specimens were placed into a separate Petri dish where they could be further inspected under a dissecting microscope to achieve an accurate identification.

RESULTS

EGGS AND HABITAT

Eggs were found at five out of six sampling locations, with the Lasalle location being the sole location with no eggs detected (Table 1). Peak deposition rate (# eggs counted/number of days the mat was deployed) was recorded on April 15, 2024 (covers deposition occurring between April 10 and 15) across all locations where eggs were collected and the deposition rate was consistently highest at the Southeast location during every collection interval (Table 1).

Some water quality parameters recorded during the deployment and retrieval of the eggs mats appeared consistent among locations, but shifted during the sample period with water temperatures increasing, pH levels remaining stable (although values for the last two events were not retained due to a probe malfunction), and dissolved oxygen declining between the third and fourth events (Table 2; Figure 3). Conductivity and turbidity appeared more stable at most locations, but the former tended to be higher and more variable at the East location and dropped markedly at the West during the April 15 sampling (Figure 3). Turbidity was similarly more variable at the East and West locations, likely due to their proximality to Indian Creek and the Burlington wastewater treatment plant outfall in the east, and Grindstone Creek and the Desjardin Canal that drains Cootes Paradise Marsh and its watersheds in the west (Figure 1).

There was considerable variation in substrate composition among egg mat locations, with some areas dominated by sand (e.g., East location), while others had substrates more typically associated with Walleye spawning habitat (e.g., gravel, cobble; Table 3).

The two models of egg deposition did not seem to perform well within Hamilton Harbour, although data points were limited (N=6). While the linear relationship between log(mean total eggs) and the mean probability of egg deposition based solely on the proportion of gravel was significant (*p*= 0.04) and also had a moderate R^2 value (0.63), this relationship appeared to be driven by the Southeast location that had both high mean probability of egg deposition and high mean total egg counts (Figure 4). All remaining locations had mean probability of egg deposition values <0.2. In contrast, the full model fit the data poorly ($R^2 = 0.004$), and all egg mat locations had a mean probability of egg deposition value > 0.55 (Figure 4).

Two of the six temperature loggers that were deployed were not recovered, presumably due to excessive sedimentation or wave energy. Temperatures at the remaining four locations were highly correlated (Pearson correlations 0.93-0.99), suggesting temperature conditions throughout the system tended to be comparable, with the largest differences between the Southeast and Lasalle locations (the latter being slightly warmer; Figure 5; Appendix A).

SEDIMENT

Visual inspection of the egg mats on retrieval indicated that sediment accumulation was highest in the Southeast and East, moderate in the North and Northeast, and low in the West and Lasalle locations (Table 4; Figure 6)

Sediment composition varied significantly among locations (organics, F=12.5, p=0.0005; sand, F=12.5, p=0.0005; silt, F=12.4, p=0.0005), with higher percent organic and silt in the West, Lasalle, and Northeast locations, and higher percent sand in the North, East, and Southeast locations (Table 4; Figure 6; Appendix B and C). Mean percent organic ranged from the highest values in the West (16.1 ± 2.2) and Lasalle (11.5 ± 5.2), to the lowest values in the Southeast (1.3 ± 0.5) and North (1.1 ± 0.2; Figure 6). The highest mean percent sand was found in the Southeast (98.1 ± 2.0), North (97.8 ± 0.9) and East (96.4 ± 2.0), and lowest in Northeast (68.4 ± 29.2), Lasalle (42.1 ± 8.9) and West (38.6 ± 4.8). The percent silt values were similar to the percent organic and opposite the percent sand, with high percent silt in the West (57.6 ± 8.3), Lasalle (56.2 ± 14.2), and Northeast (30.7 ± 27.8), and lowest in East (3.4 ± 1.9), North (2.1 ± 0.8), and Southeast (1.8 ± 1.9).

The North, East, and Southeast locations had consistently high proportions of sand deposition on the egg mats and low variability in the data. Conversely, the West, Lasalle, and Northeast locations had a mix of sand, silt, and organic matter, where the proportion was variable, changing by sampling date (Table 4).

LARVAE

A total water volume of 7810 m^3 was passed through the 240 tow net samples; however, no fish larvae of any kind were collected (Table 5). Water quality conditions appeared fairly consistent among sampling locations (ranges: temperature = 12.5 -

16.7°C; dissolved oxygen = 9.82 - 14.76 mg/L, pH = 8.5 - 9.1, conductivity = 692- 744 µS/cm, and turbidity = 0.8-2.4 NTU; mean and SD in Table **5**). Algae was commonly observed in the samples, and on a few occasions, large numbers of zooplankton were collected (Figure 7).

The temperature-based egg development model (Jones et al. 2003) predicted Walleye eggs deposited on the April 10, 2024, would be fully developed between May 1, 2024 (West location) and May 3, 2024 (Southeast location;), and with similar differences among locations, eggs deposited on April 24 would be fully developed between May 8 and 11 of May, (Figure 5). Therefore, the timing of our swim-up larvae surveys (May 7-16, 2024) was within the estimated timeframe for capturing larval Walleye, however, none were captured in Hamilton Harbour.

DISCUSSION

This study identified a number of new findings to inform an evaluation of recruitment success for stocked Walleye in Hamilton Harbour. Egg deposition was observed throughout the harbour, with deposition rates broadly correlated with a habitat-linked Walleye egg deposition model based on gravel substrate, but not the more comprehensive Raabe and Bozek (2012) habitat model. Sedimentation levels were generally high, and greatest in the exposed eastern end of the harbour. Finally, no larval Walleye were found, indicating that egg or yolk-sac fry survival is a major bottleneck for Walleye recruitment.

Walleye eggs were found at multiple locations throughout Hamilton Harbour, with a clear peak in the number of eggs deposited in the Southeast location. We demonstrated a moderate positive relationship between observed egg deposition and a model of deposition based on gravel substrates (Raabe and Bozek 2012); however, this trend was driven by egg mats from one location (Southeast) that had primarily gravel substrates and where roughly 78% of all eggs were collected. Additional sampling on other gravel areas throughout the harbour would be required to confirm this relationship. The complex model that incorporated distance to shore, water depth, and proportions of gravel, cobble, and rubble (Raabe and Bozek 2012) performed poorly. Both models were developed in a smaller isolated lake (Raabe and Bozek 2012), so their apparent limited transferability to Hamilton Harbour may reflect differences in the type of habitat Walleye are selecting in larger systems that have greater fetch, wind, and wave energy in the nearshore (see Midwood et al. 2025).

Despite the lack of success from tested models, the presence of Walleye eggs at multiple locations is a positive indicator of the potential for recruitment in the stocked Walleye population. The Southeast sampling location had the highest egg deposition rates, as well as gravel/boulder substrate, which is typical Walleye spawning habitat. In contrast, while the Lasalle location had potentially suitable boulder/cobble substrate, we found no egg deposition. The absence of eggs at Lasalle is somewhat surprising given Walleye presence in the general area during the spawning window, as evident from acoustic telemetry data and electrofishing surveys (J.D. Midwood, unpublished data).

Conditions at the specific location where egg mats were deployed may be unsuitable, with the high rate of silt accumulation observed on deployed mats potentially acting as a limiting factor. Other factors, including turbidity or mechanical energy, may further influence specific site selection. Evidence of selection for or against specific habitat conditions in Hamilton Harbour is important as it points towards potential locations and types of habitat additions or remediation actions that could be taken to increase spawning shoal habitat availability, quality, and ultimately, egg deposition rates.

Sedimentation has been identified as a limiting factor for Walleye recruitment in other systems (Krabbenhoft et al. 2023). The substantial sediment accumulation observed on egg mats in this study indicates that sedimentation is an important co-factor in Hamilton Harbour as well. Variation in sediment proportion across sampling dates was likely related to storm events resuspending and then depositing the smaller and lighter sand, silt, and organic particles. The East and Southeast locations receive significant mechanical energy, with little protection from prevailing westerly and south-westerly winds and waves, leaving deposited eggs vulnerable to damage, transport, and burial. These locations had the highest rates of sediment accumulation (predominantly sand), where some egg mats were completely buried in the substrate. The north shore of the harbour is somewhat protected from prevailing winds, with the North and Northeast locations having moderate sediment accumulation. Finally, locations that have the most protection from wind and waves (West: in lee of shoreline; Lasalle: protected by islands; and Northeast: in lee of shoreline) had higher proportions of fine organic matter (i.e., algal deposition), and silt. The total sediment accumulation was less at these protected locations, but recent work by Gatch et al. (2020) found decreased Walleye egg survival with silt sedimentation compared to sand. The accumulation of organic matter and silt may impact the diffusion of oxygen into the eggs, influencing hatching success. Wind and wave velocity play an obvious role in sedimentation, where particles can be resuspended and deposited on eggs. In addition, eggs can be moved from the spawning location to shore, or to deeper, less favourable habitat. Walleye eggs are adhesive for 15-24 hours following deposition, after which they are non-adhesive and semi-buoyant (Scott and Crossman 1998; Raabe and Bozek 2015). The wave velocity required to move non-adhesive eggs (5.0 cm/s) is less than the velocity to move sand (6.9 cm/s) (Raabe and Bozek 2015). As a result, the eggs would be most vulnerable to burial on sandy substrates in the first 24 hours when they may adhere to the substrate, becoming more vulnerable to transport in the following days, particularly in the high-energy East and Southeast locations. Eggs deposited at the more protected and lower energy locations (i.e., West, Lasalle) would be susceptible to burial from fine silt and organic sediment before the eggs harden and become semi-buoyant.

Although water clarity may not have had a direct impact on Walleye recruitment, the West location had high turbidity as well as high proportions of silt and organic matter deposited on the egg mats. The west end of Hamilton Harbour is more productive with higher nutrient inputs from Grindstone Creek and Cootes Paradise Marsh, and can be prone to algal blooms. The East location is near Indian Creek, a known source of urban runoff and sediment to the system, and an area that also receives treated water from the Burlington wastewater treatment plant outfall. Although it had the highest turbidity, there was limited deposition of organic and silt sediment at this location, likely due to high fetch.

Although the greatest influence from inflowing waters on Walleye eggs is likely from suspended sediment and resulting deposition, waters that contain treated sewage also carry a myriad of other chemicals and pharmaceuticals that can influence early life-phase development in aquatic species (Baker et al. 2022). The likelihood and magnitude of exposure to such compounds for Walleye in Hamilton Harbour is unknown, but is linked to source proximity (Kiesling et al. 2019) and has been identified as an important area of future research (Midwood et al. 2024). Collecting fertilized Walleye eggs, assessing them for deformities, and then hatching them in the lab and/or harbour to determine hatch rate and presence of deformities and abnormalities could help address whether exposure to contaminants and/or sedimentation is a limiting factor in recruitment.

The occurrence of eggs at multiple locations across Hamilton Harbour, coupled with the absence of larval Walleye, suggests there is a recruitment bottleneck between these two life phases. This is consistent with recruitment bottlenecks identified in other Walleye populations, where there are typically low survival rates between emergence and mid-summer (Raabe et al. 2020). Even in highly productive systems, such as Lake Erie and Lake Winnipeg, Walleye face considerable challenges in recruitment. Large gaps between successful recruitment years are common, with successful recruitment only occurring when a suite of ideal conditions are present simultaneously. Documented sedimentation rates at multiple locations paired with the presence of silt at areas with more limited deposition are suggestive that low egg survival rates, which are naturally low and variable even in optimal conditions (Roseman et al. 1996), contribute to reduced recruitment to the larval phase. Other factors not explored herein, including egg and larval predation (particularly from Round Goby [*Neogobius melanostomus*]), transport, and direct mortality from winds, waves, and currents (Krabbenhoft et al. 2023), also likely contribute to reduced survival but require further study. It is also possible that larval sampling methods were insufficient in extent or effort to capture low densities of larval Walleye, or that large quantities of Daphnia sp. obscured larval Walleye in the sample. These tows were conducted 50 m from the shoreline and at the surface, so the lack of larval Walleye could be a result of sampling at the wrong depth (i.e., we assumed surface presence given phototactic behaviour in larval Walleye; McElman and Balon 1979 in Sesterhenn et al. 2014), or sampling over the wrong habitat. In addition, Walleye larval drift has been found to be higher at night (Jude 1992; D’Amours et al. 2001) and larval tows in the current study occurred during the day. A pilot study using light traps was also undertaken in 2024 (deployed for one night, at Lasalle and near East and Southeast locations), but was similarly not successful in catching larval Walleye. In the future, a more in-depth light trap study could be used to target specific substrate types and different depths, although they have a limited effective sampling area and can be ineffective if Walleye densities are low. Finally, predator/prey and food-web interactions were not investigated in this study but could provide further insight into factors driving an early life recruitment bottleneck.

Walleye historically spawned in the tributaries leading into Hamilton Harbour (Goodyear et al. 1982), but evidence of historical Walleye spawning in Hamilton Harbour proper is limited (although early records show Walleye in abundance during the spawning season around the 1840s; Dymond et al. 1929; Whillans 1977; Goodyear et al. 1982). Surveys of the north shore using an echolocator found rocky shoals buried under 30-60 cm of fine sediment off Lasalle Park, with indications that these shoals may have been historically more expansive and could have provided suitable spawning habitat (Holmes and Whillans 1984; Holmes 1986). Habitat modifications could aim to match substrate conditions at the Southeast location, which may include seeding the North location (for example) with more mixed substrate (e.g., gravel/boulders). To improve survival at the Southeast location, a better understanding of the source of sediments is needed, and this may be possible through hydrodynamic modelling, which in turn could inform whether placement of break walls or other similar barriers could reduce sediment loading. Modeling passive larval transport in the system (similar to Sesterhenn et al. 2014) is also important to determine if Walleye that emerge from areas with high egg counts (e.g., Southeast location) can reach suitable nursery habitat or whether they are pushed onshore or stranded offshore. Modeling used to identify candidate locations throughout the system, coupled with targeted restoration, could be used to reestablish the critical connection between spawning and nursery habitats. Recovery of a naturally reproducing population of Walleye remains an important goal for the Hamilton Harbour Area of Concern, but at present, remains elusive given ongoing impairments to habitat quality within the system.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Canada Water Agency via the Great Lakes Action Plan. We greatly appreciate the advice of Hans Biberhofer on sediment analysis and the support of Jennifer Unsworth and Lyka Hildalgo with sediment sample processing equipment.

REFERENCES

Baker, B.B., Haimbaugh, A.S., Sperone, F.G., Johnson, D.M., and Baker, T.R. 2022. Persistent contaminants of emerging concern in a great lakes urban-dominant watershed. J. Great Lakes Res. **48**(1): 171–182. doi:10.1016/j.jglr.2021.12.001.

Barton, B.A. 2011. Biology, management, and culture of walleye and sauger. American Fisheries Society, Bethesda, MD.

Bates, D., Maechler, M., Bolker, B., and Walker, S. 2015. Fitting linear mixed-effects models using Lme4. J. Stat. Softw. **67**(1): 1–48. doi:doi:10.18637/jss.v067.i01.

Bowlby, J.N., and Hoyle, J.A. 2017. Developing restoration targets for nearshore fish populations in two Areas of Concern in Lake Ontario. Aquat. Ecosyst. Health Manag. **20**(3): 242–251. doi:10.1080/14634988.2017.1295760.

Bozek, M., Baccante, D., and Lester, N. 2011a. Walleye and sauger life history. In: Biology, Management, and Culture of Walleye and Sauger, Bethesda, Maryland: 233–301.

Brooks, J.L., Midwood, J.D., Gutowsky, L.F.G., Boston, C.M., Doka, S.E., Hoyle, J.A., and Cooke, S.J. 2019. Spatial ecology of reintroduced walleye (*Sander vitreus*) in Hamilton Harbour of Lake Ontario. J. Great Lakes Res. **45**(1): 167–175. doi:10.1016/j.jglr.2018.11.011.

Brooks, J.L., Midwood, J.D., Smith, A., Cooke, S.J., Flood, B., Boston, C.M., Semecsen, P., Doka, S.E., and Wells, M.G. 2022. Internal seiches as drivers of fish depth use in lakes. Limnol. Oceanogr. **67**(5): 1040–1051. doi:10.1002/lno.12055.

Brooks, J.L., Ledee, E.J., Larocque, S.M., Cooke, S.J., Brown, E., and Midwood, J.D. 2025. The influence of thermal and hypoxia induced habitat compression on Walleye (*Sander vitreus*) movements in a temperate lake. Movement Ecology 13(1).

D’Amours, J., Thibodeau, S., and Fortin, R. 2001. Comparison of lake sturgeon (*Acipenser fulvescens*), Stizostedion spp., Catostomus spp., Moxostoma spp., quillback (*Carpiodes cyprinus*), and mooneye (*Hiodon tergisus*) larval drift in Des Prairies River, Quebec. Can. J. Zool. **79**(8): 1472–1489. doi:10.1139/cjz-79-8-1472.

Dymond, J.R., Hart, J.L., and Pritchard, A.L. 1929. The fishes of the Canadian waters of Lake Ontario. Univ. Library.

Gatch, A.J., Koenigbauer, S.T., Roseman, E.F., and Höök, T.O. 2020. The Effect of Sediment Cover and Female Characteristics on the Hatching Success of Walleye. North Am. J. Fish. Manag. **40**(1): 293–302. John Wiley and Sons Inc. doi:10.1002/nafm.10407.

Goodyear, C.D., Edsall, T.A., Ormsby Depsey, D.M., Moss, G.D., and Polanski, P.E. 1982. A Summary by Geographic Area: Atlas of the Spawning and Nursery Areas of Great Lakes Fishes. Ann Arbor, Michigan.

Hamilton Harbour remedial action plan (HHRAP). 2003. Remedial Action Plan for Hamilton Harbour Stage 2 Update 2002. Canada Ontario Agreement. Prepared for the Ontario Ministry of the Environment and Environment Canada.

Holmes, J.A. 1986. The Impact of Dredging and Spoils Disposal on Hamilton Harbour Fisheries: Implications for Rehabilitation. Can.Tech.Rep.Fish.Aquat.Sci. **1498**: ix + 1-146.

Holmes, J.A., and Whillans, T.H. 1984. Historical review of Hamilton Harbour fisheries. Can. Tech. Rep. Fish. Aquat. Sci. **1257**: 65 p.

Jude, D.J. 1992. Evidence for Natural Reproduction by Stocked Walleyes in the Saginaw River Tributary System, Michigan. North Am. J. Fish. Manag. **12**(2): 386–395. doi:10.1577/1548-8675(1992)012<0386:efnrbs>2.3.co;2.

Kiesling, R.L., Elliott, S.M., Kammel, L.E., Choy, S.J., and Hummel, S.L. 2019. Predicting the occurrence of chemicals of emerging concern in surface water and sediment across the U.S. portion of the Great Lakes Basin. Sci. Total Environ. **651**: 838–850. doi:10.1016/j.scitotenv.2018.09.201.

Krabbenhoft, C.A., Ludsin, S.A., Marschall, E.A., Budnik, R.R., Almeida, L.Z., Cahill, C.L., Embke, H.S., Feiner, Z.S., Schmalz, P.J., Thorstensen, M.J., Weber, M.J., Wuellner, M.R., and Hansen, G.J.A. 2023. Synthesizing Professional Opinion and Published Science to Build a Conceptual Model of Walleye Recruitment. Fisheries **48**(4): 141–156. doi:10.1002/fsh.10884.

Larocque, S.M., Boston, C.M., Brooks, J.L., Jacob, W., Cooke, S.J., Doka, S.E., and Midwood, J.D. 2024a. Telemetry-derived seasonal fish-habitat associations and spatial use in the Hamilton Harbour Area of Concern in western Lake Ontario. Can. Tech. Rep. Fish. Aquat. Sci. **3593**: vii + 193 p.

Larocque, S.M., Bzonek, P.A., Brownscombe, J.W., Martin, G.K., Brooks, J.L., Boston, C.M., Doka, S.E., Cooke, S.J., and Midwood, J.D. 2024b. Application of telemetry-based fish habitat models to predict spatial habitat availability and inform ecological restoration. J. Fish Biol.: 1–18. Wiley. doi:10.1111/jfb.15899.

Midwood, J.D., Balshine, S., Beech, S., Boston, C.M., Brown, E., Budgell, E., Croft-White, M. V., Gardner Costa, J., Larocque, S.M., Mehdi, H., Rebalka, A., Reddick, D., Turner, N.A.., Theysmeyer, T., and Vanden Byllaardt, J. 2024. Assessment of the fish populations beneficial use impairment in the Hamilton Harbour Area of Concern. Can. Tech. Rep. Fish. Aquat. Sci. **3628**: xxi + 315 p.

Midwood, J.D., Brooks, J.L., Bzonek, P.A., Cooke, S.J., Croft-White, M. V., Reddick, D.T., Turner, N.A., Larocque, S., and Hasler, C.T. 2025. Fine-scale behaviour of walleye (*Sander vitreus*) on a spawning shoal in Hamilton Harbour, Ontario. J. Great Lakes Res. **52**(1); 102728. doi:10.1016/j.jglr.2025.102728.

Midwood, J.D., Croft-White, M.V., Turner, N.A., Bzonek, P.A., and Reddick, D.T. 2026. Barriers to natural recruitment of stocked Walleye (*Sander vitreus*) in the Hamilton Harbour Area of Concern. Can. Tech. Rep. Fish. Aquat. Sci. 3749: viii + 46 p.

Ontario Ministry of Natural Resources (OMNR). 2017. Lake Ontario Fisheries 2016 Annual Report of the Lake Ontario Management Unit. Ontario Ministry of Natural Resources and Forestry, Picton, Ontario.

Ontario Ministry of Natural Resources (OMNR). 2020. Lake Ontario Fisheries 2019 Annual Report of the Lake Ontario Management Unit. Ontario Ministry of Natural Resources and Forestry, Picton, Ontario.

Ontario Ministry of Natural Resources (OMNR). 2025. Lake Ontario Fish Communities and Fisheries: 2024 Annual Report of the Lake Ontario Management Unit. Ontario Ministry of Natural Resources, Picton, Ontario, Canada.

Raabe, J.K., and Bozek, M.A. 2012. Quantity, structure, and habitat selection of natural spawning reefs by walleyes in a north temperate lake: A multiscale analysis. Trans. Am. Fish. Soc. **141**(4): 1097–1108. doi:10.1080/00028487.2012.679017.

Raabe, J.K., and Bozek, M.A. 2015. Influence of wind, wave, and water level dynamics on walleye eggs in a north temperate lake. Can. J. Fish. Aquat. Sci. **72**(4): 570–581. doi:10.1139/cjfas-2014-0320.

Raabe, J.K., VanDeHey, J.A., Zentner, D.L., Cross, T.K., and Sass, G.G. 2020. Walleye inland lake habitat: considerations for successful natural recruitment and stocking in North Central North America. Lake Reserv. Manag. **36**(4): 335–359. doi:10.1080/10402381.2019.1697771.

Roseman, E.F., Taylor, W.W., Hayes, D.B., Fofrich, J., and Knight, R.L. 2002. Evidence of Walleye spawning in Maumee Bay, Lake Erie. Ohio J. Sci. **102**(3): 51–55.

Roseman, E.F., Taylor, W.W., Hayes, D.B., Haas, R.C., Knight, R.L., and Paxton, K.O. 1996. Walleye egg deposition and survival on reefs in Western Lake Erie (USA). Ann. Zool. Fennici **33**(3–4): 341–351.

Scott, W.B., and Crossman, E.J. 1998. Freshwater Fishes of Canada. *Edited By*J.C. Stevenson. Oakville, Ontario.

Sesterhenn, T.M., Roswell, C.R., Stein, S.R., Klaver, P., Verhamme, E., Pothoven, S.A., and Höök, T.O. 2014. Modeling the implications of multiple hatching sites for larval dynamics in the resurgent Saginaw Bay walleye population. J. Great Lakes Res. **40**(S1): 113–122. doi:10.1016/j.jglr.2013.09.022.

Whillans, T.H. 1977. Fish community transformation in three bays within the lower Great Lakes. University of Toronto, Department of Geography.

TABLES

Table 1. Summary of the total number of eggs collected on each mat for each recovery date (all in 2024). Egg mats were recovered mid-day, since Walleye primarily spawn at night; all eggs collected on an egg mat were deposited prior to the collection date. The deposition rate is the number of eggs per day. See Figure 1 for locations.

Location	Mat	10-Apr (6d)	15-Apr (5d)	19-Apr (4d)	24-Apr (5d)	Total (20d)
East	A	1	1	0	0	2
	B	0	1	0	0	1
	C	0	0	1	0	1
	Egg Total	1	2	1	0	4
	Rate	0.17	0.40	0.25	0.00	0.20
Lasalle	A	0	0	0	0	0
	B	0	0	0	0	0
	C	0	0	0	0	0
	Egg Total	0	0	0	0	0
	Rate	0.00	0.00	0.00	0.00	0.00
North	A	0	5	0	0	5
	B	0	10	0	0	10
	C	0	4	2	0	6
	Egg Total	0	19	2	0	21
	Rate	0.00	3.80	0.50	0.00	1.05
Northeast	A	0	3	0	1	4
	B	0	4	0	0	4
	C	0	2	1	0	3
	Egg Total	0	9	1	1	11
	Rate	0.00	1.80	0.25	0.20	0.55
Southeast	A	0	9	0	7	16
	B	0	60	3	15	78
	C	1	49	7	21	78
	Egg Total	1	118	10	43	172
	Rate	0.17	23.60	2.50	8.60	8.60
West	A	0	6	0	0	6
	B	4	2	0	0	6
	C	0	0	0	0	0
	Egg Total	4	8	0	0	12
	Rate	0.67	1.60	0.00	0.00	0.60

Table 2. Summary information at each location (Figure 1) for water quality parameters collected during each egg mat deployment or recovery event. Values are presented as mean ± standard deviation. Refer to Appendix A for raw data.

Location	Temperature (˚C)	pH	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Turbidity (NTU)
West	8.75 ± 1.73	8.48	11.7 ± 0.9	660 ± 87	4.79 ± 2.92
North	8.31 ± 1.34	8.48	11.7 ± 0.7	687 ± 11	2.07 ± 1.10
Lasalle	8.41 ± 1.37	8.46	11.8 ± 0.6	687 ± 2	2.02 ± 0.57
Northeast	8.28 ± 1.50	8.47	11.9 ± 0.7	689 ± 4	2.32 ± 0.36
East	8.96 ± 1.66	8.44	11.7 ± 0.7	834 ± 77	6.97 ± 4.20
Southeast	7.68 ± 1.27	8.52	11.4 ± 0.5	697 ± 20	1.63 ± 0.58

Table 3. Physical habitat conditions measured for each egg mat location (Figure 1). Substrate composition (%) is estimated based on a visual assessment in the field.

								Composition (%)			
Location	**Egg Mat**	**Latitude**	**Longitude**	**Depth (cm)**	**Distance to Shore (m)**	**Silt**	**Sand**	**Gravel**	**Rubble**	**Cobble**	**Boulder**
West	A	43.27114	-79.88091	63	6.1			5		95	
West	B	43.27116	-79.88097	62	5.7			5		95	
West	C	43.27116	-79.88100	74	6.3			5		95	
North	A	43.28971	-79.86464	81	7.9		100				
North	B	43.28971	-79.86462	84	7.9		100				
North	C	43.28975	-79.86457	86	8.3		100				
Lasalle	A	43.30264	-79.84193	92	4.9	30				50	20
Lasalle	B	43.30265	-79.84188	56	7.1					10	90
Lasalle	C	43.30270	-79.84191	68	7.4		10	10		40	40
Northeast	A	43.31012	-79.82227	67	2.3					5	95
Northeast	B	43.31014	-79.82219	45	1.7					75	25
Northeast	C	43.31016	-79.82213	43	2.7					85	15
East	A	43.31010	-79.80457	45	1.0		100				
East	B	43.31005	-79.80456	49	1.2		100				
East	C	43.31002	-79.80454	51	1.8		100				
Southeast	A	43.29500	-79.79568	68	1.9			20		30	50
Southeast	B	43.29498	-79.79567	86	2.7		20	60			20
Southeast	C	43.29996	-79.79565	67	1.6			90			10

Table 4. Percent organic, sand, and silt at six locations in Hamilton Harbour (Figure 1). Percent organic was calculated as loss on ignition. Percent sand and silt of the inorganic remains were calculated by fractionation using standard sieves. The sum of percent sand and silt does not equal 100 because of the presence of other larger particles not reported here. A qualitative measure of sediment accumulation was assigned categorically based on sediment coverage of the central egg mat (egg mat B) during recovery (see Figure 2). Egg mat photos were not taken on April 19, 2024.

Location	Sample Date	Organic (%)	Sand (%)	Silt (%)	Qualitative Sediment Accumulation
West	15-Apr-24	13.9	41.1	55.5	Low
West	19-Apr-24	18.3	45.5	50.6	
West	24-Apr-24	16.2	29.2	66.8	Low
North	15-Apr-24	1.2	98.1	1.8	Moderate
North	19-Apr-24	0.9	98.5	1.4	
North	24-Apr-24	1.2	96.8	3.0	Low
Lasalle	15-Apr-24	13.7	34.9	63.6	Low
Lasalle	19-Apr-24	15.2	31.7	65.1	
Lasalle	24-Apr-24	5.6	59.7	39.8	Low
Northeast	15-Apr-24	2.6	86.5	13.1	Moderate
Northeast	19-Apr-24	14.1	34.7	62.6	
Northeast	24-Apr-24	2.6	83.8	15.9	Moderate
East	15-Apr-24	2.1	98.0	1.9	High
East	19-Apr-24	6.2	94.1	5.6	
East	24-Apr-24	2.0	97.0	2.8	Missing
Southeast	15-Apr-24	0.9	98.8	1.1	High
Southeast	19-Apr-24	2.2	95.9	4.0	
Southeast	24-Apr-24	0.7	99.6	0.4	Moderate

Table 5. Summary of sampling info for larval net tow surveys presented as mean ± standard deviation. See Figure 1 for specific sampling locations.

Location	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Conductivity (µS/cm)	Turbidity (NTU)	Volume Filtered (m^3)	Net Efficiency (%)
West	14.41 ± 1.80	10.65 ± 1.15	8.61 ± 0.13	725 ± 10	1.91 ± 0.30	40 ± 6	79 ± 14
West Basin	13.75 ± 1.33	11.47 ± 0.83	8.67 ± 0.15	696 ± 2	0.96 ± 0.13	50 ± 14	86 ± 22
North	13.98 ± 1.50	11.51 ± 0.72	8.55 ± 0.07	696 ± 1	0.82 ± 0.05	42 ± 10	80 ± 23
Central Basin	13.95 ± 1.11	12.00 ± 1.06	8.74 ± 0.11	697 ± 3	1.16 ± 0.24	48 ± 13	80 ± 23
Lasalle	14.59 ± 1.27	12.48 ± 0.80	8.83 ± 0.18	697 ± 3	1.39 ± 0.26	40 ± 10	76 ± 24
Northeast	14.81 ± 1.30	12.43 ± 0.80	8.77 ± 0.19	704 ± 10	1.34 ± 0.20	40 ± 10	82 ± 36
North Basin	14.93 ± 1.27	13.03 ± 1.39	8.85 ± 0.21	698 ± 8	1.36 ± 0.15	46 ± 23	71 ± 30
East	14.90 ± 1.38	12.25 ± 0.46	8.75 ± 0.13	703 ± 8	1.83 ± 0.58	41 ± 15	75 ± 31
Southeast	14.57 ± 0.74	12.17 ± 0.17	8.73 ± 0.03	708 ± 9	1.57 ± 0.11	40 ± 19	72 ± 32
East Basin	15.21 ± 0.93	12.57 ± 0.56	8.78 ± 0.13	717 ± 21	1.53 ± 0.67	46 ± 11	86 ± 24

FIGURES

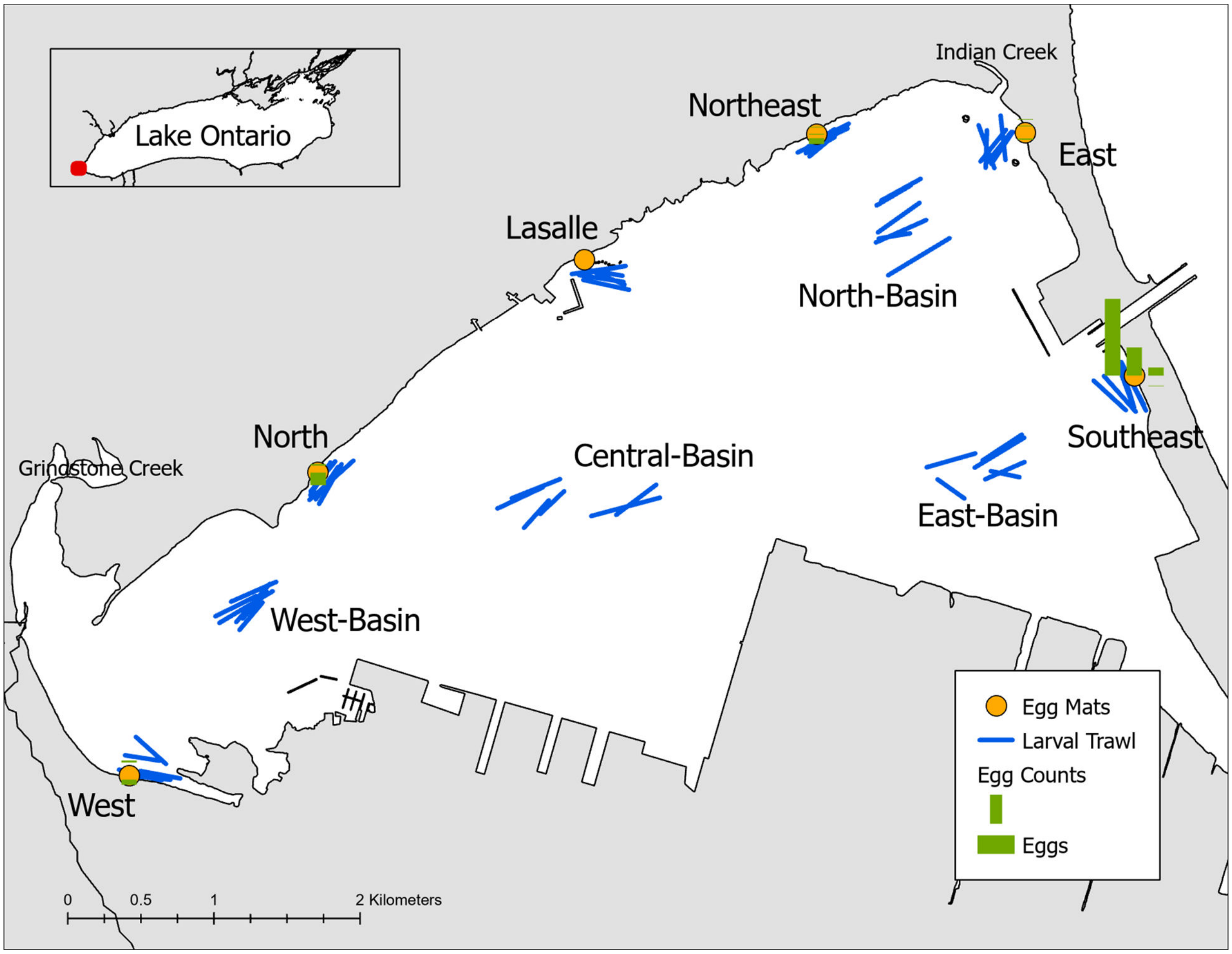

Figure 1. Location of egg mat and larval net tow surveys in Hamilton Harbour. The relative number of eggs collected during each egg mat deployment period is shown by the height of the green bars (see Table 1 for details on egg collection). Key locations of interest in the harbour are also noted.

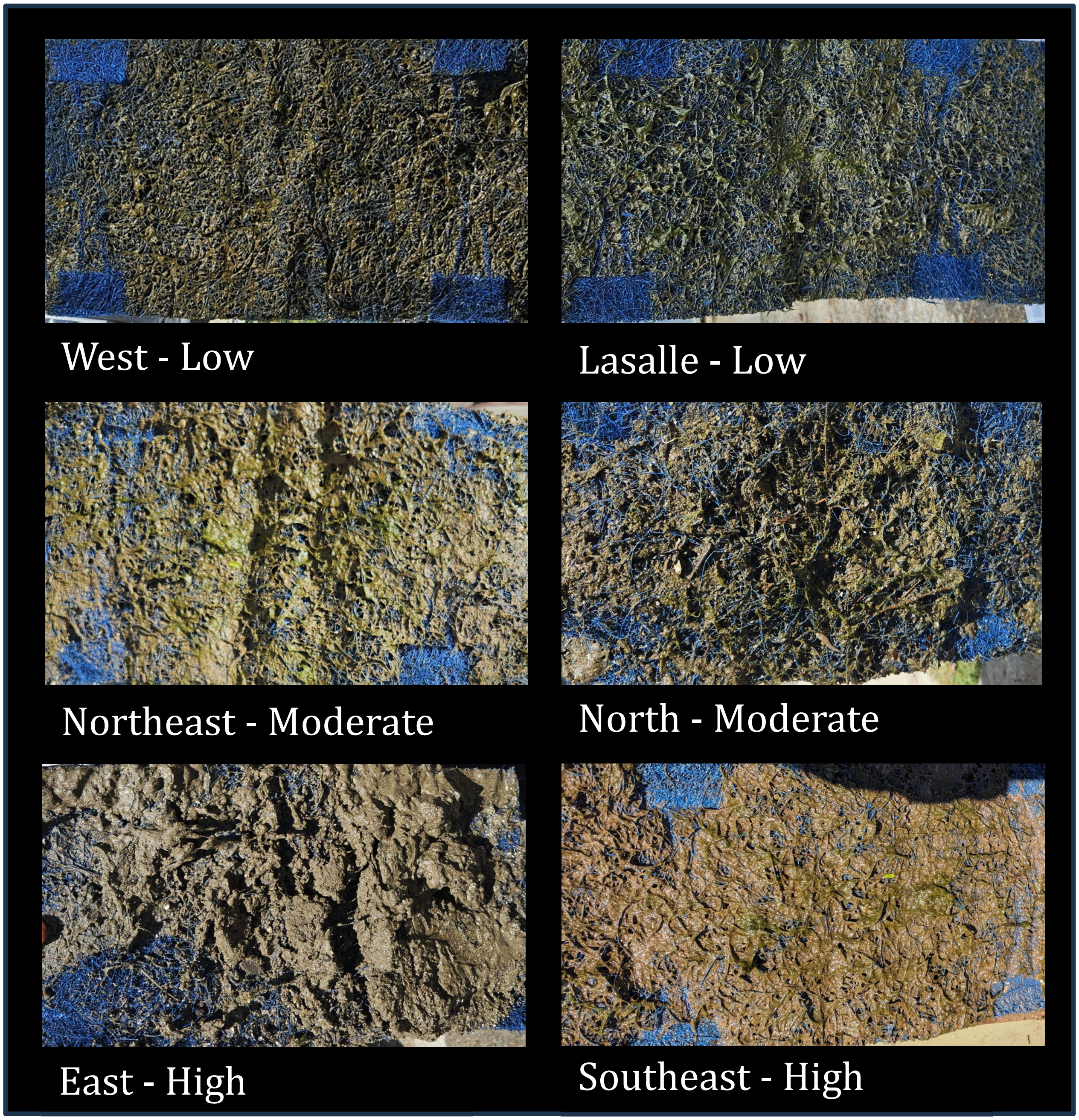

Figure 2. Egg mat examples from April 15, 2024. Photos were taken after mats were transported in plastic bags to the shore. Sediment accumulation on egg mats was visually categorized as low (<25%), moderate (25-75%) or high (>75%), based on mat coverage.

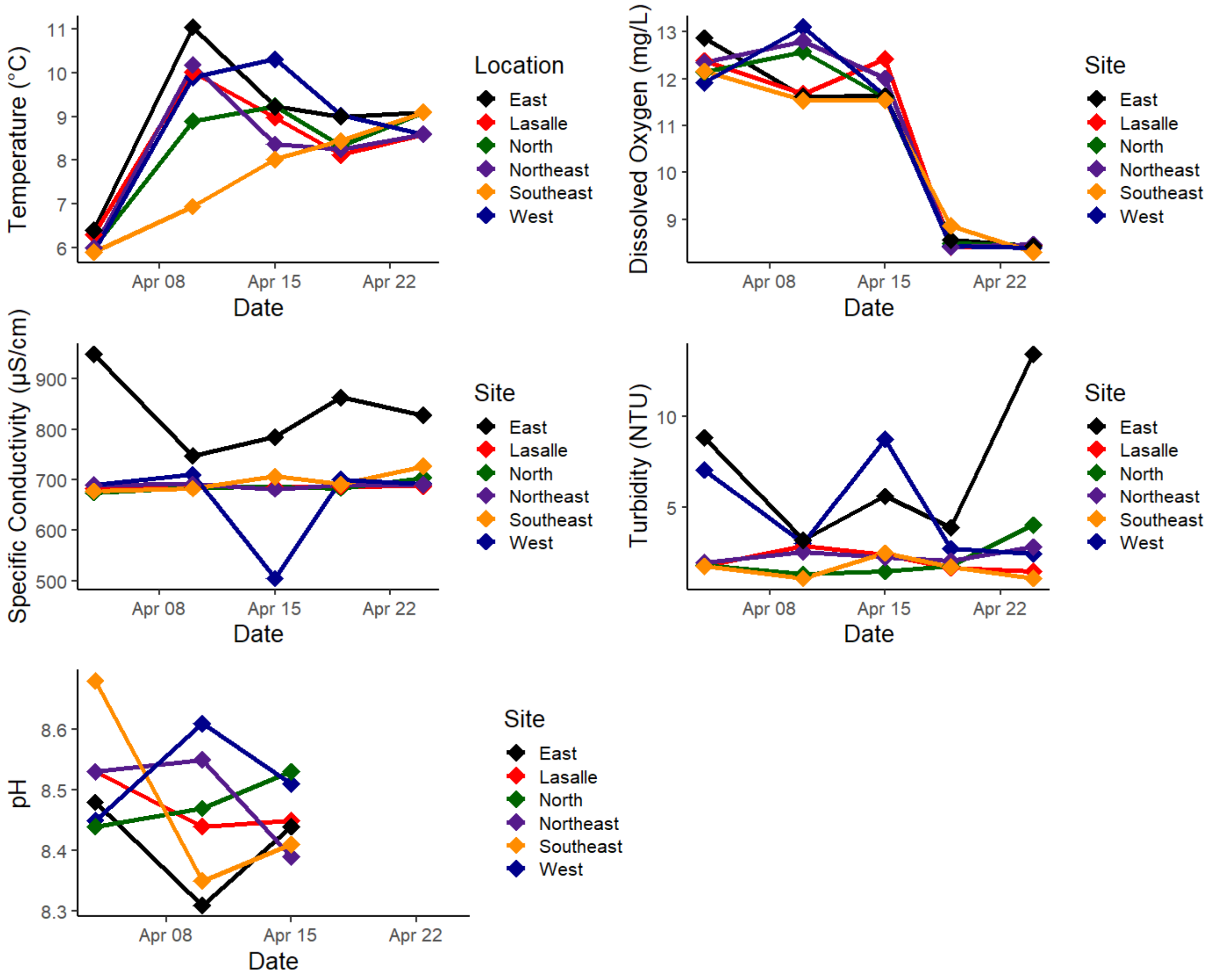

Figure 3. Temporal trends in water quality measurements collected during deployment and retrieval of Walleye egg mats. Mean values among locations are presented in Table 2.

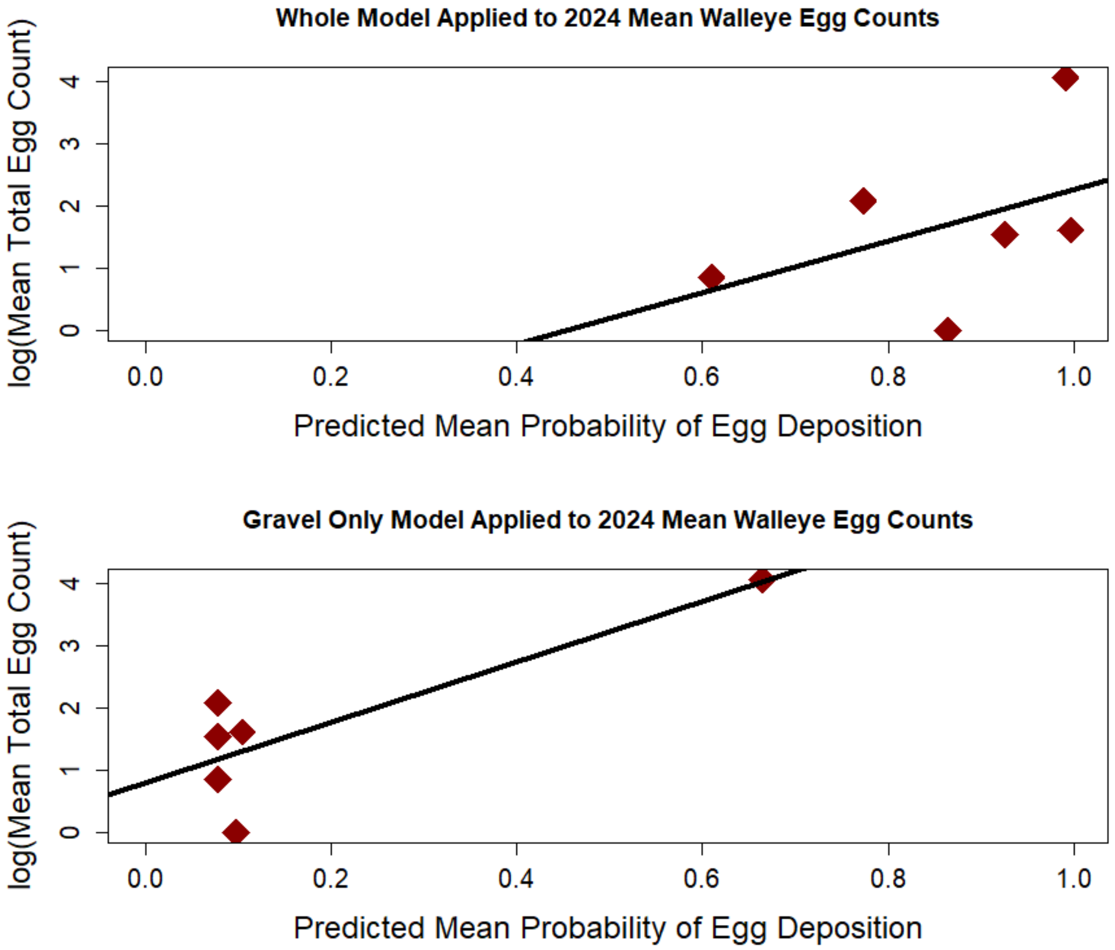

Figure 4. Relationship between predicted mean probability of egg deposition from a multiparameter (whole – top panel) model and a % gravel only model (bottom panel; Raabe and Bozek 2012) on the log-transformed mean total egg count at a given location. Input parameters were based on field surveys (Table 3). The whole model had poor overall fit (R^2 = 0.004, F_{16}= 1.02, p= 0.369) while the % gravel model had significant linear fit (R^2 = 0.63, F_{16}= 9.54, p= 0.04).

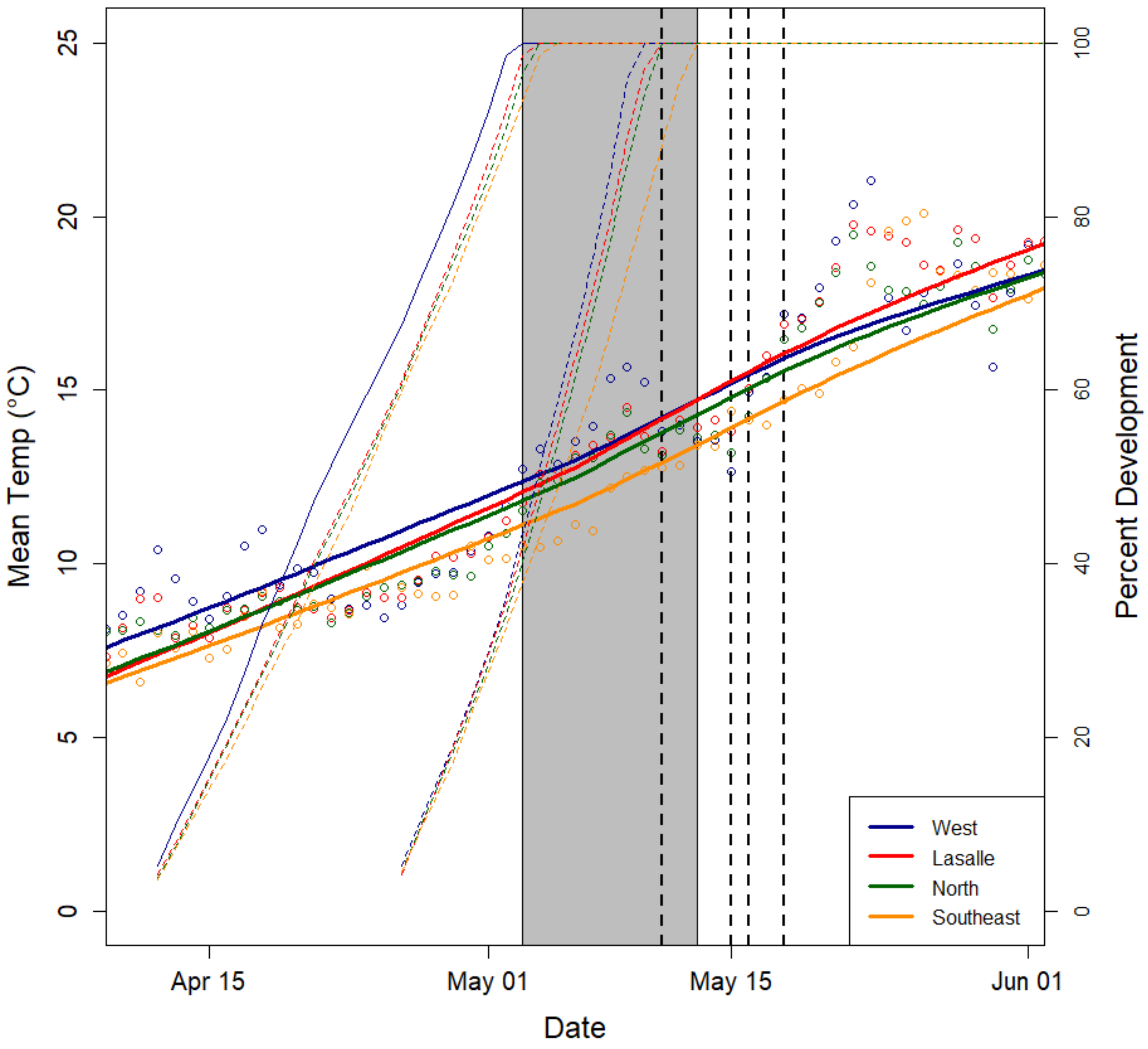

Figure 5. Solid coloured lines indicate mean daily water temperature at locations where temperature loggers were recovered. Warming patterns were similar with overall high (>0.93) Pearson correlation values among locations. Coloured dashed lines indicate the percent development of eggs at each location where daily temperature data were available. The egg development model (Jones et al. 2003) was applied daily to eggs that were released on April 10, 2024 and April 24, 2024. The grey bar indicates the emergence window (100% development) based on modelled release dates. Larval Walleye would in theory begin to show up in surveys within this window (if emerging from the earlier egg release date) and would be present in the system after this window (if emerging from the later egg release date). Vertical dashed black lines indicate dates when larval net tows were completed.

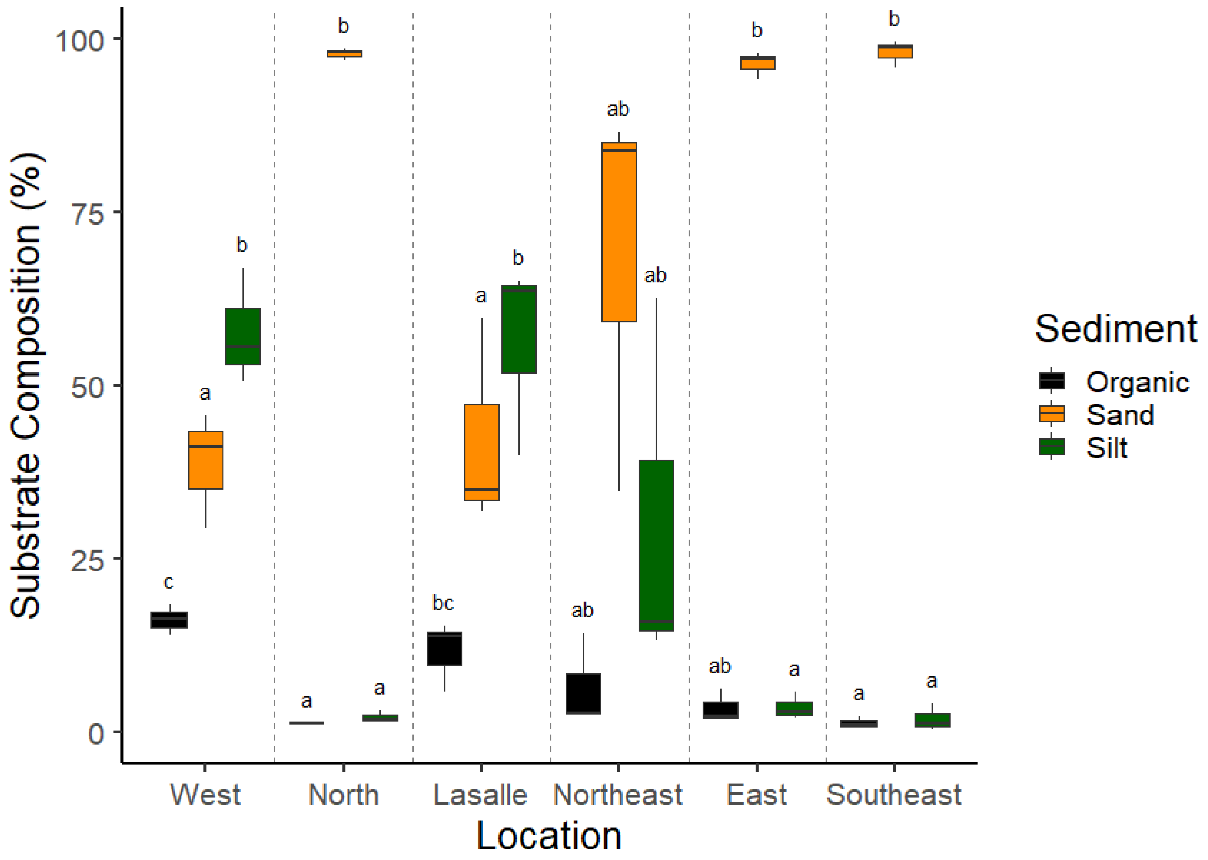

Figure 6. Mean percent organic, sand, and silt for the six study locations, using a linear mixed-effects model where location was a fixed effect and date was the random effect. See Appendix B and C for details.

Figure 7. Example of large amounts of zooplankton (later identified as Daphnia sp.) collected during larval net tows on May 7, 2024. Larval net tow information from this date is not included in the present report since they were limited to just the West location due to engine issues, but no larval Walleye were captured in this sample.

APPENDIX A

Appendix A: Water quality data collected using a YSI sonde at the six egg matt stations on 4, 10, 15, 19, and April 24, 2024.

Site	Date	Time	Temperature (°C)	pH	DO (mg/L)	Conductivity (µS/cm)	Turbidity (NTU)
West	4-Apr-24	12:43	5.90	8.45	11.9	690	7.07
North	4-Apr-24	12:00	6.00	8.44	12.2	675	1.79
Lasalle	4-Apr-24	14:14	6.30	8.53	12.4	683	1.74
Northeast	4-Apr-24	14:40	6.00	8.53	12.4	691	1.96
East	4-Apr-24	15:04	6.40	8.48	12.9	948	8.82
Southeast	4-Apr-24	15:30	5.90	8.68	12.2	678	1.75
West	10-Apr-24	10:50	9.89	8.61	13.1	711	3.01
North	10-Apr-24	11:55	8.90	8.47	12.6	685	1.30
Lasalle	10-Apr-24	12:24	10.03	8.44	11.7	689	2.85
Northeast	10-Apr-24	13:07	10.19	8.55	12.8	692	2.54
East	10-Apr-24	13:37	11.05	8.31	11.6	748	3.18
Southeast	10-Apr-24	10:05	6.94	8.35	11.5	683	1.08
West	15-Apr-24	10:50	10.32	8.51	11.6	505	8.76
North	15-Apr-24	11:05	9.24	8.53	11.6	687	1.49
Lasalle	15-Apr-24	11:20	8.98	8.45	12.4	687	2.36
Northeast	15-Apr-24	11:35	8.37	8.39	12.0	682	2.23
East	15-Apr-24	10:10	9.23	8.44	11.6	785	5.59
Southeast	15-Apr-24	9:45	8.02	8.41	11.5	707	2.48
West	19-Apr-24	10:19	9.03	11.05	8.4	701	2.71
North	19-Apr-24	10:09	8.33	11.51	8.5	684	1.78
Lasalle	19-Apr-24	9:43	8.12	11.40	8.4	687	1.68
Northeast	19-Apr-24	9:33	8.25	11.40	8.4	691	2.04
East	19-Apr-24	9:25	9.00	11.43	8.6	863	3.87
Southeast	19-Apr-24	9:14	8.44	11.03	8.9	692	1.73
West	24-Apr-24	11:00	8.59	10.86	8.4	693	2.41
North	24-Apr-24	10:41	9.10	10.79	8.5	705	4.00
Lasalle	24-Apr-24	10:26	8.60	11.16	8.5	688	1.48
Northeast	24-Apr-24	10:17	8.60	11.17	8.5	691	2.81
East	24-Apr-24	10:06	9.10	10.82	8.4	828	13.39
Southeast	24-Apr-24	9:52	9.10	10.87	8.3	727	1.09

APPENDIX B

Appendix B: Model output from a linear mixed-effects model using the lmer function from the R package lme4, exploring difference in sediment composition (organic, sand, silt) among locations, where location was a fixed effect and date was the random effect (Bates et al. 2015). EMMean = Estimated Marginal Means.

	EMMean	SE	Df	Lower CL	Upper CL
Organics					
West	16.1	2.13	7.39	11.14	21.13
North	1.1	2.13	7.39	-3.89	6.09
Lasalle	11.5	2.13	7.39	6.51	16.49
Northeast	6.4	2.13	7.39	1.44	11.43
East	3.4	2.13	7.39	-1.56	8.43
Southeast	1.3	2.13	7.39	-3.73	6.26
Sand					
West	38.6	8.04	12	21.1	56.1
North	97.8	8.04	12	80.3	115.3
Lasalle	42.1	8.04	12	24.6	59.6
Northeast	68.3	8.04	12	50.8	85.9
East	96.4	8.04	12	78.8	113.9
Southeast	98.1	8.04	12	80.6	115.6
Silt					
West	75.6	7.64	12	41.0	74.3
North	2.1	7.64	12	-14.6	18.7
Lasalle	56.2	7.64	12	39.5	72.8
Northeast	30.5	7.64	12	13.9	47.2
East	3.4	7.64	12	13.2	20.1
Southeast	1.8	7.64	12	-14.8	18.5

APPENDIX C

Appendix C: Pairwise comparison among locations from the linear mixed-effects model comparing sediment composition among locations using the lmer function from the R package lme4, where location was a fixed effect and date was the random effect (Bates et al. 2015). EMMean = Estimated Marginal Means. Significant comparisons (p<0.05) are italicized and these results are also presented in Figure 5.

	Estimate Difference	SE	Df	T ratio	p
Organics					
East – Lasalle	-8.07	2.43	10	-3.322	0.0629
East – North	2.33	2.43	10	0.961	0.9203
East – Northeast	-3.00	2.43	10	-1.236	0.8109
East – Southeast	2.17	2.43	10	0.892	0.9399
East – West	*-12.70*	*2.43*	*10*	*-5.231*	*0.0038*
Lasalle – North	*10.40*	*2.43*	*10*	*4.283*	*0.0147*
Lasalle – Northeast	5.07	2.43	10	2.087	0.3640
Lasalle – Southeast	*10.23*	*2.43*	*10*	*4.215*	*0.0163*
Lasalle – West	-4.63	2.43	10	-1.908	0.4493
North – Northeast	-5.33	2.43	10	-2.197	0.3172
North – Southeast	-0.17	2.43	10	0.069	1.0000
North – West	*-15.03*	*2.43*	*10*	*-6.191*	*0.0010*
Northeast – Southeast	5.17	2.43	10	2.128	0.3459
Northeast – West	*-9.70*	*2.43*	*10*	*-3.995*	*0.0227*
Southeast – West	*-14.87*	*2.43*	*10*	*-6.123*	*0.0011*
Sand					
East – Lasalle	*54.27*	*11.3*	*10*	*4.815*	*0.0068*
East – North	-1.43	11.3	10	-0.127	1.0000
East – Northeast	28.03	11.3	10	2.487	0.2149
East – Southeast	-1.73	11.3	10	-0.154	1.0000
East – West	*57.77*	*11.3*	*10*	*5.126*	*0.0044*
Lasalle – North	*-55.70*	*11.3*	*10*	*-4.942*	*0.0056*
Lasalle – Northeast	-26.23	11.3	10	-2.328	0.2672
Lasalle – Southeast	*-56.00*	*11.3*	*10*	*-4.969*	*0.0054*
Lasalle – West	3.50	11.3	10	0.311	0.9995
North – Northeast	29.47	11.3	10	2.615	0.1797
North – Southeast	-0.30	11.3	10	0.027	1.0000
North – West	*59.20*	*11.3*	*10*	*5.253*	*0.0036*
Northeast – Southeast	-29.77	11.3	10	-2.641	0.1737
Northeast – West	29.73	11.3	10	2.638	0.1737
Southeast – West	*59.50*	*11.3*	*10*	*5.279*	*0.0035*
Silt					
East – Lasalle	*52.73*	*10.8*	*10*	*-4.891*	*0.0061*
East – North	1.37	10.8	10	0.127	1.0000

East – Northeast	-27.10	10.8	10	2.514	0.2072
East – Southeast	1.60	10.8	10	0.148	1.0000
East – West	*54.20*	*10.8*	*10*	*5.027*	*0.0050*
Lasalle – North	*54.10*	*10.8*	*10*	*5.018*	*0.0051*
Lasalle – Northeast	25.63	10.8	10	2.378	0.2498
Lasalle – Southeast	*54.33*	*10.8*	*10*	*5.039*	*0.0049*
Lasalle – West	1.47	10.8	10	-0.136	1.0000
North – Northeast	-28.47	10.8	10	-2.640	0.1732
North – Southeast	0.23	10.8	10	0.022	1.0000
North – West	*-55.57*	*10.8*	*10*	*-5.154*	*0.0042*
Northeast – Southeast	28.70	10.8	10	2.662	0.1679
Northeast – West	-27.10	10.8	10	-2.514	0.2072
Southeast – West	*55.80*	*10.8*	*10*	*-5.176*	*0.0041*