Seasonal Movement Patterns of Walleye (*Sander vitreus*) in Muskegon River and Muskegon Lake, Michigan.

by
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Professor Paul W. Webb, Chair
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Acknowledgments

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Abstract

Walleye (*Sander vitreus)* are known to travel long distances between spawning, foraging and over wintering habitats. In the Muskegon system walleye have the choice of moving between Muskegon River, Muskegon Lake and Lake Michigan throughout the year. The purpose of this study was to determine the seasonal movement of walleye in the Muskegon system.

In 2004 and 2005 a total of 15 walleye were implanted with radio transmitters and 5 with ultrasonic transmitters. During March, April, and May walleye were located in Muskegon River, near Croton Dam, presumably to spawn. By June 10 of 12 fish tracked had departed the river for Muskegon Lake or left the Muskegon system. In June, July and August 85% (17/20) of tracked walleye inhabited Muskegon Lake or were outside the Muskegon system. From September through February 6 of 7 tracked fish were located in lacustrine habitat. I documented one walleye periodically traveling between Muskegon Lake and Lake Michigan during November and December. Based on movement results telemetry data were categorized into three time periods; spring, which included pre- and post spawning periods (March – May), summer (June – August), and winter (September – February).

Range (total distance displaced) of tagged walleye was greatest during spring due to spawning migrations in Muskegon River. Spring range of all walleye varied from 3,467 to 150,900 m; summer range varied from 131 to 46,114 m; and winter range from 326 to 42,650 m. There were significant differences between spring and summer ranges ($p < 0.001$) and between spring and winter ranges ($p = 0.024$), but not between

summer and winter ranges ($p = 0.223$). During summer, total range of fish inhabiting Muskegon River was significantly different than those fish in Muskegon Lake. These differences between Muskegon River and Lake are attributed to the energetic costs for large walleye to search long distances for prey in flowing water versus searching for prey in the lacustrine environment. Movement results from this study emphasize the importance of the habitat connection within this system, and may also assist managers in determining when and where to calculate population estimates.

Introduction

Long range movements of walleye *(Sander vitreus)* have been well documented in rivers and lakes throughout the Midwest (Eschmeyer and Crowe 1955, Holt et al. 1977, Paragamian 1989, and DePhilip et al. 2005). Walleye movement patterns are complex due to habitat needed for foraging, spawning, and overwintering. Most telemetry studies focus on an area where walleye movement is constricted between two dams (Paragamian 1989, DePhilip et al.2005,), to an inland lake, or have access to a lake and river (Holt et al. 1977). The Muskegon watershed is unique in that the lower 75 km of Muskegon River, Muskegon Lake, and Lake Michigan are connected providing fishes a large, diverse choice of habitats and free movement between them throughout the year. Because this system consists of three distinct habitats, a better understanding of walleye movement can lead to improved walleye management for the Muskegon system.

Previous studies of walleye in the Muskegon River have focused on mark-recapture methods and provided evidence for long range movement between spawning locations (Eschmeyer and Crowe 1955, Crowe 1962). Eschmeyer and Crowe (1955) tagged walleye in Muskegon River during the spring and noted fish traveled considerable distances traveled between captures. The farthest of their recaptured fish was found 282 kilometers away in northern Lake Michigan, and fourteen walleyes had moved more than 161 kilometers between release and recapture. It is also known that walleye from the eastern side of Lake Michigan and Muskegon Lake can be found in Muskegon River during the spring spawning run (Crowe 1962).

Mark-recapture investigations cannot determine the behavior of a fish between release and recapture. Telemetry can be used to determine the timing of fish movement among habitat types, and the routes taken. Seasonal movement and estimates of movement rates can be used to determine if mobile fish populations should be managed as one or as discrete units (Schweigert and Schwarz 1993).

The purpose of this investigation was to conduct a telemetry study to determine the movement patterns of walleye in the Lower Muskegon River system. Telemetry was used to track the movement of fish between Muskegon River, Muskegon Lake, and Lake Michigan. The specific objectives of this study were 1) to ascertain when walleye inhabit Muskegon River, Muskegon Lake, or Lake Michigan, and 2) determine the seasonal movement patterns of walleye in Muskegon River and Muskegon Lake.

Study Site

The Muskegon watershed is located on the western side of Michigan's Lower Peninsula. Muskegon River originates in Houghton and Higgins lakes in Roscommon County and flows southwesterly for a distance of 365 km, entering Lake Michigan by way of Muskegon Lake (Eschmeyer 1950). Croton Dam, 75 km from Muskegon Lake, was the upper boundary of the study site. Land cover within the study area mainly consists of agriculture and forest, with urban areas through the cities of Muskegon and Newaygo.

The area from Croton Dam to 30 km downstream has higher gradient, more pool-riffle transitions, and greater concentrations of gravel and pebble substrate types. This section has a single channel with nearly no braiding. The lower half of the study site consists of a silt-sand substrate with increased channel braiding and shallower depths. Habitat is more uniform with fewer pool-riffle sequences. Muskegon River splits into the North and South branches 4.6 km from the mouth, then empties into Muskegon Lake. The average annual discharge of Muskegon River at Croton Dam is 51.9 m^3/s.

Muskegon Lake is a 1,679 hectare drowned river mouth that was created historically by fluctuating Lake Michigan water levels and the closing of a channel by wind induced erosion of sand dunes. It is connected to Lake Michigan by a shipping channel on its east side and also to Bear Lake by a channel on the north shore. The maximum depth is 25.6 m with an average depth around 10 m. The majority of the lake has silt or sand substrate. The littoral zone of the northern shore has gradual slopes, whereas the southern shore is generally deeper and drops off more rapidly. Average secchi depth during the spring and summer periods was 3 m ranging from 2.5 to 3.5 m. The town of Muskegon and North Muskegon line the shore of the lake making most of the adjacent land cover urbanized. Chemical companies, a paper mill and foundries are also found within the immediate vicinity. The area has been identified by the Environmental Protection Area (EPA) as an Area of Concern (EPA 2004).

Methods

Twenty walleye ranging from 401 to 725 mm total length were captured for transmitter implantation using a DC electrofishing boat during 2004 and 2005. Ten walleye were radio tagged during 2004; seven in April and June, in two locations in

Muskegon River and three captured and released on July 1 in Muskegon Lake (Table 1). In 2005 five walleye were radio tagged from Muskegon River, four during the first week of April and one during the first week of June. An additional five walleye from Muskegon Lake were implanted with ultrasonic tags, three during the last week of May and two during the first week of July (Table 1; Figure 1). Fish were captured and then released, immediately after surgery, near their capture site. Transmitters were surgically implanted as described in Ross and Kleiner (1982). A net stretcher was wrapped around the fish to restrain movement and a transmitter inserted with a trailing antenna protruding. After surgery, 2 ml (50 mg/ml) of oxytetracycline was injected through the incision. The procedure took less than ten minutes, and fish were held in a live-well until swimming upright and showing signs of normal activity, and then released. Sex was determined when possible by gonadal release.

Radio transmitters (Advanced Telemetry Systems, model F1840, Isanti, Minnesota) weighed between 18-20 g and had a 25 cm trailing antenna. The life expectancy of the battery was 180 to 339 days, and each transmitter emitted a signal with a unique frequency between 150.000 – 150.999 MHz. Ultrasonic transmitters (Sonotronics, model CT-82-2, Tucson, Arizona) weighed between 16 – 19 g, and had a battery life expectancy of one year. Two types of radio receivers from Advanced Telemetry Systems were used. A R2100 receiver with directional antenna was used to actively track fish from shore or boat. Two fixed station R4500C receivers with accompanying directional antennas were used to determine when fish passed between Muskegon River and Muskegon Lake, or to Lake Michigan (Figure 1). One of these receivers was placed on the main channel of Muskegon River 4.8 km from the lake.

This receiver was upstream before the channel splits into the North and South Branch. The second R4500C was located on the channel connecting Muskegon Lake and Lake Michigan. The R4500C receivers could not detect the sonic transmitters. An ultrasonic receiver (Sonotronics USR-96) and hand-held directional hydrophone were used to track fish implanted with ultrasonic tags. Walleye with ultrasonic tags were located from April to August 2005. Walleye with radio tags were located from April 2004 to August 2005. Only eight walleye had working tags from November 2004 to January 2005, and range could only be determined for four walleye. Two walleye during this time were captured by anglers, therefore removing them from the sample, and lack of detections for four other fish limited range calculations.

During the study walleye were tracked from boat and shore. Using ultrasonic, and radio equipment in Muskegon Lake a systematic pattern was used to search for fish. A course was set, east to west, through the middle of Muskegon Lake, and the boat stopped at every 1 km until reaching the opposite shoreline. West of the Bear Lake channel four additional listening stations were added, two north of the center line course and two south of the center course. At each stopping point the boat motor was turned off and the hydrophone slowly rotated 360° to search for fish in all directions (Figure 2). Using this methodology all ultrasonic tagged fish were found. Detections were limited for walleye tagged with radio transmitters, presumably due to depth constraints on radio telemetry. During each tracking session, all areas were searched.

Upon detecting a signal at a listening station the fish was approached until signal strength peaked, then repeated from another direction to get a precise location. Locations were recorded on a map, using landmark features and GPS coordinates.

Water temperature, time, and water depth were recorded. Diel movement patterns for numerous fish could be tracked during 12 and 24 hour periods by moving among individual walleye, and pinpointing the location of each fish one to two times an hour. Changes in signal strength or direction of a particular fish appeared to indicate active movement. For these active fish, tracking was concentrated to record their movements.

To calculate areas most used by walleye a 300 by 300 m grid was overlain on Muskegon Lake (Figure 3). From this, the number of walleye detections within each cell were determined and classified by the number of times fish were located in that cell from June – August 2004 and June - August 2005. Relative abundance of walleye was determined by:

$$\frac{\text{Number of walleye detections / 300 x 300 m quadrant}}{\text{Three month period}}$$

Areas containing 1 – 10 detections classified as present, 11 – 30 as low, 31 – 50 medium, and 51+ as high frequency of occurrence.

Muskegon River was searched by floating downstream until all known radio tagged fish in the river were located. Once a radio tagged fish was located, the bearing was followed until signal strength decreased, and then repeated from another direction to establish a fix. Upon locating a fish its position was marked with a GPS, followed by a more precise written description based on nearby landmarks. Water temperature, time, and depth were noted. Locations and other data were later transferred to a Global Information Systems (GIS) map.

Individual fish locations were used to calculate seasonal range and local range. Seasonal range was defined as a cumulative distance between all walleye locations within that season. Local range was defined as sites where walleye were located for at least four days within a two week period. Two types of daily movements were measured, displacement distance and diel activity. In both Muskegon River and Muskegon Lake displacement was measured as the distance between daytime locations, every 1 – 3 days in the summer and spring and three to five weeks in winter. Displacement distance is not a measure of the total linear distance moved but a minimum estimate of position change.

Diel activity was measured during summer 2005 in Muskegon Lake. Activity levels were calculated for four periods of the day; at dawn, during the day, at dusk, and during the night. Dawn was defined as one half hour before sunrise and one half hour after sunrise. Dusk was defined as one half hour before sunset and one half hour after sunset. Walleye activity during the day and night periods were monitored at least once for each hour during the period. An individual fish was located during each period and monitored for one hour. After finding a walleye the boat was anchored ~50 m from the fish. At five minute intervals, for one hour, signal strength was monitored. Fish were defined as active if the signal strength or direction changed between five minute intervals. I calculated the percent of active intervals for each period.

Catch per effort (CPE) was measured to assist in determining the time of migration for walleye moving out of Muskegon River. A sudden decrease of walleye in the river, combined with the downstream movement from radio tagged fish indicated that walleye were leaving the river for Muskegon Lake or Lake Michigan. Biweekly boom-electrofishing of Muskegon River was conducted during the spring and summer in 2004 and 2005, with effort concentrated on capturing walleye. The boom electroshocking boat (SR-18H; Smith-Root Inc.) ran on DC current and emitted around 170 volts. Total shocking time was one hour, immediately after sunrise. Movement of walleye and accessibility to the river determined where sampling occurred. Various areas from the mouth, to Croton dam, were sampled and these results combined to attain a complete view of Muskegon River.

In 2004 temperature recording thermographs (Onset Computer Corp. 1998) were placed in three pools used by walleye in August, and one thermograph in Muskegon Lake. In March 2005 two thermographs were placed in Muskegon River, one at the fixed receiver station in the lower river and the other 10 km from Croton dam. Two other thermographs were deployed in Muskegon Lake, one in the east half of the lake and the other in the west. Data from all thermographs within the river was limited because of unknown persons prematurely removing them from the study sites during mid August. Data was recovered from these four thermographs, and the 2004 lake temperature logger. During 2005 two thermographs in Muskegon Lake and the temperature logger near the river fixed receiver were not recovered.

Tracking data was graphed and visually analyzed in ArcGIS 9.1 (Environmental Systems Research Institute) for migration and distribution patterns. Data analyses were completed using SYSTAT 10 (SPSS Inc. 2000). A two-sample T test was used to determine whether there were differences in migration distances between seasons. Walleye catch per effort (CPE) in the river was evaluated by month using a two-way analysis of variance (ANOVA) with a Bonferroni correction. Significance was set at $\alpha = 0.05$ for all tests.

Results

During March and April in 2004 and 2005 walleye were located in Muskegon River, primarily within 10 km of Croton Dam (Figure 4). Walleye were presumably making spawning migrations and spawning during this time period in the river. Eight of ten surviving walleye that were tagged during 2004 in Muskegon Lake and Muskegon River migrated to the river during March and April in 2005.

As May progressed walleye began to migrate downstream out of Muskegon River and into Muskegon Lake or out of the Muskegon system. Walleye often traveled 10 – 60 km downstream in the span of a few days and fixed receiver stations suggest walleye made these migrations at night, with detections between 1900 and 0910. Ten of twelve walleye that were tracked in the river during March and April departed the river before June 1, while one fish resided in Muskegon River throughout the year and the other until at least August 2005 (end of study period). Two of twelve fish left the Muskegon system during April and May. All surviving fish (2/2) that were tagged in Muskegon Lake during 2004, and found in the river in March and April 2005 returned to Muskegon Lake before June 2005 (Table 1).

During June, July, and August few walleye were found in Muskegon River. Eighty five percent (17/20) of tagged walleye were found in Muskegon Lake or had moved out of the Muskegon system during this time period. All fish initially captured and released in the river during April and May were not found past June in riverine habitat. Walleye that inhabited Muskegon Lake during the summer exhibited a summer range up to 5,830 m with most detections in the eastern half of the lake (Figure 3). Of 842 walleye locations, the majority were found near the northeast shore of Muskegon

Lake, but all fish were located at some time within the western half of the lake (Figure 3).

The three walleye that remained in Muskegon River during June, July, and August 2004 were captured and tagged in the river on 24 June 2004 and 14 July 2004. These fish stayed in the river within 35 km of Croton Dam from tagging date until August. River-resident fish had small total ranges, less than 2,000 m, and up to three local ranges were utilized.

In September, one walleye tagged in the river during June, migrated 70 km downstream from Muskegon River, through Muskegon Lake and out of the Muskegon system. In November, another walleye located in the river through the summer, migrated downstream 43 km into Muskegon Lake, before being caught by an angler. Only one walleye stayed year round in Muskegon River.

From September 2004 through February 2005 seven walleye were tracked. By November 2004 two of the tagged walleye had been captured and kept by anglers, and another left the Muskegon system and was not detected during this time period. Two of three fish moved out of the river during this time, while all other fish stayed only in the lacustrine habitat. Limited information was collected during this time period because of depth constraints on radio telemetry in Muskegon Lake, although fixed sites continued to record between lake movements. From October through February 86% (6/7) of tagged fish occupied Muskegon Lake for at least three months. Walleye 4 made periodic movements between Muskegon Lake and Lake Michigan during November and December.

From these movement results telemetry data were categorized into three time periods; spring, which included pre- and post spawning periods (March – May), summer (June – August), and winter (September – February). These periods were chosen based on fish behavior rather than solar seasons.

Seasonal range

Spring range of all walleye varied from 3,467 to 150,900 m; summer range varied from 131 to 46,114 m; and winter range from 326 to 42,650 m. There were no significant differences in mean ranges of fish between years, or among individual fish within the summer period ($p = 0.407$) or spring period ($p = 0.067$).

There was a significant difference between the spring range of 14 walleye and the summer range of 18 tagged fish for both 2004 and 2005 ($p < 0.001$). Significant differences between spring ($n = 14$) and winter ($n = 4$) ranges were also documented ($p = 0.024$), but not between summer ($n = 18$) and winter ($n = 4$) ranges ($p = 0.223$).

The mean summer range of fish inhabiting only Muskegon Lake during the summer was similar between years; the same was true for average summer range of fish in Muskegon River. However, there was a significant difference ($p = 0.003$) between the range of fish only found in Muskegon Lake ($n = 10$) and those only found in Muskegon River ($n = 3$), from June - August. Mean summer range of fish in Muskegon Lake was 2,693 m and 639 m for fish in Muskegon River.

Muskegon River Abundance

CPE for walleye from Muskegon River decreased starting after April. Catch rate was significantly different between May and June ($p = 0.034$) and May and July ($p = 0.012$) but not between June and July ($p = 0.545$). This pattern of abundance data corresponds to a lack of radio tagged walleye (17/20) inhabiting the river after the spring period. Few walleye were found in Muskegon River during the summer months of June, July, and August. Combined abundance data for 2004 and 2005 indicate that most walleye did not reside in the river for the duration of summer (Table 2).

Activity

During summer, in Muskegon River, the three fish that stayed here were never observed actively moving between local ranges, but found in one area one day and then suddenly in another area the next day. These summer river-resident walleye did not move between sites more than five times during a summer period. Over the summer temperature loggers did not record mean differences of more than one degree between locations.

Walleye in Muskegon Lake were most commonly inactive (67% of the time) during all periods of the day. Walleye activity peaked during the half hour before sunset and half hour after sunset and then declined continually through the night to sunrise, with minimum activity during the day (Figure 5). Day and sunrise activity was sporadic, and often fish did not move for up to 12 hours. During the sunset and night periods, walleye exhibited a variety of movement patterns from patrolling short sections parallel to the shoreline, moving inshore and then back offshore, and random roaming.

At night walleye were found at depths ranging from 2 to 11 m. More than 40% of the fish observations were at 7 m water depth and all ultrasonically implanted fish used this depth most commonly. During the day, walleye occupied depths from 4 to 12 m, with 33% of observations at 8 m. During the day walleye were located only fifteen times in depths shallower than 7 m, and over 70% of the time fish were found in depths from 7 to 9 m (Figure 6). The mean daytime depth all walleye were found at was 8.3 m. The mean night depth was 7.0 m.

Discussion

Walleye displayed complex seasonal movements that can be attributed to spawning, over wintering, and foraging. Tagged walleye in this study were found in Muskegon River during March, April and May to presumably spawn near Croton Dam. During May, radio-tagged walleye migrated out of the river into lacustrine habitat, and by June 10 of 12 walleye tagged during April and May had departed the river.

As walleye started to move downstream they often traveled distances from 10 to 60 km in a couple of days. I did not observe if fish continually swam downstream without stopping or moved in increments. Fixed station data suggest that when walleye were swimming long distances downstream they did so during low light conditions, and during the night. Similar findings, of nighttime downstream walleye movement were observed by DePhilip et al. (2005) in the AuSable River. They tracked one walleye's return to a reservoir, locating it eight times, from 2240 to 0400 in which it traveled 19.6 km in 5.25 hours. This walleye was observed continuously moving downstream.

During the end of the spring period, 10 of 12 tracked walleye left the river for lacustrine habitat, and abundance data show that by June there were approximately half as many walleye in the river compared to May. I expected more walleye to stay longer in Muskegon River after spawning to rest and take advantage of available prey. From March through June 2004, 307,104 salmonids were stocked all within 35 km of Croton Dam (http://www.michigandnr.com/fishstock/). In a concurrent study Diana (2006) examined growth and diets of walleye in Muskegon River and Muskegon Lake. She concluded that walleye take advantage of densely stocked rainbow trout after spawning, but shortly afterwards the movement of alewife into Muskegon Lake also provides a strong forage base there. Similarly, abundant forage bases between the two habitats allows for walleye to choose which habitat to occupy for foraging.

Although some fish were tagged and stayed in the river during the summer, a large proportion of walleye entered, and then left Muskegon River in April and May. This may indicate a learned behavior for walleye to enter the river, spawn, and then return to the lake environment, an area they are more familiar with. Other studies have shown genetic preferences of walleye for spawning and feeding areas (Jennings et al. 1996, Rasmussen et al. 2002, Palmer et al. 2005). The movement of walleye completing their spawning cycle and leaving the river could be due to their familiarity with that habitat for spawning and then the lacustrine habitat for feeding.

During the summer months of June, July, and August, 85% (17/20) of tagged walleye inhabited either Muskegon Lake or were outside the Muskegon system. Three fish stayed within the river during the summer. Abundance (CPE) data support telemetry data that a significant number of walleye left Muskegon River between the change of seasons from May to July. It is unclear if unfavorable conditions (ie. temperature, forage, habitat) in the river push walleye out of the river, if prey abundance declines over this time period, or if it is a heritable behavior for walleye to summer in Muskegon Lake or Lake Michigan.

Habitat selection from September through February was similar to the summer period, as all but one fish inhabited Muskegon Lake or was outside the Muskegon system during this period. Two fish that spent the summer in the river migrated into lacustrine habitat during winter. DePhilip et al. (2005) also noted that walleye in the Au Sable River only over wintered in a reservoir located downstream from summer locations. These sudden long range movements may indicate that winter conditions in Muskegon River may be unsuitable for walleye during this time. A combination of cold temperatures, low flows, lack of deep pools with low current velocity, and prey availability may all contribute to these two walleye moving considerable distances to over winter (Kitchell et al. 1977, Paragamian 1989). The one fish that stayed in Muskegon River year round may indicate that a population of resident walleye inhabits the river.

During October and November one fish was observed making periodic movements between Muskegon Lake and Lake Michigan. These movements may be a result of searching for optimal temperatures or high densities of prey. It is not known where in Lake Michigan or how far this walleye traveled outside of Muskegon Lake. The fish may have moved far from Muskegon before returning or may have stayed within a few kilometers of the area.

Differences in seasonal ranges indicate that walleye had a significantly larger range from March – May, compared to June – August, and September – February. This appeared to be due to spawning migrations into Muskegon River and then a return migration to Muskegon Lake or somewhere outside the Muskegon system. These results support previous findings of long range movements by walleye during the spring season (Crowe 1962, Pitlo 1984, Paragamian 1989, DePhilip et al. 2005). Locations were concentrated for fish in Muskegon River within 35 km of Croton Dam. Croton Dam blocked the upstream migration of walleye, but its tailwaters provided quality gravel-cobble substrate for walleye spawning (Crowe 1962). In the Cedar River in Iowa (Paragamian 1989), and the Au Sable River in Michigan (DePhilip et al. 2005) walleye stayed primarily within 25 km below dams, possibly because of degraded habitat downstream of this distance. The same observation was true for walleye in this study.

The other significant difference in ranges was between fish in Muskegon River and Muskegon Lake during the summer, with fish in Muskegon Lake showing a greater range than those in the river. Although diel activity of riverine walleye was not measured (due to accessibility), I believe these small summer ranges were related to foraging behavior. In the Au Sable River, DePhilip et al. (2005) found that walleye often patrolled short sections of shoreline (5 – 10 m) through the night, and would usually confine this activity to their local range. Other studies of fluvial brown trout populations (Clapp et al. 1990, Ovidio et al. 2002, Diana et al. 2003) have shown that although they occasionally make long range diurnal movements many fish rarely move over 100 m. Walleye in the fluvial system may utilize a sit and wait approach or be confined to a smaller area to search for prey. The strategy observed in this study may be related to the energetic costs for large walleye to search long distances for prey in flowing water. If walleye choose home sites that contain suitable habitat, high prey densities, and preferred prey types their range can be decreased and foraging concentrated in a smaller area.

Walleye in Muskegon Lake were largely inactive during daylight hours, often remaining in a single location for periods up to 13 hours. From dawn to dusk walleye were more active than during the day, yet the period where most activity was recorded was during twilight. Other studies have examined walleye activity in lacustrine environments and shown walleye are most active at night (Eschmeyer 1950, Rawson 1957, Holt et al. 1977). Since walleye are known to avoid light (Ryder 1977, Paragamian 1989) it is not surprising that activity increased and the depth where walleye were found decreased during dusk through dawn. I hypothesize that walleye in Muskegon Lake actively searched for prey as soon as light conditions were favorable, at sunset, and their activity decreased through the night either because of high foraging success early in the night, or due to prey behavior and vulnerability during this time (Moore and Moore 1976). Alewives, a known prey item of walleye in this system, are particularly vulnerable to predation in low light conditions, especially during dusk and dawn periods (Richkus 1974, Richkus and Winn 1979). Instead of using a sit and wait approach, tagged walleye in Muskegon Lake actively moved to different areas within the lake to forage.

The walleye in this study exhibited a seasonal pattern of inhabiting the river during the spring (March – May), and then were primarily found in Muskegon Lake or outside the Muskegon system for the rest of the year. The habitat connection between

Muskegon River, Muskegon Lake, and Lake Michigan provides a complex area for walleye to move among. Protection of this connectivity for walleye to carry out their life cycle is critical to sustain a walleye population in the Muskegon system. Knowledge of walleye movement in this system can also aid fisheries managers in understanding natural walleye population estimates. Estimates during the spring include walleye from Muskegon Lake and Lake Michigan, whereas studies during the summer and winter focus on the Muskegon system population.

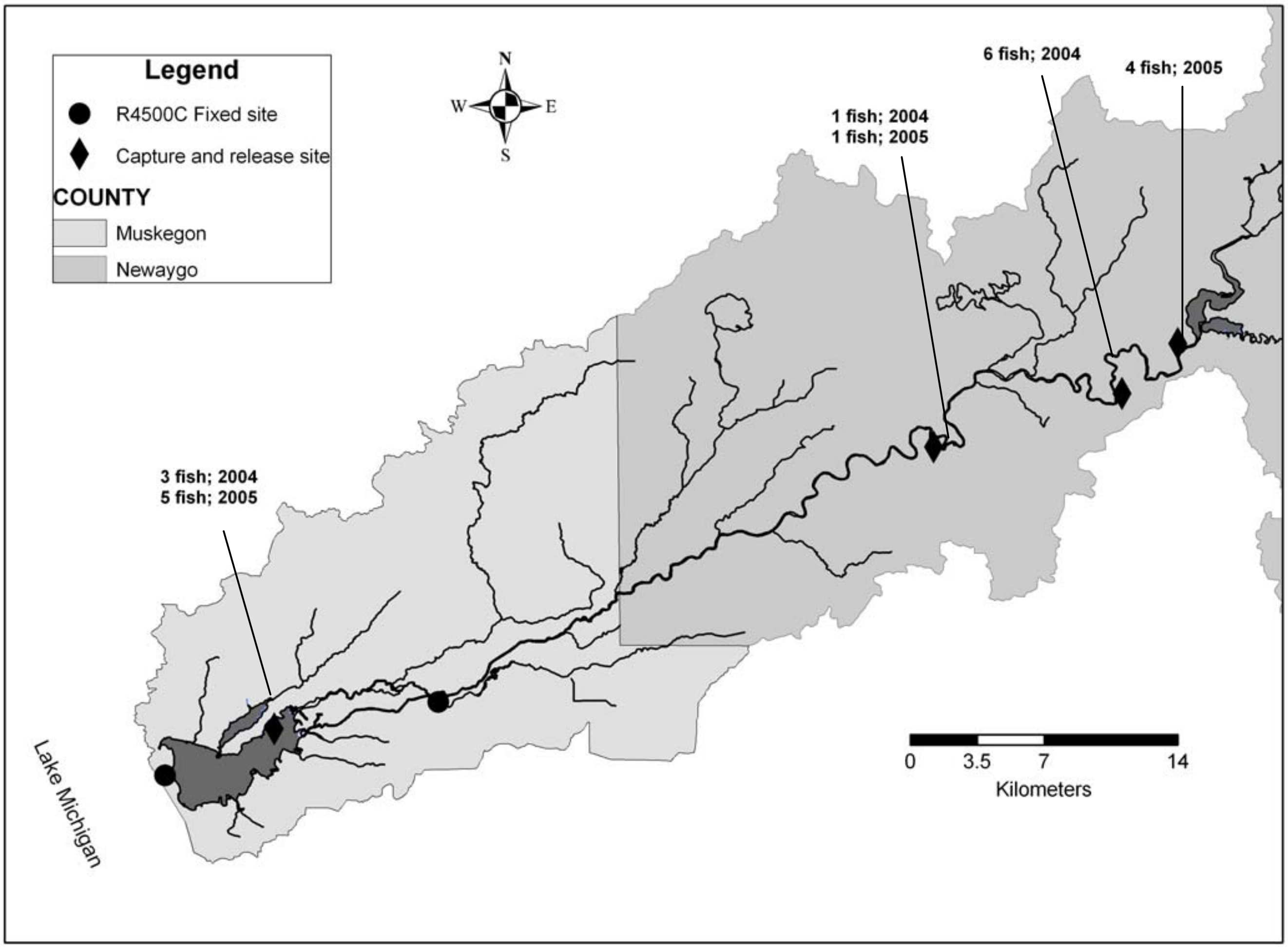

FIGURE 1. Map of Muskegon River Watershed from Croton Dam to Lake Michigan, showing sites of walleye release and locations of fixed receivers.

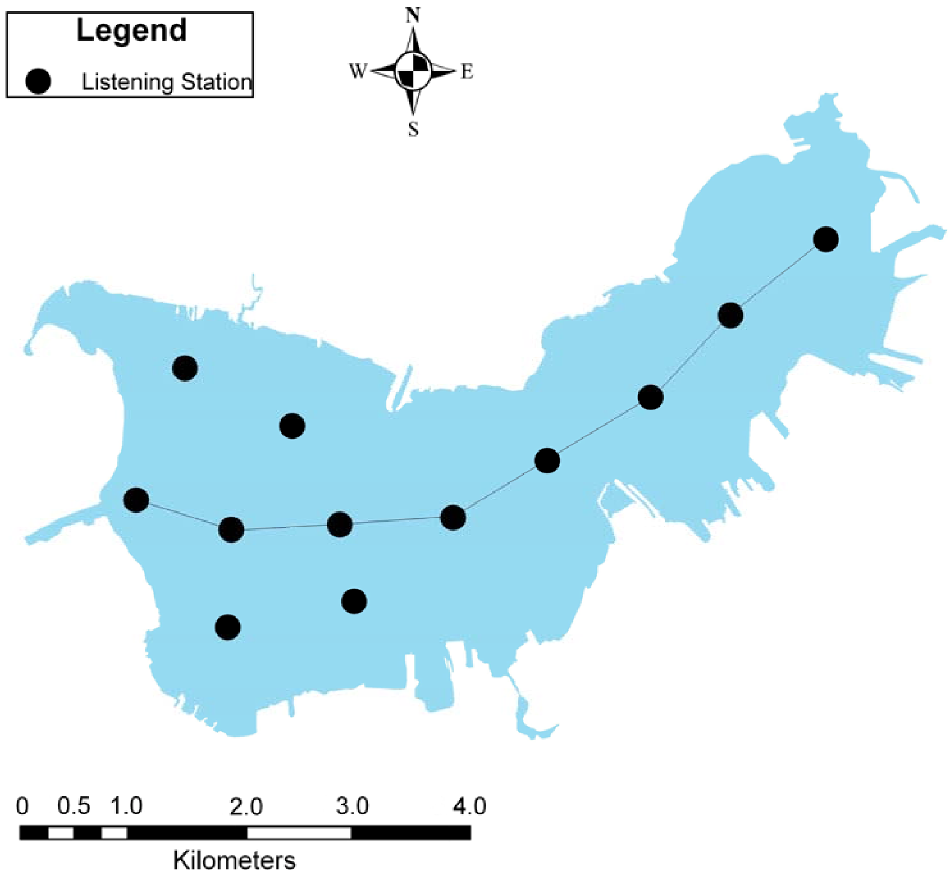

FIGURE 2. Map of Muskegon Lake showing telemetry listening stations used in 2004 and 2005. The main east to west transect is shown by the solid line, with four additional listening stations north and south of the line.

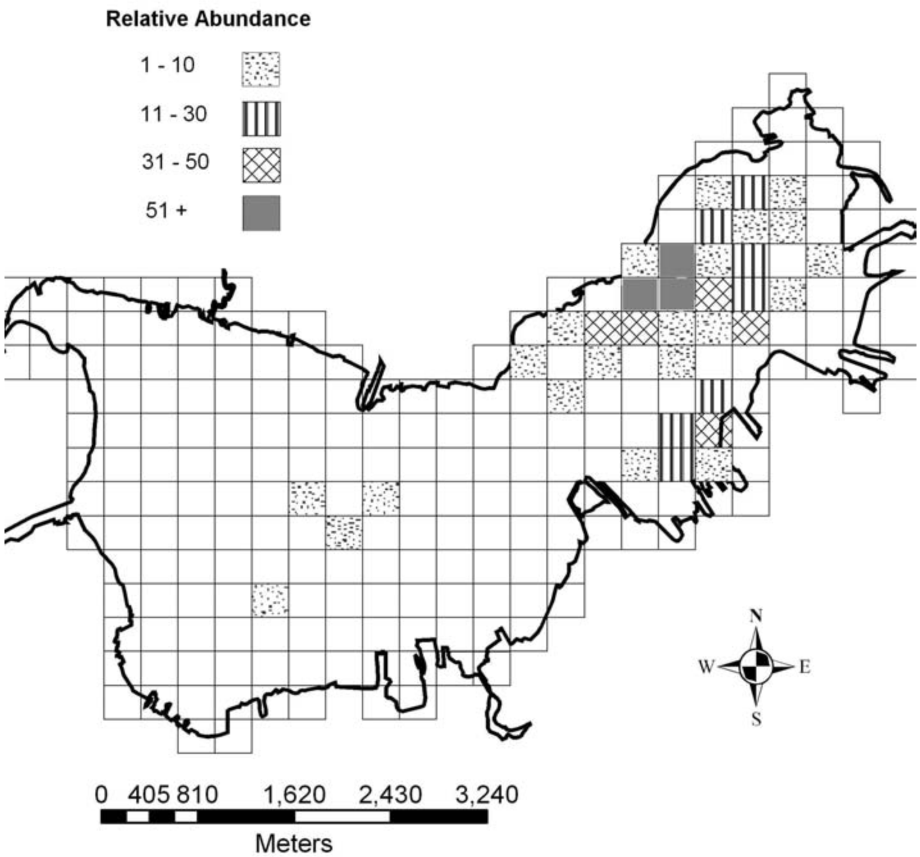

FIGURE 3. Map of Muskegon Lake showing cells (300 x 300 m) with differing relative abundances (number of walleye / summer period) of tagged walleye locations during summer 2004 and 2005.

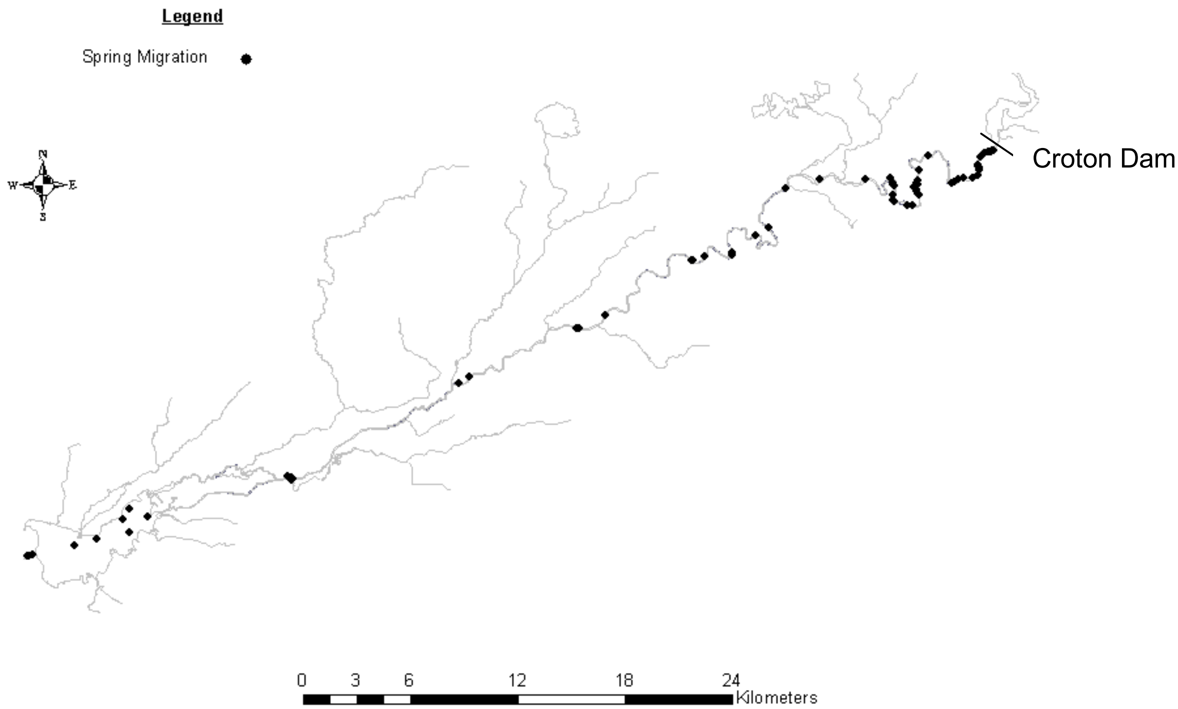

FIGURE 4. Map of Muskegon River showing all locations of radio tagged walleye during March – May for 2004 and 2005. Note the concentration of fish just below Croton Dam.

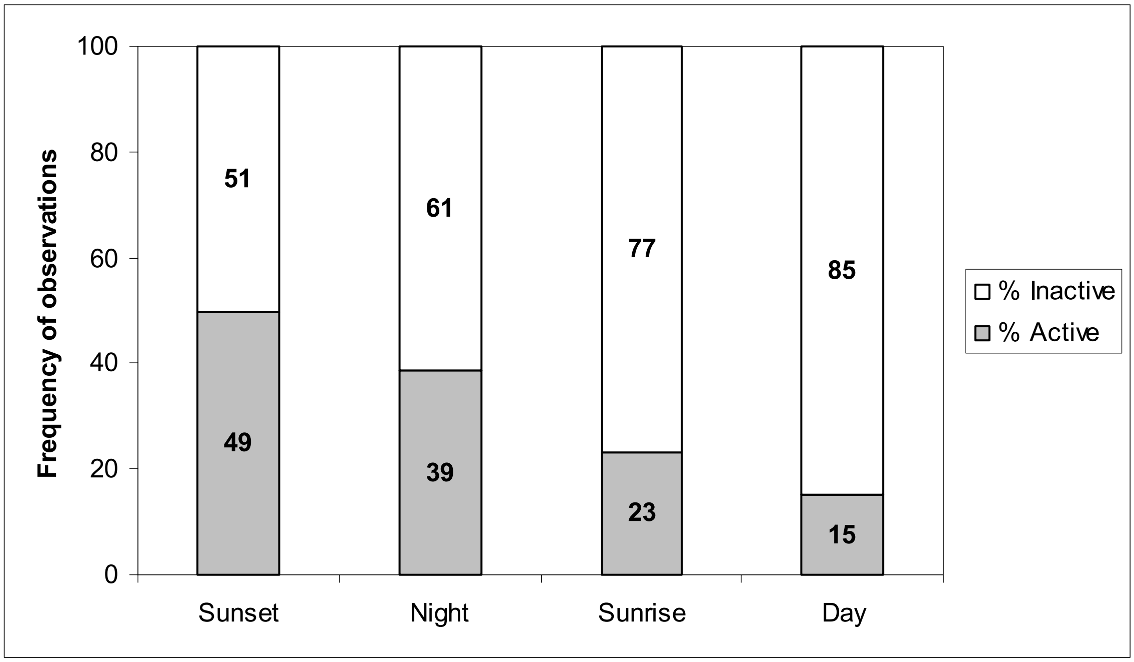

FIGURE 5. The percent of active and inactive intervals for walleye from Muskegon Lake during four diel periods. Data for three fish during June-August, n=371 five minute intervals.

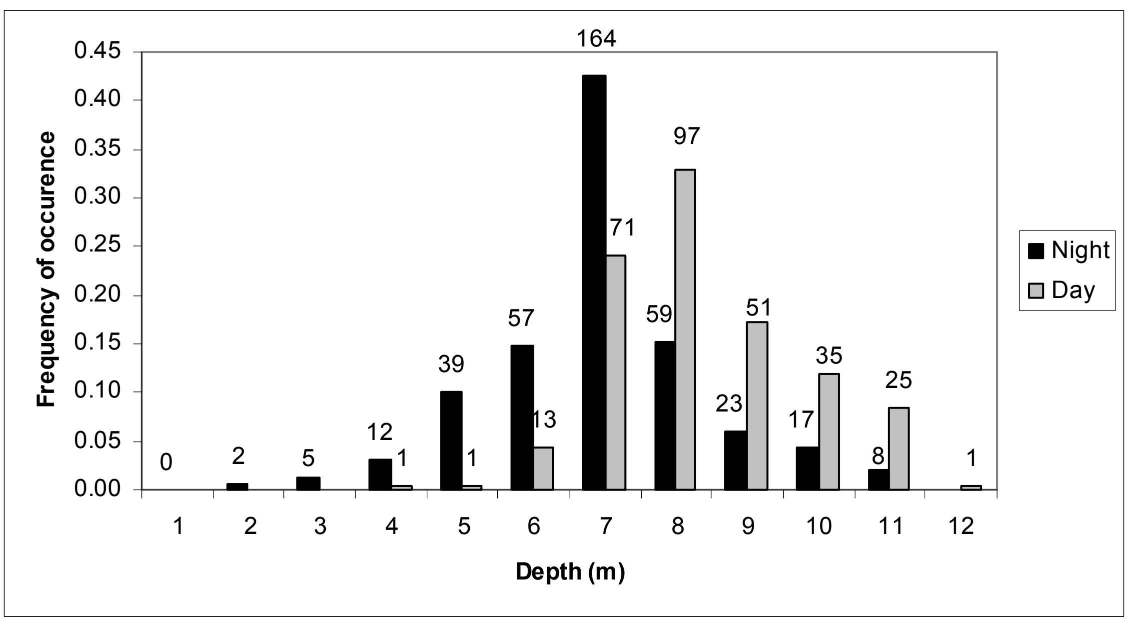

FIGURE 6. Relative frequency of walleye locations at various depths in Muskegon Lake at night and during the day. Values above bars represent number of fish observations.

TABLE 1. Summary information on walleye tracked in Muskegon Lake and Muskegon River. Down arrow indicates movement from river to Muskegon Lake, up arrow indicates movement from Muskegon Lake to river, hollow circle indicates fish leaving the Muskegon system, and solid circle indicates fish returning to Muskegon Lake from outside the system. Approximate time of movement is in parentheses.

Fish Number	Sex	Total Length (mm)	Weight (gm)	Age (years)	Tag Type	Location Implanted	Date Implanted	Movement Between River and Lake	Date Last Located	Last Recorded Location	Number of Days Located
1	M	581	1864	6	Radio	River	4/29/04	↓ (May 04), ↑ (Mar 05), ↓ (May 05)	5/19/05	Lake	12
2	M	575	1846	6	Radio	River	4/29/04	↓ (May 04), ↑ (Mar 05), ↓ (May 05)	6/15/05	Lake	22
3	M	525	1374	5	Radio	River	4/29/04	↓ (Jun 04), ↑ (Mar 05), ↓ (Apr 05)	4/27/05	Lake	14
4	M	520	1240	5	Radio	River	4/29/04	↓ (May 04), ○ (May 04), ● (Dec 04) ↑(Mar 05), ↓ (Apr 05)	5/16/05	Lake Fixed Site	10
5	?	401	2100	4	Radio	River	6/25/04	Stayed in river	8/3/05	River	41
6	?	568	2500	6	Radio	River	6/25/04	↓ (Sep 04), ↑(Mar 05)	8/3/05	River	56
7 [1]	?	645	2800	7	Radio	River	7/14/04	↓ (Nov 04)	11/30/04	Lake	14
8	?	570	2000	6	Radio	Lake	7/5/04	↑ (Mar 05), ↓ (Apr 05)	4/11/05	Lake	5
9	?	698	2700	8	Radio	Lake	7/5/04	↑ (Mar 05), ↓ (May 05)	5/26/05	Lake	7
10 [2]	?	645	2800	8	Radio	Lake	7/5/04	Stayed in lake	12/18/04	Lake	5
11	F	710	5400	8	Radio	River	4/5/05	↓ (Apr 05)	4/20/05	Lake	11
12	F	725	6000	8	Radio	River	4/5/05	↓ (Apr 05), ○ (Apr 05)	4/23/05	Lake Fixed Site	13
13	F	631	4400	7	Radio	River	4/5/05	↓ (Apr 05)	4/11/05	Lake	3
14	F	673	5300	8	Radio	River	4/5/05	↓ (Apr 05)	7/20/05	Lake	16
15	?	534	1600	5	Radio	River	6/7/05	↓ (Jun 05)	6/10/05	Lake	5
16	?	660	2700	8	Ultrasonic	Lake	5/31/05		8/1/05	Lake	17
17	?	670	2650	8	Ultrasonic	Lake	5/31/05		6/22/05	Lake	4
18	?	681	3150	8	Ultrasonic	Lake	5/31/05		8/2/05	Lake	23
19	?	487	1100	4	Ultrasonic	Lake	7/6/05		8/1/05	Lake	10
20	?	580	2100	6	Ultrasonic	Lake	7/6/05		8/2/05	Lake	12

[1] Angler captured on November 30, 2004
[2] Angler captured on December 18, 2004

TABLE 2. Summary of combined catch-per-effort data for 2004 and 2005 from Muskegon River. Table includes sampling duration, total number of walleye captured, and catch-per-effort (CPE).

Date	Sampling Time (h)	Number of Fish	CPE
May	7.38	48	6.50
June	9.35	28	2.99
July	5.92	10	1.69

Literature Cited

Clapp, D. F., R.D. Clark, and J. S. Diana. 1990. Range, activity, and habitat of large, free-ranging brown trout in a Michigan stream. Transactions of the American Fisheries Society 119:1022-1034.

Crowe, W. R. 1962. Homing behavior in walleyes. Transactions of the American Fisheries Society 91:350-354.

DePhilip, M. M., J. S. Diana, and D. Smith. 2005. Movement of walleye in an impounded reach of the Au Sable River, Michigan. Environmental Biology of Fishes 72:455-463.

Diana, C.M. 2006. Prey utilization and somatic growth of walleye *Sander vitreus* in the Muskegon River and Muskegon Lake, Michigan. Master's Thesis. University of Michigan, Ann Arbor.

Diana, J. S., J.P. Hudson, and R.D. Clark, Jr. 2003. Movement patterns of large brown trout in the mainstream Au Sable River, Michigan. Transactions of the American Fisheries Society 133: 34-44.

Environmental Protection Agency (EPA). 2004. Muskegon Lake area of concern. http://www.epa.gov/glnpo/aoc/msklake.html. March 2006.

Eschmeyer, P. H. 1950. The life history of the walleye, *Stizostedion vitreum vitreum*, in Michigan. Michigan Department of Conservation Bulletin No. 3, Institute of Fisheries Research, Ann Arbor.

Eschmeyer, P. H. and W. R. Crowe. 1955. The movement and recovery of tagged walleyes in Michigan, 1929-1953. Michigan Department of Conservation Miscellaneous Publication No. 8, Ann Arbor.

Holt, C. S., G. S. Grant, G. P. Oberstar, C. O. Oakes, and D. W. Bradt. 1977. Movement of walleye (*Stizostedion vitreum*), in Lake Bemidji, Minnesota as determined by radio-biotelemetry. Transactions of the American Fisheries Society 106:163-169.

Jennings, M. J., J. E. Claussen, and D. P. Philipp. 1996. Evidence of heritable preferences for spawning habitat between two walleye populations. Transactions of the American Fisheries Society 125: 978-982.

Kitchell, J.F., M.G. Johnson, C.K. Minns, K.H. Loftus, L. Greig, and C.H. Oliver. 1977. Percid habitat: the river analogy. Journal of the Fisheries Research Board of Canada 34:1936-1940.

Moore, J. W., and I.A. Moore. 1976. The basis of food selection in flounders, *Platichthys flesus*, in the Severn Estuary. Journal of Fish Biology 9:139-156.

Ovidio, M., E. Baras, D. Goffaux, F. Giroux, and J. C. Philippart. 2002. Seasonal variations of activity pattern of brown trout (*Salmo trutta*) in a small stream, as determined by radiotelemetry. Hydrobiologia 470:195-202.

Palmer, G.C., B.R. Murphy, and E.M. Hallerman. 2005. Movements of walleyes in Claytor Lake and the Upper New River, Virginia, indicate distinct lake and river populations. North American Journal of Fisheries Management 25:1448-1455.

Paragamian, V. L. 1989. Seasonal habitat use by walleye in a warmwater river system, as determined by radiotelemetry. North American Journal of Fisheries Management 9:392-401.

Pitlo, J., Jr. 1984. Wing and closing dam investigations. Iowa Conservation Commission, Federal Aid in Fish Restoration, Completion Report F-96-R, Des Moines.

Rasmussen, P. W., D. M. Heisey, S. J. Gilbert, R. M. King, and S. W. Hewett. 2002. Estimating postspawning movement of walleyes among interconnected lakes of Northern Wisconsin. Transactions of the American Fisheries Society 131: 1020-1032.

Rawson, D. S. 1957. The life history and ecology of the yellow walleye, *Stizostedion vitreum*, in Lac LaRonge, Saskatchewan. Transactions of the American Fisheries Society 86: 15-37.

Richkus, W. A. 1974. Factors influencing the seasonal and daily patterns of alewife (*Alosa pseudoharengus*) migration in a Rhode Island river. Journal of the Fisheries Research Board of Canada 31:1485-1497.

Richkus, W. A. and H. E. Winn. 1979. Activity cycles of adult and juvenile alewives, Alosa pseudoharengus, recorded by two methods. Transactions of the American Fisheries Society 108:358-365.

Ross, M. J. and C. F. Kleiner. 1982. Shielded-needle technique for surgically implanting radio frequency transmitters in fish. Progressive Fish Culturist 44:41-43.

Ryder, R. A. 1977. Effects of ambient light variations on behavior of yearling, subadult, and adult walleye (*Stizostedion v. vitreum*). Journal of the Fisheries Research Board of Canada 34:1481-1491.

Schweigert, J. F., and C. J. Schwarz. 1993. Estimating migration rates for Pacific herring (*Clupea pallasi*) using tag-recovery data. Canadian Journal of Fisheries and Aquatic Sciences 50:1530-1540.

SPSS Inc. 2000. SYSTAT for Windows 10. Chicago, Illinois.