FLOODING IN THE SHIAWASSEE FLATS AND IMPLICATIONS FOR FISH RECRUITMENT IN SAGINAW BAY

by

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ABSTRACT

River floodplains can provide migratory fish species with spawning, nursery and foraging areas; but are among the world's most threatened ecosystems due to pervasive land drainage, mainstream dredging, channel straightening and levee construction. The availability of food and habitat in estuary wetland areas varies with the frequency, timing, extent and duration of flood pulses. The relationship between floodplain dynamics and biological productivity is further complicated in temperate areas where mismatches between life history staging and flooding are frequent. The floodplains of the lower Saginaw River Watershed have been substantially altered by development with unknown impacts on migratory fishes in Saginaw River and the Saginaw Bay of Lake Huron. As anthropogenic changes continue to alter surface and Great Lakes hydrology it is important that we better understand how lower river and coastal fisheries are affected by floodplain connectivity.

I examined the dynamics and annual trends in spring flooding of the Shiawassee Flats area, a large floodplain wetland of the Saginaw River, and the corresponding abundance of juvenile migratory game and forage fish in Saginaw Bay during a twenty- year period (1996 to 2015). Annual spring and summer flood inundation was highly variable in timing, duration and extent. Across the 20 year period, catch rates for juvenile walleye and yellow perch were not significantly correlated with inundation or other hydrologic variables. Juvenile rainbow smelt catch rates were correlated with the duration of inundation while juvenile gizzard shad catch rates were correlated with flood extent and earlier seasonal flooding. When the analysis was restricted to the period following the recovery of natural walleye recruitment in the Bay (2006 to 2015), juvenile walleye, rainbow smelt, and white bass densities were correlated with longer lasting floodplain inundation, while juvenile yellow perch numbers were associated with earlier flooding. Juvenile spotttail shiner were correlated with later, longer floods.

Overall, I found that some statistical links exist between floodplain inundation in the Shiawassee Flats and juvenile populations of key migratory species in Saginaw Bay. However, the volatile ecological history of the Bay fish community, together with the limited size of my data series, suggest observed correlations between YOY catches and flooding in the Flats region are preliminary at best and further exploration is required.

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CONTENTS

INTRODUCTION

Estuarine (a.k.a. rivermouth) wetlands occur at the interface of tributary river systems and receiving waters (lakes or oceans) and are an integral part of all coastal habitats, including those of the Laurentian Great Lakes (Larson et al. 2013). As such they can have a strong influence on coastal fisheries since migratory fishes must pass through them to spawn upstream; and juveniles moving downstream, as well as coastal species, utilize them as productive nursery/foraging areas. Annual flood pulses have a strong influence on the overall productivity of river floodplain systems (Junk et al. 1989). Flooding of these estuarine wetlands temporarily expands submersed habitat availability, providing additional nutrients to often nutrient-poor coastal zones and altering local nutrient processing characteristics. The resulting wetlands often play an integral role in providing fish with seasonal habitats for refuge, feeding, spawning and nursery (King et al. 2003).

River channels flood when channel flow conveyance capacity is insufficient and resulting water surface elevations (WSE) exceed bank height. Seasonal flooding is part of the natural ecological process of riverine ecosystems, but upstream dams, channelization, creation of levees and dikes can cause significant changes in a river's flow and flooding regime over time. Human impacts on the landscape can greatly alter the frequency, depth and duration of estuarine floodplain inundation. Channelization may cause water and available nutrients to pass downstream too quickly, while levees and dikes disrupt connectivity, impeding access to floodplain habitat and nutrients. Alterations to estuary hydrologic and ecological character, in turn, may directly or indirectly influence coastal fish communities. Changes in the timing, duration or extent of a flood event can alter the availability of food and habitat of dependent fishes. There is clear evidence of strong linkages between large seasonal floods in tropical regions and improved fishery yields (see review by Junk et al. 1989). However, in temperate zones and especially in the Upper Midwest flooding is less predictable and extensive than in tropical regions. And not surprisingly the relationship between floodplain dynamics, biological productivity and the fishery recruitment is less clear in temperate areas where mismatches between life history staging and flooding are frequent (Beesley et al. 2012). Studies of the Apalachicola River, Florida found extensive use of floodplain habitat by larval stream fish during spring and summer (Walsh et al. 2009; Dutterer et al. 2013). Steffensen et al. (2014) studied floodplain inundation of the Missouri River and found an increased abundance of juvenile fish during a flood indicating the flood either cued increased spawning or provided refuge areas for juvenile fishes. However, Gorski et al. (2011) studied the Volga River in Europe and reported mixed results, finding inter-annual differences of juvenile fish biomass in some areas of the floodplain, but not others. Nevertheless, as anthropogenic changes continue to alter Great Lakes flow regimes it is important that we better understand how lower river and coastal fisheries are impacted by floodplain connectivity.

Saginaw Bay of Lake Huron, Michigan supports a large recreational fishery. Many of the fishes found in Saginaw Bay are known to migrate to Bay tributaries including the extensive floodplains of the Saginaw River. In this thesis I examined the dynamics and annual trends in spring flooding of the Shiawassee Flats area, a large floodplain wetland of the Saginaw River, and the corresponding abundance of juvenile migratory game and forage fish in Saginaw Bay (from 1996 to 2015). I hypothesized that migratory species including: walleye (*Sander vitreus*); yellow perch (*Perca flavescens*), both of major ecological and economic importance in the Saginaw Bay; as well as freshwater drum (*Aplodinotus grunniens*), ecologically important and known floodplain spawners; gizzard shad (*Dorosoma cepedianum*) an important prey species able to utilize floodplain habitat for spawning; and rainbow smelt (*Osmerus mordax*) and others may benefit from larger and longer floodplain inundation. It is also possible that juvenile fish recruitment of migratory species benefits from predictable spring floodplain inundation. My objective was therefore to explore and better understand the impacts floodplain inundation extent, timing and duration have on the dynamics of these species. This included (a) documenting annual variations in floodplain inundation extent and magnitude, and (b) a preliminary analysis of the impacts of this annual variability on selected species in the downstream Saginaw Bay system. My goal has been to help inform our management of both river floodplains and Great Lakes coastal fisheries.

METHODS

Research Area

The Saginaw Bay (Figure 1) is a bay of Lake Huron located on the eastern coast of Michigan. The Bay is a highly productive aquatic ecosystem and supports extensive walleye and yellow perch populations, which constitute the most important fisheries in the Bay (Fielder and Thomas 2006; Ivan et al. 2011). The Saginaw River watershed (Figure 1), the largest in Michigan, contributes 73% of the drainage of the Saginaw Bay watershed (Buchanen et al. 2013). The Shiawassee (3,004 km^2 catchment), Bad (sub-catchment of Shiawassee), Flint (3,444 km^2 catchment), Cass (2,352 km^2 catchment), and Tittabawassee (6,400 km^2 catchment) rivers come together to form the Saginaw River in a large, frequently flooded, interfluvial area known locally as the Shiawassee Flats, (Newman 2011; circled in Figure 1). The Flats area contains a complex set of active floodplains, distributary and paleo channels, ponds and emergent wetlands. The U.S. Fish and Wildlife Service (FWS) Shiawassee National Wildlife Refuge manages approximately 38.9 km^2 (9,620 acres) of the Shiawassee Flats and the Michigan Department of Natural Resources (DNR) at the Shiawassee River State Game Area (SRSGA) manages another 39.5 km^2 (9,758 acres).

There are no large hydrologic barriers, such as dams, between Shiawassee Flats and Saginaw Bay making it possible for migratory fish to utilize the tributaries and adjacent floodplain areas (Newman

2011). River-spawning fish of Lake Huron have been observed in the Shiawassee Flats area (Buchanen et al. 2013; Wiley unpublished data), but little is known about their spawning success and how floodplain connectivity affects recruitment into Saginaw Bay populations. Extensive levees, river diversion channels, ditches and water-control structures were built throughout the Shiawassee Flats area in the early 1900s (Heitmeyer et al. 2013) altering the natural flow regimes. The efficient draining of private and public lands and widespread river channelization, particularly in the Bad, Flint and Cass catchments, exacerbate the natural flashiness of these rivers and leads both to very low summer base flows and very high seasonal flood flows (Buchanen et al. 2013; Scott 2014; Stack 2015). The upper Saginaw River and Flats areas periodically experience stalled river flow and flow reversals during periods of high lake water levels and/or low flow yields from upstream watersheds. This flow irregularity could potentially affect both drift and larval fish residence time in the upper Saginaw River (Jude 1992). A model for residence time in the channel approximates residence times from as little as 8.5 hours to as much as 7.5 days (Stack 2015).

Data Collection

Spatial Flooding Data

I reconstructed the history of flooding in the Shiawassee Flats region for the 1996-2015 period by examining U.S. Geologic Survey Landsat images. Surface reflectance corrected images, at thirty-meter spatial resolution, from Landsat 5 TM (1982-2011), Landsat 7 Enhanced ETM+ (2003 to 2015), and Landsat 8 Operational Land Imager OLI (2013 to 2015) were obtained from USGS Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA) On Demand Interface (Appendix 1). I created binary maps of inundation extent using the Iso-Data unsupervised classification in ArcMap 10.5.1 (Appendix 2). The unsupervised classification uses an Iso cluster algorithm, which is an iterative process for computing the minimum Euclidean distance when assigning each candidate cell to a cluster. The classification was used distinguish flooded areas in each image from dry areas. The image revealing the largest flood extent per year was selected and the Iso-Data unsupervised classification was performed in ArcMap using a single infrared spectral band of one Landsat image per year. I combined all classes containing flooded pixels to get one “flooded” class resulting in binary maps of the flood extent. Total acres of flooded area, including original bodies of water (river and bayou) were calculated for each image to estimate the possible habitat availability.

I approximated the seasonal timing of inundation and how many days flooding lasted (duration) by examining all available spring and summer Landsat images throughout the 20-year period. Timing was estimated by identifying the earliest date of floodplain inundation per year. Duration estimates were made by approximating how long the floodplain appeared inundated as number of days there appeared to be bank overflow. I examined correlations between these three variables (Extent, Timing and Duration) and annual juvenile catch data from Michigan Department of Natural Resources (MDNR) surveys in Saginaw Bay (see below; Appendix 3). I also explored relationships of the catch data with two synthetic flood description metrics I computed: Flood scale, designated below as simply as Flood, (Flood = Extent * Duration reflecting the overall spatial impact of the flood event); and an index of early seasonal flooding intensity designated below as Flood2, where Flood2 = Extent/Timing (inverse weighting floods occurring later in the year.

Validation of remote classifications

I used aerial photos from a large flood that occurred in 2013 and images of flooded and dry areas during the 2016 spring flood (obtained from camera trap images) as ground truthing points for the inundation classification described above. I analyzed aerial photos and Global Positioning System (GPS) locations of camera traps to determine the most accurate band combination for the Iso-Data unsupervised classification. Imagery from thirty-six camera traps provided a mix of wet and dry points throughout the floodplain in April 2016 to compare with Landsat imagery of that same time. I combined these points with 10 known flooded areas from ground truthing to perform a supervised classification in ERDAS (Earth Resource Data Analysis System) using a Landsat image from April 2016. The points were divided into training data and test data for the supervised classification. Examination of 2013 flood imagery and the supervised classification in ERDAS confirmed that a single infrared spectral band (band 4 for Landsat 5 and 7, and band 5 for Landsat 8) most accurately delineated water bodies. Due to numerous mixed pixels and the lack of additional ground truthing points, unsupervised classification proved to be the most accurate way to classify inundation pixels.

Hydrologic and ancillary variables

The amount of water discharged into the flats region was determined by aggregating flows at the lowest upstream gauges of the major tributaries to the Flats using U.S. Geological Survey streamflow-gaging stations. The variable ‘InputQ’ was the summed daily discharge for the following gauged tributary systems: the Flint River gage (near Flint, #04148500), Cass River gage (at Frankenmuth, #04151500), Shiawassee River gage (at Owosso, #04144500), and the Tittabawassee River (at Midland, #04156000), and was used as an index of the total flow of water through the Shiawassee Flats (Figure 1). I calculated the annual flows from March to August to account for water entering the Shiawassee flats during the period during spawning and juvenile fish data collection (conducted in early September each year). Water level elevation at the mouth of the Saginaw River (NOAA CO-OPS; Essexville, Michigan) was also explored as a potentially relevant hydrologic variable since it is related to flow velocities and residence times in the Saginaw River between the Flats and the Bay (Stack 2015). The gage, operated by the

National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services, records daily water levels and produces monthly averages.

Water surface temperature plays a key role in fish spawning and an attempt was made to obtain water temperate of the bay. There was no consistent data set for the period examined, but modeled water surface temperature estimates (Celsius) from GLERL's Large Lake Thermodynamics Model was used as a proxy (Hunter 2016). The spring average modeled temperatures (March, April and May) were examined as well as the average temperature from March through May.

Fish data collection

The MDNR collects index samples of juvenile fish in Saginaw Bay annually as part of a long-term trawl-based monitoring program (Fielder and Thomas, 2014). Twenty years of data were obtained courtesy of the MDNR's Lake St. Clair Fisheries Research Station (33135 South River Road Harrison Twp, MI). Annual Trawling takes place in early September of each year. Trawling locations varied slightly by year but are designed to represent the entire Saginaw Bay. Up to 40 trawls are planned and executed as weather permits, and each trawl typically lasts for ten minutes. Fish caught in trawls are identified, counted and aged. I utilized catch data of age-0 fish from 1996 to 2015 and standardized the data into Catch per Unit Effort (CPUE) as catch per hour (Table 3). I examined catch rates of species known to migrate into or through the Shiawassee Flats based upon recent sampling in the floodplain area (Buchanen et al. 2013, Wiley unpublished data). These included: (1) walleye and (2) yellow perch, both of ecological and economic importance in the Saginaw Bay; (3)freshwater drum (*Aplodinotus grunniens*), ecologically important and known floodplain spawners; (4) gizzard shad (*Dorosoma cepedianum*) an important prey species able to utilize floodplain habitat for spawning; (5) rainbow smelt (*Osmerus mordax*), (6) trout-perch (*Percopsis omiscomaycus*), (7) white perch (*Morone americana*), (8) white bass (*Morone chrysops*), (9) emerald shiner (*Notropis atherinoides*) and (10) spottail shiner (*Notropis hudsonius*).

Analysis

A twenty-year time series data set was developed for both flood parameters and species of interest from the MDNR index trawl data. I initially analyzed the complete twenty-year series for both inundation parameters and Young of Year (YOY) fishes. Because of the recent recovery of walleye stocks in the bay (Fielder & Thomas, 2014), I also partitioned the dataset into pre- and post- recovery blocks and analyzed the fisheries data again in post-recovery years (Figure 2). Because walleye are the principal predator (and a targeted game species) in this system, I reasoned that the fish community as a whole may be significantly structured by the relative year class strength of walleye and so other species of interest may be significantly affected by their population status (e.g., Iva net al. 2011).

Satellite image analyses were performed using ArcGIS (ESRI, Inc.), and ERDAS Imagine software (Erdas, Inc. 2013). Hydrographic data was compiled in HEC-DssVUE (USACE 2009). All Statistical analyses were performed using RStudio statistical software (RStudio Team 2015). I created matrices using Pearson's correlation to assess the strength between variables, ranging from -1 to 1 (Appendix 4). Simple regression analysis was used to assess high associations between inundation variables and YOY catch rates, and multiple regression analysis was used when two hydrologic variables were significantly correlated with a YOY catch variable. Two-tailed critical values for Pearson Correlation coefficients are used throughout.

RESULTS

Annual Variation in Spring Floodplain Inundation

The annual spring and summer flood inundation was highly variable in timing, duration of inundation and extent of inundation. Floodplain inundation in the study area over the past twenty years has varied from 15 to 47.6 km^2 (Figure 3, Appendix 2). Inundation has started as early as mid-March (Julian day 74) and as late as the end of June (Julian day 180, Figure 4). Most of the floodplain inundation, however, began in the early spring. The estimated duration of floodplain inundation varied considerably: from as little as one week to as long as three months (Figure 5).

Relationship between Flow and Spring Floods

The extent of floodplain inundation and duration of flooding were both correlated with the volume of water delivered to the Shiawassee Flats area by local rivers. The flow, between March and August, not surprisingly, is significantly correlated with extent of inundation (r = 0.574, Table 1, Appendix 4). Duration of inundation was significantly positively correlated with extent (r = 0.546, Appendix 4). The duration of inundation was also positively correlated with the water level in Lake Huron (Essexville gauge, r = 0.598). Duration was well described by a multiple linear regression model with river flow, lake level and timing as significant predictors (Table 1).

Inundation influence on juvenile migratory fishes

Looking across the twenty-year period (1996-2015) for which I mapped flood extents, catch rates for YOY walleye were not significantly correlated with inundation or other hydrologic variables. YOY walleye appeared to be more sensitive to predicted spring water temperatures. There was a clear increasing trend in YOY walleye catch rate over time (r = 0.522) reflecting recovery of the Bay population beginning in 2002. But, simple linear detrending this of variable did not improve the correlation between walleye catch rate and inundation variables. Catch rates for YOY yellow perch also were not significantly correlated with inundation or hydrologic variables across the 20 years. Likewise, no significant correlation was found for freshwater drum, white perch, white bass, trout perch, spottail shiner or emerald shiner. YOY Rainbow smelt catch rates were significantly correlated with duration of inundation (r = 0.532, Appendix 4). However, the relationship was highly dependent on a single year's extremely high catch of over 6,000 rainbow smelt, and is therefore suspect.

I did find a significant correlation between inundation extent and gizzard shad catch (r = 0.439, Appendix 4). There was also a marginal negative correlation between gizzard shad catch rates and timing of inundation suggesting earlier flooding was better, although it was not significant at $p<0.05$ (r = -0.411). An MLR model including both variables was statistically significant (F-Statistic $p< 0.02$) and explained 39% of the variation (un-adjusted R-square) in catch over the 20-year period (Table 2).

Post Walleye Recovery (2006-2015)

When correlation analysis was constrained to recent years in which walleye have regained both a relatively stable population and significant level of natural reproduction (Fielder& Thomas, 2006; Ivan et al., 2011) five of the ten species examined had significant correlations with one or more of my inundation variables [walleye, yellow perch, smelt, white bass, and spottail shiner] despite the reduction in number of observations and loss of statistical power. Walleye YOY catch was correlated with both flood Duration (Figure 6) and Flood2 (r=0.67 and 0.56, respectively); suggesting positive effects of earlier inundation dates as well as longer lasting flooding. Natural log transformed walleye catch was strongly correlated with duration of inundation and Flood2 (0.6 and 0.68, respectively). Natural log of yellow perch catch was also negatively associated with flood timing (-0.61) also indicating better response to earlier flooding than late although that result is heavily leveraged by one year's low catch. Log-transformed YOY smelt catch was significantly correlated with the duration of inundation (p = 0.068). YOY white bass catch was also significantly correlated with duration of inundation, inundation extent, Flood and Flood2 (r = 0.64, 0.63, 0.68, 0.66 respectively; Appendix 5). Spottail shiner catch was negatively correlated with Flood2 (-0.58) and positively correlated with flood Timing (0.55), suggesting a response to longer duration inundation that continues later in the year. Emerald shiner catch was not correlated with the floodplain inundation variables but was strongly correlated (0.77) with water level at the Saginaw River mouth, with higher WSE values associated with stalling of the lower river, marginal flooding along the Saginaw River mainstem, and long residence times between the Flats and the Bay (Stack, 2015).

DISCUSSION

I examined the spatiotemporal patters of the flood regime in the Shiawassee Flats area to understand annual variations in floodplain inundation, extent and duration, and explore how inundation in the Flats may relate to annual variability on selected species in the downstream Saginaw Bay system. Overall, I found (a) wide inter annual variation in flooding, with strong statistical relationships between inundation extent, duration, seasonal timing and Bay WSE. I also found (b) some interesting relationships between inter annual inundation variation and catch rates of YOY fish in the Bay. However, other factors such as pollution, invasive species interactions, and restricted connectivity certainly complicate any interpretation of the statistical findings as discussed further below.

The flood pulse concept (Junk et al. 1989; Gutreuter et al. 1999) is the theory that some fish species can take advantage of predictable flooding characteristics in a way that ultimately improves recruitment. This has been known to occur in tropical regions where large floods occur predictably during the wet season, but connection between large seasonal floods and fishery yields is less understood in temperate regions with more variable seasonal rainfall. Winemiller (1996) found that unpredictable nature of annual precipitation in many temperate regions leads to unpredictable flood frequency and magnitude, and therefore local aquatic community reorganizations occur unpredictably on a scale of years and decades, rather than annual cycles.

The Shiawassee Flats area does have some predicable floodplain inundation each year with most flooding starting in the spring. Floodplain inundation started between mid- March and April for 13 of the 20 years examined, or 65% of the time. Inundation started in May six of the years, and late flooding, in June, only occurred during one of the years. This fairly predictable inundation could have provided increased nutrients from the fallow farmland and woodlands increasing food availability for larval and juvenile fish. The inundated land areas could have also provided increased habitat for spawning and availably of refuge for larval and juvenile fish making their way downstream.

The water discharged through the Shiawassee Flats region from March to August had a strong effect on the extent of floodplain inundation. Larger peak discharges (hydrologic “floods”) tended to result in longer periods of floodplain inundation. But varying water levels in Saginaw Bay result in variations in downstream slope from the flats to the Bay, and consequently alter discharge rates from the Flats to the Bay. Thus, slopes towards the Bay can alter drainage rate, varying the duration of floodplain inundation and thereby indirectly potentially affect up-river fish spawning and YOY recruitment. Statistical evidence for a direct connection to Bay water level in the annual MDNR Saginaw Bay survey dataset was limited to emerald shiners in my study.

Relationship to juvenile fishes

There was more variation in flooding extent than timing, and considerable variation in the duration of inundation. With an inconsistent amount of habitat availability each year and highly unpredictable duration of this availability it is possible that some migratory fish species are not able to take advantage of floodplain inundation to significantly improve survival. While this high inter annual variability may have prohibited some migratory species from taking advantage of increased floodplain availability when it occurred, walleye, smelt, white bass, gizzard shad, and spottail shiner appear to be able to negotiate such variation.

Walleye and yellow perch, both of which are important game species and of ecological importance in Saginaw Bay, are known to spawn in the Saginaw river system in early spring when temperatures reach 6°C and 7.2°C, respectively (Scott and Crossman 1973; Hayden et al. 2014; Neibur et al. 2015). Juvenile walleye catch exhibited a long term trend, with catch rates gradually increasing throughout the 20-year period (1996 to 2015). I found no relationship between their catches in the Bay and upstream inundation or river flow rates. However, when the analysis was restricted to 2006 to 2015, the post walleye recover period, YOY walleye appeared to respond to earlier, larger floodplain inundation and YOY yellow perch to early flooding. In either case, variables other than hydrologic ones are likely playing a large role in regulating juvenile walleye and yellow perch survival.

One such factor is possibly the alewife (Alosa pseudoharengus) populations in the Bay and improved walleye stocking success (Johnson et al. 2015). Another factor undoubtedly affecting recruitment is the abundance of predators in the Bay. Walleye and yellow perch in North America experience high variability in annual spawning success and age-0 survival (Schneider et al. 2007). Community dynamics play a large role in Saginaw Bay, with alewife being the most notable example. Yellow perch and spottail shiners are known predators of walleye eggs (Fielder 2002), but yearling and older alewives are thought to be significant predators, preying on newly hatched walleye and perch fry. The Michigan DNR believed the surprisingly high walleye and yellow perch catch rates in 2003 was due to the combination of (1) ideal climatic conditions that improved food availability, and (2) the low abundance of adult alewives in the Bay (Fielder and Thomas 2006). Although not obvious in catch rates of juvenile fish in these data, alewife likely had impacts on many forage fish species in the bay, and the collapse of the alewife population in 2004 is thought to have greatly affected forage fish species composition and abundance (Riley et al. 2008). Juvenile walleye catch rates were also likely influenced by hatchery produced YOY stocked in the Saginaw Bay. Prior to the year 2002, hatchery fish accounted for much, if not most, of recruitment in Saginaw Bay. For example, in 2003 MDNR determined that 28% of walleye year class came from stocking (Fielder and Thomas 2006).

Smelt are important for fisheries management due to their role as a forage fish and their ability to affect food webs through predation or competition with native fish (O'Brien et al. 2014). Rainbow smelt, introduced into the Great Lakes during the early 1900s, have become particularly important prey for age-0 walleye in the Saginaw Bay (Stein et al. 2017) and interact with a wide size spectrum of species which can have a major influence on energy flow and storage in lakes via food web restructuring (Evans and Loftus 1987). Smelt spawning is known to occur early, when water temperatures are between 3 and 10 °C (O'Brien et al. 2012). Smelt catch rates in my dataset improved with increased floodplain inundation. With early spawning, it is possible that juvenile rainbow smelt are present and able to take advantage of the effects of large floods, regardless of the timing. It should be noted, however, that the regression was strongly influenced by one year, 1997, where a catch rate of over 6,000 juvenile rainbow smelt per hour coincided with floodplain inundation lasting approximately 97 days.

The gizzard shad is also a non-native of the Great Lakes but is now a well-established and important prey species in Lake Huron (Pothoven et al. 2017). Gizzard shad spawn in late spring (typically when temperatures reach 16°C) but are also reported to spawn as early as mid-March and as late as August in sloughs, floodplains, ponds, lakes and large rivers (Miller 1960). Positive correlations with larger inundation extents and a negative response to late floodplain inundation could be indicative additional habitat availability in high floodplain inundation years. The negative response to later floodplain inundation likely reflects a mismatch between spawning habitat availability and ideal spawning time and/or a lack of habitat for refuge when the gizzard shad is in its critical juvenile stage. Late floodplain inundation also occurs under markedly different temperature, food availability and river velocity regimes, which might negatively affect juvenile gizzard shad migration through the main stem river in some way.

White bass and spottail shiners are important forage species of the Great Lakes. White bass reproduce in the spring in waters that range from 12 to 20°C, while spottail shiners spawn from mid-April to mid-June in water temperatures between 18 and 22°C. The improved catch rates of YOY white bass associated with large floods occurring earlier and YOY spottail shiner with large floods occurring later, suggest a benefit of any matchup with increased floodplain habitat during spawning.

Freshwater drum, trout perch and white perch are also known to migrate to Flats region but catches in the Bay did not appear to be correlated to upstream inundation for the twenty-year period or the walleye post recovery period. Emerald shiners were however correlated with Bay WSE, which suggests some primary association on lateral flooding in the Saginaw River proper.

Caveats and Complicating Factors

While I have shown that there is substantial floodplain inundation in the Flats area most years, it is unclear how much floodplain is "connected" in a way that allows or facilitates fish passage (in or out). It is possible that levels and dikes in the Flats area have reduced historic inundation levels as well as led to a disconnected floodplain system. The inundation I observed from satellite imagery, therefore, may be indicative, but is not equivalent to actual floodplain availability for spawning and YOY fish, and this discrepancy has undoubtedly had some impact on the results. Obviously fish can only take advantage of annual floodplain that they are able to access during the flooding period. It is unknown exactly how much of the Flats region floodplain is permanently disconnected by the creation of levels and dikes, but clearly much of Saginaw River floodplain is still isolated from the river by an extensive system of levees and pumps that maintain the land for agriculture (Buchanen et al. 2013), particularly outside of the refuge properties. Dikes are also present within in both the SNWR and MDNR Game Area to maintain habitat for local and migratory waterfowl, although efforts increase connectivity are actively underway. My ground truthing data collection within the SNWR revealed flooding in diked pools that remain largely disconnected from the Shiawassee River and may only become connected when flood levels exceed dike heights. Additional ground truthing in wooded areas of the SNWR showed evidence of flooding that did not appear directly connected to the Shiawassee river and may only become flooded through groundwater seepage and or river infiltration through the dike walls. Hydrologic connectivity between diverse patches of the riverscape is crucial for the recruitment of numerous animal and plant species (Amoros & Bornette, 2002), but levees lead to changes in fluvial dynamics that greatly affect floodplain access. Levees and dikes can lead to scouring to the river bed, lowering bed elevations and further impeding overbank flooding. Deepened mainstream channels can lead to decreased floodplain inundation or complete disconnection of the floodplain to the river channel (Ligon et al., 1995; Light et al. 2006; Burgess et al. 2012). Alexander et al. (2012) examined floodplain connectivity in the Mississippi River Basin and found that dikes direct the river flow toward the center of the channel, increasing the velocity, causing scouring of the bed sediment, and resulting in a deeper channel. In disconnected floodplain systems, floodplains act more like traps when overbank flow is achieved.

Even when floodplain inundation may dramatically increase areas of submerged habitat available for nursery and/or spawning, other factors such as pollution and invasive species may reduce potential benefits of increased floodplain habitat in the Shiawassee Flats. The catchments of the Flint, Cass, Shiawassee, and Tittabawassee Rivers contain both large urban centers, and vast agricultural regions affecting water quality in the Saginaw River watershed (Buchanen et al. 2013; MDNR 1988). Legacy industrial chemical contamination also dates back to the early 20th century (Buchanen et al. 2013; Millsap

2010). Since larval and juvenile fishes are particularly susceptible to pollution, poor water quality in floodplain habitat may at mitigate any quantitative gains in potential habitat.

Invasive phragmites and hybrid cattails are prevalent throughout the Saginaw Bay Watershed. *Phragmites australis*, or common reed, is an invasive plant that is prevalent throughout the Saginaw Bay watershed impacting valuable wetlands. The invasive cattail (*Typha angustifolia T. x glauca*), a hybrid of the native broadleaf Cattail and introduced Narrowleaf Cattail has also spread throughout the Saginaw Bay watershed and poses a major threat to wetlands. Although the Shiawassee National Wildlife Refuge successfully controls the spread of invasive species within the refuge, wetlands outside of the refuge have been severely degraded (DOI USFWS 2007). The monotypic stand of phragmites is believed to reduce biodiversity, but the impact of this invasive on the floodplain and recruitment of fishes in Saginaw Bay is unknown. Two studies examining the impact of *phragmites australis* on Mummichog (*Fundulus heteroclitus*) in the low salinity marshes of the Mullica River in southern New Jersey observed that larval and juvenile abundance in the native grass, *Spartina*, was 2–3 orders of magnitude greater than in Phragmites (Able and Hagan 2000; Able and Hagan 2003) suggesting that invasion reduces nursery habitat. The effect of reduced vegetation and structural diversity as the result of Typha invasion may also negatively impact fish communities as well (Mitchell et al. 2011).

The prevalence of invasive species occurring in the inundated areas of the flats could be negating the gains of extent and duration for many species

CONCLUSION

Riverine floodplains are highly complex, dynamic and diverse ecosystems, and among the world's most threatened ecosystems due to the pervasiveness of levees, dams, and other factors such as rapid spreading of non-native plant species (Tockner et al. 2010). It has been already demonstrated that flooding in the Flats region alters upstream wetland habitat availability (this study; Buchanan et al., 2013), floodplain nutrient cycling and export (Scott 2014; Argiroff et al. 2017), invertebrate diversity and productivity (Pollock 2017), and planktonic algal and water delivery rates to the bay (Stack 2015). The impact of floodplain inundation on migratory fish in Saginaw Bay of Lake Huron, however, is to date largely unknown. Overall, in this study I found that statistically significant links exist between floodplain inundation in the Shiawassee Flats and several juvenile migratory species in Saginaw Bay. However the volatile ecological history of the Bay fish community, together with the limited size of my data series, suggest observed correlations between YOY production and flooding in the Flats region are preliminary at best and further exploration is required. Furthermore, while annual floodplain inundation may increase areas of submerged habitat available for nursery and/or spawning, other factors such as pollution, invasive species and restricted connectivity may mitigate potential benefits of increased floodplain habitat in the

Shiawassee Flats. Examination of Landsat imagery and juvenile catch rates beyond the study period would provide a larger post walleye recovery dataset for improved analysis. Further clarity on the amount of floodplain habitat connected to the mainstream and suitable for refuge or spawning would also allow for improved accuracy in analyzing of these linkages.

In particular, gaining a better understanding of the hydrologic connectivity, and the negative impacts of invasive species, on the habitat suitability of major floodplain units at SNWR would help inform ongoing restoration efforts in the Shiawassee Flats area. It would also help clarify their role with respect to coastal fisheries and restoration efforts in Saginaw Bay and the associated Area of Concern (AOC). At present Great Lakes Restoration Initiative funds are being used by Ducks Unlimited and the U.S. Fish and Wildlife Service to restore the habitat quality and aquatic connectivity of former emergent wetlands within the Shiawassee National Wildlife Refuge. This restoration will improve aquatic connectivity between the wetlands and the Saginaw River; and hopefully prove to be beneficial to the many obligate and adfluvial fish species found in Saginaw Bay.

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FIGURES

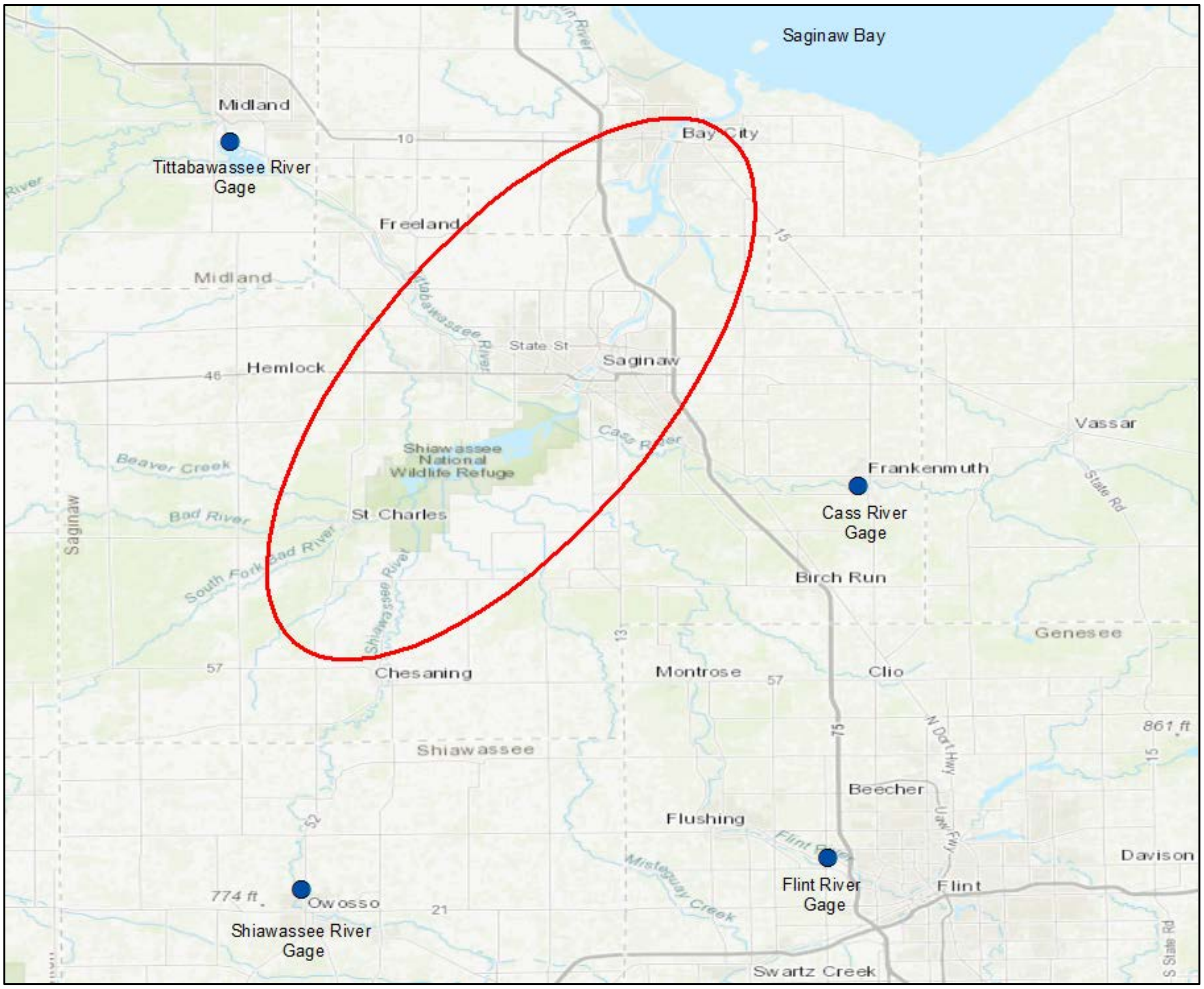

Figure 1. Shiawassee Watershed and Flats Area. Map of the Shiawassee Flats Study area. The Floodplain area where the Shiawassee, Bad, Flint, Cass, and Tittabawassee converge is circled in red. Gage station locations used to calculate flow rates, including gages on the Flint, Cass, Shiawassee, and Tittabawassee River, are marked in blue.

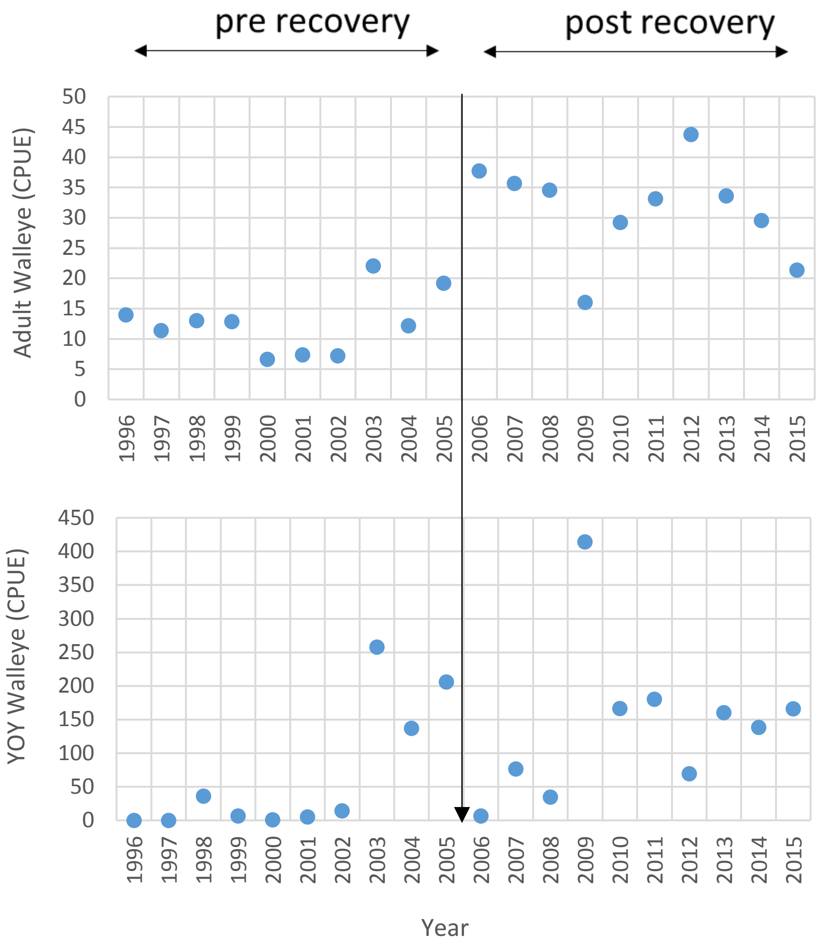

Figure 2. Time series showing post walleye recovery of adult and YOY walleye as indicated by catch rates (catch per hour) fall of each year.

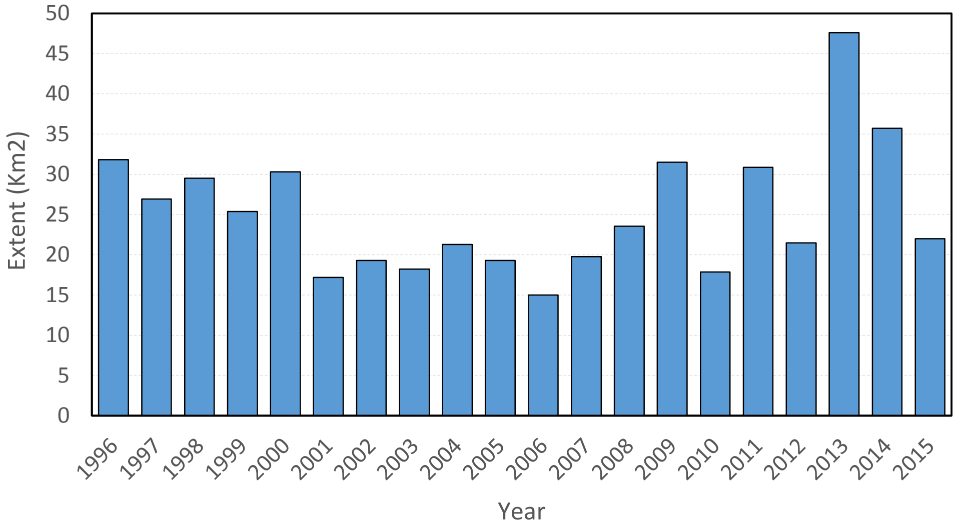

Figure 3. Time series showing annual extent of floodplain Inundation in square kilometers per annual spring flood.

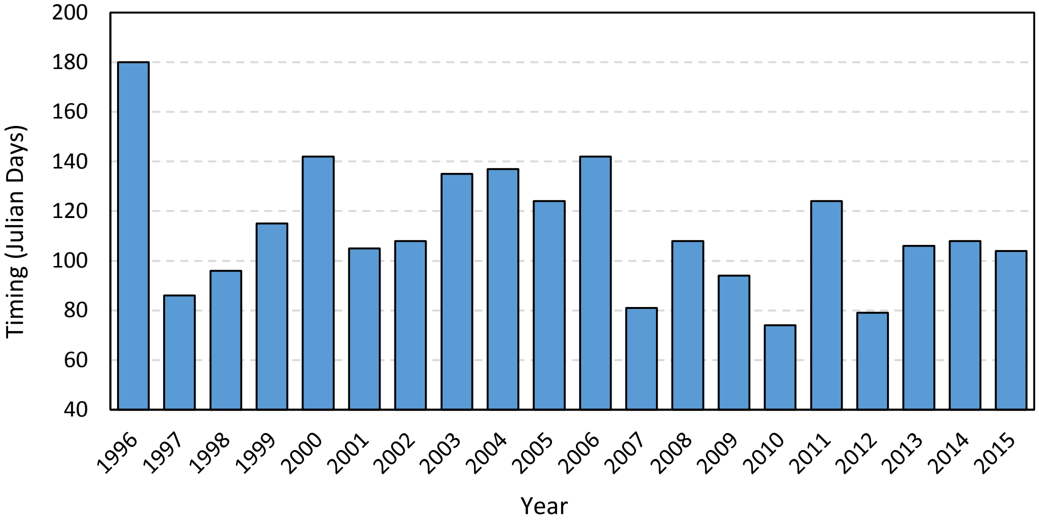

Figure 4. Time series showing estimated start day of floodplain Inundation. First day of observed floodplain inundation each year recorded in Julian day.

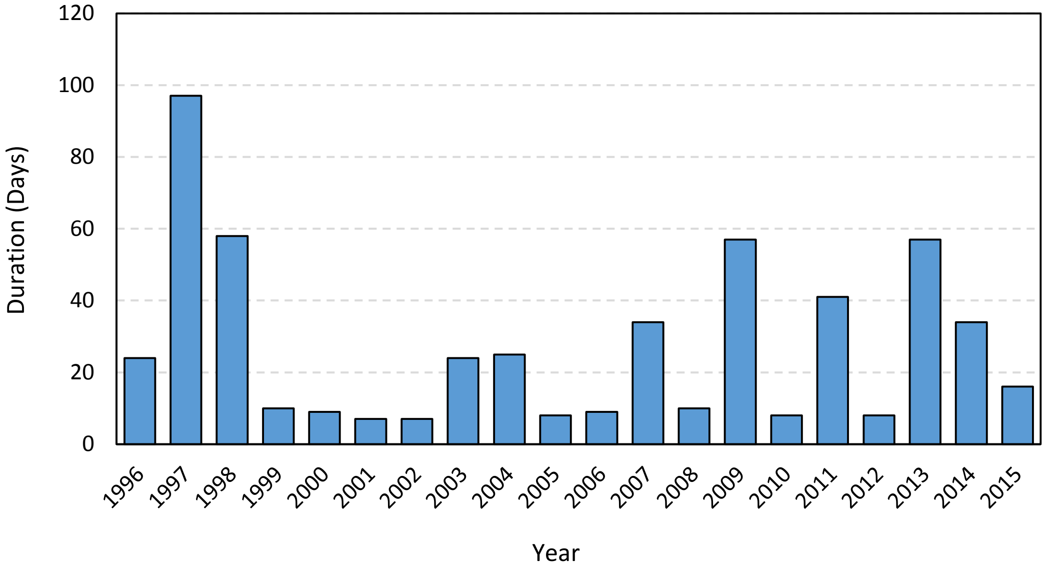

Figure 5. Time series showing estimated duration of floodplain inundation each year. Duration shown as total estimated days that floodplain remained inundated each year.

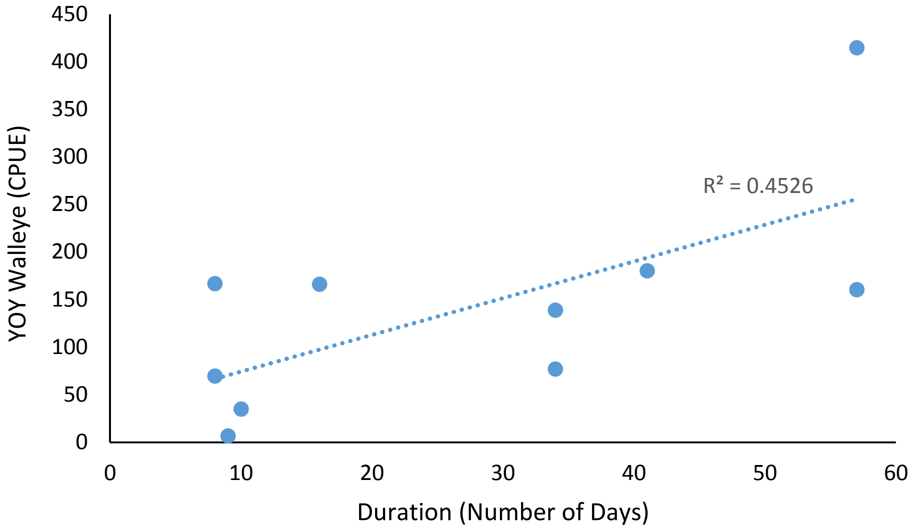

Figure 6. Post walleye recovery (2006 – 2015) catch rate response to annual duration of inundation. YOY walleye catch per hour against days floodplain remained inundated.

TABLES

Table 1.

Multiple regression of flood duration as function of river flow, water level and seasonal timing

Dependent variable: **Duration**
No Selector
R squared = 60.3 R squared (adjusted) = 52.8
S = 16.68 with 20 – 4 = 16 degrees of freedom

Source	**Sum of Squares**	**Df**	**Mean Square**	**F-ratio**
Regression	6756.43	3	2252.14	8.1
Residual	4450.12	16	278.13	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**Prob**
Constant	-7034.72	2097.00	-3.35	0.0040
River Flow	49.069e-6	14.49e-6	3.39	0.0038
Water Level	12.2005	3.624	3.37	0.0039
Timing	-0.2678	0.151	-1.77	0.0952

Table 2.

Multiple regression of juvenile Gizzard Shad cpu as a function of flood extent and timing

Dependent variable: **Juvenile Gizzard Shad**
No Selector
R squared = 0.39 R squared (adjusted) = 0.32
S = 50.92 with 20 – 3 = 17 degrees of freedom

Source	**Sum of Squares**	**Df**	**Mean Square**	**F-ratio**
Extent	14044	1	14044.1	5.417
Timing	14594	1	14593.9	5.629
Residuals	44074	17	2592.6	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**Prob**
Constant	102.043	61.5899	1.657	0.1159
Extent	0.015	0.0060	2.512	0.0224
Timing	-1.0705	0.4512	-2.373	0.0297

Appendix 1. USGS Landsat images Analyzed

Year	Landsat Scene Identifier	Acquisition	Spacecraft ID
1996	LT50200301996180PAC03	06/28/96	LANDSAT_5
1997	LT50200301997086PAC02	03/27/97	LANDSAT_5
1998	LT50210301998096XXX02	04/06/98	LANDSAT_5
1999	LT50210301999115PAC03	04/25/99	LANDSAT_5
2000	LE70210302000142EDC00	05/21/00	LANDSAT_7
2001	LT50210302001120AAA02	04/30/01	LANDSAT_5
2002	LE70200302002124EDC00	05/04/02	LANDSAT_7
2003	LT50210302003142LGS01	05/22/03	LANDSAT_5
2004	LT50200302004138GNC02	05/17/04	LANDSAT_5
2005	LT50200302005124GNC01	05/04/05	LANDSAT_5
2006	LT50200302006143GNC01	05/23/06	LANDSAT_5
2007	LT50210302007105GNC01	04/15/07	LANDSAT_5
2008	LT50210302008108GNC01	04/17/08	LANDSAT_5
2009	LT50210302009094GNC01	04/04/09	LANDSAT_5
2010	LT50210302010081GNC01	03/22/10	LANDSAT_5
2011	LT50200302011125EDC00	05/05/11	LANDSAT_5
2012	LE70210302012079EDC00	03/19/12	LANDSAT_7
2013	LC80210302013121LGN03	05/01/13	LANDSAT_8
2014	LC80210302014108LGN01	04/18/14	LANDSAT_8
2015	LC80200302015104LGN01	04/14/15	LANDSAT_8

(Accessed: https://espa.cr.usgs.gov/)

Appendix 2. Mapped Extent of Annual Spring Peak Inundation of Shiawassee Flats

1996

1997

1998

1999

2000

2001

2002

2003

2004

2005

2006

2007

2008

2009

2010

2011


2012


2013


2014


2015

Appendix 3a. Juvenile Fish Catch Rates

Year	Walleye	Yellow perch	Rainbow smelt	Gizzard shad	Freshwater Drum	White perch	White bass	Trout-perch	Emerald shiner	Spottail shiner
1996	0.20	217.84	73.14	54.12	31.96	1368.24	0.39	0.00	0.00	0.00
1997	0.00	494.06	6232.13	33.75	1.31	2065.88	5.63	0.19	0.00	14.81
1998	36.24	447.18	295.35	131.02	142.29	1813.47	2.69	19.10	0.24	0.00
1999	6.98	119.30	5.58	10.81	0.35	654.42	0.00	0.00	0.00	0.00
2000	1.09	42.67	2306.08	15.68	18.24	4872.77	0.18	142.25	0.00	0.00
2001	5.50	698.50	2089.75	30.75	19.25	3159.25	0.00	111.25	1.50	0.00
2002	14.20	197.24	776.45	103.77	38.70	1806.25	0.34	1.35	0.00	0.00
2003	257.75	14694.25	1912.25	39.75	5.00	2958.50	6.25	0.00	2.50	0.25
2004	137.09	2725.81	1253.46	10.06	14.25	1692.91	237.82	22.12	0.84	25.14
2005	206.25	1397.75	884.75	9.75	82.00	1427.25	129.25	0.00	2.75	0.00
2006	6.61	37.43	10.73	14.04	15.69	126.61	0.55	0.00	0.00	25.87
2007	76.94	532.24	240.71	55.06	56.24	5133.88	29.65	0.00	2.12	0.00
2008	34.97	1278.54	88.09	119.24	7.83	3468.34	30.57	20.45	1.53	35.92
2009	414.57	1871.43	327.71	101.14	3.43	378.29	76.29	0.00	0.00	0.00
2010	166.80	1193.70	14.70	41.70	10.50	2781.00	56.70	0.00	0.30	0.00
2011	180.25	920.00	1807.00	80.25	75.75	1475.00	84.50	162.00	0.25	0.00
2012	69.43	727.14	5.71	204.00	420.57	1298.00	41.43	36.57	0.57	0.00
2013	160.27	933.07	385.33	196.00	10.67	301.87	92.00	0.00	0.00	0.00
2014	138.67	282.13	7.73	98.93	11.73	317.60	26.13	0.00	0.00	0.00
2015	166.05	963.35	534.42	162.42	2.23	822.70	60.84	0.00	10.88	0.00

Appendix 3b. Hydrologic variables

Year	Extent (Acres)	Timing (Julian day)	Duration (Days)	Flood (Extent*Duration)	Flood2 Extent/Timing	Mar-Aug Flow (feet per second)	Water level Spring (feet)	Water Temp Spring °C	Water Temp March °C	Water Temp April °C	Water Temp May °C
1996	7867	180	24	188808	43.71	1117695	579.05	0.52	0	0	1.55
1997	6656	86	97	645632	77.40	860670	580.61	1.70	0.42	1.7	2.99
1998	7288	96	58	422704	75.92	677111	580.21	5.08	2.25	3.59	9.41
1999	6270	115	10	62700	54.52	409176	578.27	4.56	1.84	3.31	8.52
2000	7490	142	9	67410	52.75	590193	577.23	3.89	2.22	2.99	6.45
2001	4248	105	7	29736	40.46	645758	576.97	2.85	1.11	2.39	5.05
2002	4763	108	7	33341	44.10	820209	577.69	3.61	1.84	3.08	5.91
2003	4502	135	24	108048	33.35	441812	576.85	1.04	0	0.4	2.72
2004	5260	137	25	131500	38.39	1164178	577.43	2.42	1.17	2.35	3.74
2005	4768	124	8	38144	38.45	634519	577.90	2.36	0.58	2.42	4.08
2006	3704	142	9	33336	26.08	942476	577.46	3.66	1.56	2.97	6.45
2007	4885	81	34	166090	60.31	857313	577.43	2.43	0.84	2.05	4.39
2008	5820	108	10	58200	53.89	764540	577.15	1.63	0.01	1.65	3.22
2009	7781	94	57	443517	82.78	1145416	578.11	1.10	0	0.6	2.71
2010	4416	74	8	35328	59.68	647422	577.79	2.93	1.12	2.55	5.12
2011	7626	124	41	312666	61.50	1279598	577.23	1.15	0	0.83	2.62
2012	5307	79	8	42456	67.18	612477	577.52	4.01	2.14	3.05	6.83
2013	11760	106	57	670320	110.94	1297801	576.67	2.31	1.13	2.12	3.69
2014	8824	108	34	300016	81.70	1095412	577.73	0.56	0	0	1.67
2015	5436	104	16	86976	52.27	721065	579.18	1.09	0	0.56	2.71

Appendix 4. Pearson's R correlation matrix of flood and hydrologic variables. Pearson's r values are displayed on the top right and p-values are displayed on the bottom left. Green shaded cells indicate a statistically significant correlation ($P \leq 0.05$) for n=20 (df = 18).

	Year	Extent	Timing	Duration	Mar-Aug Flow	Water level Spring	Water Temp Spring	Water Temp March	Water Temp April	Water Temp May	Walleye	Rainbow smelt	Trout-perch	Yellow perch	White perch	White bass	Gizzard shad	Emerald shiner	Spottail shiner	Fwater drum
Year		0.168	-0.385	-0.109	0.319	-0.350	-0.328	-0.302	-0.299	-0.336	0.522	-0.414	-0.051	-0.033	-0.288	0.353	0.573	-0.050	0.359	0.164
Extent	0.479		0.081	0.546	0.574	0.121	-0.242	-0.139	-0.292	-0.243	0.154	-0.015	0.074	-0.217	-0.319	0.064	0.439	-0.243	-0.272	-0.097
Timing	0.094	0.735		-0.256	0.186	-0.219	-0.221	-0.145	-0.257	-0.219	-0.160	-0.043	0.168	0.175	-0.105	0.037	-0.411	0.155	-0.081	-0.293
Duration	0.647	0.013	0.275		0.449	0.552	-0.254	-0.251	-0.251	-0.244	0.188	0.532	-0.134	-0.014	-0.173	0.034	0.173	-0.021	-0.204	-0.126
Mar-Aug Flow	0.171	0.008	0.432	0.047		-0.094	-0.491	-0.380	-0.426	-0.541	0.254	-0.048	0.040	-0.275	-0.394	0.431	0.220	0.155	-0.237	-0.182
Water level Spring	0.131	0.612	0.353	0.012	0.694		0.014	-0.025	-0.043	0.058	-0.177	0.377	-0.343	-0.227	-0.240	-0.245	0.130	-0.139	0.095	0.098
Water Temp Spring	0.158	0.304	0.350	0.279	0.028	0.954		0.959	0.960	0.984	-0.487	-0.141	0.102	-0.300	0.122	-0.203	-0.047	-0.035	-0.281	0.378
Water Temp March	0.196	0.559	0.543	0.286	0.098	0.915	0.000		0.917	0.914	-0.508	-0.116	0.148	-0.314	0.122	-0.166	0.002	-0.094	-0.337	0.417
Water Temp April	0.201	0.212	0.275	0.287	0.061	0.858	0.000	0.000		0.905	-0.487	-0.057	0.092	-0.338	0.174	-0.059	-0.102	0.098	-0.289	0.324
Water Temp May	0.148	0.303	0.353	0.299	0.014	0.808	0.000	0.000	0.000		-0.454	-0.187	0.084	-0.258	0.088	-0.282	-0.035	-0.080	-0.241	0.372
Walleye	0.018	0.517	0.499	0.426	0.279	0.456	0.029	0.022	0.029	0.044		-0.158	-0.158	0.452	-0.269	0.486	0.162	-0.247	0.206	-0.102
Rainbow smelt	0.070	0.949	0.856	0.016	0.840	0.101	0.554	0.625	0.812	0.431	0.507		0.282	0.141	0.255	-0.079	-0.324	0.097	-0.062	-0.193
Trout-perch	0.833	0.757	0.479	0.575	0.869	0.138	0.669	0.533	0.701	0.725	0.506	0.228		-0.136	0.362	-0.027	-0.127	-0.127	-0.137	0.118
Yellow perch	0.891	0.358	0.460	0.954	0.241	0.337	0.199	0.177	0.144	0.273	0.045	0.553	0.569		0.152	0.038	-0.130	-0.038	0.159	-0.117
White perch	0.218	0.171	0.658	0.467	0.086	0.307	0.609	0.609	0.463	0.714	0.251	0.277	0.117	0.522		-0.207	-0.300	0.028	0.007	-0.054
White bass	0.127	0.788	0.878	0.886	0.058	0.297	0.391	0.483	0.803	0.229	0.030	0.740	0.910	0.872	0.381		-0.015	0.216	0.133	-0.002
Gizzard shad	0.008	0.053	0.072	0.465	0.352	0.586	0.843	0.992	0.668	0.883	0.496	0.164	0.594	0.585	0.199	0.949		-0.178	0.225	0.483
Emerald shiner	0.835	0.302	0.514	0.930	0.515	0.558	0.884	0.692	0.681	0.737	0.294	0.684	0.594	0.873	0.907	0.359	0.452		-0.084	-0.196
Spottail shiner	0.120	0.247	0.734	0.389	0.314	0.690	0.230	0.147	0.217	0.306	0.383	0.796	0.565	0.503	0.976	0.575	0.340	0.725		-0.092
Fwater drum	0.490	0.684	0.210	0.596	0.444	0.682	0.100	0.067	0.163	0.106	0.668	0.415	0.620	0.622	0.821	0.994	0.031	0.407	0.700	

Appendix 5. Pearson's R correlation matrix of flood and hydrologic variables for post walleye recovery period (2006 – 2015). Pearson's r values are displayed on the top right and p-values are displayed on the bottom left. Green shaded cells indicate a statistically significant correlation ($P \leq 0.05$) for n=10 (df = 8).

	Year	Extent	Timing	Duration	Flood	Flood2	Mar-Aug Flow	Water level Spring	Water Temp Spring	Walleye	Rainbow Smelt	Trout-perch	Yellow perch	White perch	White bass	Gizzard shad	Emerald shiner	Spottail shiner	Fwater drum
Year		0.52	-0.14	0.17	0.30	0.51	0.10	0.35	-0.40	0.24	0.18	0.06	0.04	-0.46	0.47	0.68	0.42	-0.57	0.13
Extent	0.13		0.11	0.81	0.93	0.90	0.78	-0.36	-0.48	0.42	0.27	0.10	0.20	-0.43	0.63	0.50	-0.24	-0.34	-0.19
Timing	0.70	0.76		0.06	0.10	-0.32	0.50	-0.16	-0.17	-0.23	0.34	0.30	-0.40	-0.49	-0.19	-0.25	-0.05	0.50	-0.36
Duration	0.64	0.00	0.88		0.94	0.75	0.86	-0.23	-0.51	0.67	0.40	0.13	0.32	-0.25	0.64	0.17	-0.25	-0.47	-0.30
Flood	0.39	0.00	0.78	0.00		0.86	0.86	-0.35	-0.41	0.56	0.31	0.06	0.27	-0.39	0.68	0.33	-0.29	-0.40	-0.27
Flood2	0.13	0.00	0.36	0.01	0.00		0.53	-0.30	-0.31	0.51	0.05	-0.08	0.35	-0.23	0.66	0.58	-0.26	-0.54	0.00
Mar-Aug Flow	0.79	0.01	0.14	0.00	0.00	0.12		-0.40	-0.47	0.42	0.53	0.34	0.03	-0.43	0.47	-0.02	-0.38	-0.20	-0.38
Water level Spring	0.32	0.30	0.66	0.52	0.33	0.41	0.25		-0.31	0.34	-0.06	-0.25	0.18	-0.17	-0.02	0.02	0.77	-0.27	-0.12
Water Temp Spring	0.25	0.16	0.64	0.14	0.24	0.38	0.17	0.38		-0.52	-0.41	-0.17	-0.33	0.13	-0.36	-0.04	-0.27	0.17	0.56
Walleye	0.51	0.23	0.52	0.03	0.09	0.14	0.23	0.34	0.13		0.27	0.03	0.73	-0.32	0.68	0.10	-0.02	-0.54	-0.25
Rainbow Smelt	0.62	0.45	0.34	0.25	0.38	0.89	0.11	0.88	0.24	0.44		0.88	0.16	-0.07	0.60	0.00	0.09	-0.27	-0.08
Trout-perch	0.87	0.78	0.41	0.73	0.86	0.82	0.33	0.48	0.64	0.94	0.00		0.04	0.01	0.37	-0.02	-0.16	-0.10	0.24
Yellow perch	0.91	0.58	0.25	0.37	0.45	0.32	0.93	0.62	0.35	0.02	0.65	0.91		0.08	0.65	0.24	0.06	-0.11	-0.14
White perch	0.18	0.22	0.15	0.48	0.27	0.51	0.21	0.63	0.73	0.36	0.85	0.99	0.84		-0.21	-0.28	0.04	0.14	0.01
White bass	0.17	0.05	0.60	0.04	0.03	0.04	0.17	0.96	0.32	0.03	0.07	0.30	0.04	0.55		0.45	0.06	-0.57	-0.08
Gizzard shad	0.03	0.14	0.48	0.64	0.35	0.08	0.96	0.96	0.90	0.79	1.00	0.96	0.50	0.44	0.19		0.28	-0.26	0.47
Emerald shiner	0.22	0.50	0.90	0.49	0.42	0.47	0.27	0.01	0.44	0.96	0.80	0.65	0.88	0.92	0.87	0.44		-0.10	-0.14
Spottail shiner	0.08	0.33	0.14	0.18	0.25	0.11	0.58	0.45	0.63	0.11	0.45	0.78	0.75	0.69	0.09	0.47	0.77		-0.20
Fwater drum	0.72	0.61	0.31	0.40	0.45	1.00	0.28	0.74	0.09	0.49	0.83	0.50	0.69	0.97	0.83	0.17	0.70	0.57	