FACTORS REGULATING RESERVOIR WALLEYE POPULATIONS

BY

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CHAPTER 1: NATURAL MORTALITY, EXPLOITATION, AND ESCAPEMENT OF RESERVOIR WALLEYE

Introduction

Knowledge of factors that influence population dynamics in fisheries is critical to effectively conserve and manage populations (Allen and Hightower 2010; Isermann and Paukert 2010). Abundance and biomass of fish populations are regulated by three dynamic rates: recruitment, growth, and mortality (Allen and Hightower 2010). These rates are considered density dependent if they are affected by the number of individuals in the population (Rose et al. 2001). Density-dependence can affect how populations respond to exploitation depending on the contribution of harvest to overall mortality (Allen et al. 1998; Pierce et al. 2015). Mortality is often the dynamic rate of interest in fisheries because it can be more easily estimated than recruitment and growth. Mortality can be broken into two parts: harvest mortality and natural mortality. Restrictions on harvest are thought to reduce total mortality because of the potential additive nature of harvest and natural mortality (Allen et al. 1998). However, the compensatory mortality hypothesis suggests that total mortality will not change under low to moderate levels of harvest because of lowered natural mortality levels of the fish population due to reduced effects of density-dependent mortality processes on the population (Anderson and Burnham 1976; Bartmann et al. 1992). Mortality has shown to have both additive and compensatory properties depending on population densities (Allen et al. 1998; Wilde 1998; Weber et al. 2016). As such, harvest rates may not affect overall mortality or population abundance.

While mortality from angler harvest and natural death are the main drivers of the loss of individuals from populations, population dynamics may also be altered to due emigration of individuals. In riverine systems, emigration is common, as mobile species move along stretches of rivers in response to behavioral cues or in search of more suitable habitat (McMahon and Matter 2006). These changes in population due to emigrating individuals can alter and even negate the effects of management and stocking strategies employed by fisheries managers (Pracheil et al. 2015). This is especially of concern as damming of rivers becomes more common and habitats become more fragmented. For example, species such as Paddlefish *Polyodon spathula* and White Sturgeon *Acipenser transmontanus* make long distance movements through dammed systems on the Missouri and Mississippi rivers (Jager et al. 2001; Pracheil et al. 2015; Simcox et al. 2015). However, even in these fragmented systems, fish passage devices improve connectivity above and below the dam and allow fish to re-enter the upstream population (Roscoe and Hinch 2010; Noonan et al. 2011).

Although emigration in riverine systems is common, emigration can also occur in systems that usually have no connectivity such as reservoirs. When rivers are dammed to create reservoirs, emigration can occur when non-migratory fishes escape over or through the downstream dam. Escapement of sportfishes from reservoirs can alter populations and negatively affect angling satisfaction (Stober et al. 1983; Rischbieter 1998; Paller et al. 2006). Fish populations may also be affected by the escapement of prey fish from the reservoir. For example, Rainbow Smelt *Osmerus mordax* were found to be escaping through the Oahe Dam on the Missouri River that significantly affected the diet composition and growth of Walleye *Sander vitreus* (Fincel et al. 2014, 2016). Another concern of reservoir escapement is the downstream introduction of nonnative species that had been previously contained to the reservoir system. Nonnative fishes are commonly stocked into reservoir systems (Rahel 2000; Eby 2006) and are susceptible to downstream escapement from the reservoir. This poses a problem for fisheries managers because nonnative fishes have shown to drastically alter the composition of the native fish populations in the tailrace (Martinez et al. 1994; Schultz et al. 2003; Spoelstra et al. 2008) as well as create challenges for managing reservoir sportfish populations (Weber et al. 2013; Weber and Flammang 2019).

Walleye are one of the most important fish species in North America. They serve as top piscivorous predators in aquatic systems and also support valuable important recreational and commercial fisheries (Colby et al. 1979; Carlander 1997). The native range of Walleye covers natural lakes and rivers in the central United States and Canada (Billington et al. 2011). However, due to its popularity as a sportfish, Walleye have been introduced into reservoirs across North America (Rahel 2000; Eby 2006). In the Midwestern United States, stocking of reservoir Walleye is common and well-documented (see Ellison and Franzin 1992 for overview of stocking evaluation). In such studies, Walleye population density is often determined by natural recruitment and survival of the stocked individuals. This is especially important in systems with no natural reproduction, where the entire population is dependent on the survival of stocked individuals (Mitzner 2002). However, recent studies have shown that emigration may also be a determining factor in reservoir Walleye population densities (Weber et al. 2013; Weber and Flammang 2019). Unlike natural systems where individuals may emigrate and return to the population, reservoir emigration is permanent. As such, emigration from reservoirs may be interpreted as another form of mortality directly affecting Walleye population densities. For example Weber et al. (2013) found that 25% of the Walleye population emigrated out of Rathbun Lake, Iowa during a two-year period. This artificial mortality may have compounding effects to harvest and natural mortality, especially in highly exploited systems where compensatory mortality is not controlled by density-dependent processes.

Although studies have evaluated Walleye survival and escapement from Rathbun Lake using tailrace (Weber et al. 2013) and in-lake (Weber and Flammang 2019) data, a comprehensive study combining both components to more precisely document fine-scale temporal escapement in relation to environmental conditions is lacking. As such, we have developed a combined acoustic telemetry and tag return design to study Walleye both in the lake and in the tailrace. Telemetry studies are common for estimating mortality and emigration of fishes (Hightower et al. 2001; Perry et al. 2010; Skalski et al. 2014; Kerns et al. 2016). Our specific objectives are to 1) determine harvest mortality, natural mortality, and escapement rates of adult Walleye in Rathbun Lake, 2) determine environmental (e.g., season, temperature, flow) and anthropocentric (e.g., harvest) factors that may be influencing these rates, and 3) compare mortality and escapement rates to determine which factor may be more limiting to Rathbun Lake Walleye populations. This comprehensive approach will allow us to provide insight into factors regulating reservoir fish populations and the possible effects of exploitation, downstream escapement, and evidence of compensatory or additive mortality from density-dependent forces exhibited by the population.

Methods

Study Area.—Rathbun Lake is a 4,672-ha reservoir located in Appanoose, Lucas, Monroe, and Wayne counties in south-central Iowa. Rathbun Lake is part of the Chariton River basin that spans 5,980 km^2 between Iowa and Missouri, with 1,422 km^2 comprising the Rathbun Lake watershed. This results in a 29:1 ratio of watershed area to lake surface area. Currently, the Rathbun Lake watershed is classified as 37.7% grassland, 36.9% row crop, and 13.8% forested timber (Ikenberry 2017). Rathbun Dam construction began in the 1960s and was operating as a flood control reservoir by 1970. The dam itself is an earth-filled embankment measuring over

3,230 m in length, with the top of the dam sitting over 30 m above the Chariton River downstream. Rathbun Lake has a bottom-draw outlet with 3.7-m x 1.8-m wide gates to control discharge. Normal operational discharge varies between less than 1 to 34 m^3/s. However, maximum allowable discharge for the reservoir is 142 m^3/s. At conservation pool (mean sea elevation of 275 m), the mean depth of the lake is 5.3 m and the maximum depth is 44.2 meters. There are 190 km of shoreline, with a fairly irregular shape; however, there has been a recent loss of irregularity and embayments due to shoreline erosion. Currently, the shoreline development index is 1.4 (Ikenberry 2017). While the lake serves mainly as a flood control reservoir, it also provides many recreational opportunities and greatly benefits the local and regional economy. The lake is also one of the main sources of Walleye broodstock used by the Iowa Department of Natural Resources (IDNR) for stocking fish throughout Iowa and is home to the Rathbun Fish Hatchery. Walleye in Rathbun Lake experience no natural reproduction and are sustained only through the stocking of fry and advanced fingerling raised in the Rathbun Hatchery (Mitzner 2002). The main threats to the lake are sedimentation and excess phosphorus, as run-off from agricultural practices flow into the lake via the Chariton River.

Receiver Deployment.—Forty-two VEMCO acoustic receivers were deployed throughout Rathbun Lake and in the tailrace in March 2019. Prior to deployment, acoustic range testing was completed on Rathbun Lake to determine optimal distance between receivers. Based on range testing results, receivers could process acoustic transmissions reliably at a 600 m radius. Thirty receivers were placed in a grid pattern approximately 1200 m apart to minimize receiver overlap and maximize coverage across the entire lake (Figure 1). Two additional receivers were placed in the Chariton River below Rathbun Dam. The first was placed 70 m downstream of the outlet and the second 775 m downstream of the outlet. The remaining 10 receivers were placed in a tight grid pattern in close proximity to the dam intake tower to monitor individual fish movement and behavior patterns as another part of the study. All receivers were variants of the VEMCO VR2 product line (VR2W, VR2Tx, VR2AR) and all operate at the 69 kHz frequency level. Receivers were housed in large metal stands to ensure proper orientation and no movement of receivers during the study period. Each receiver was bolted into the metal stand and an ONSET HOBO Pendant Temperature Logger was attached to stands with receivers that could not log temperature internally. A large concrete block was attached to each metal stand with 18 to 30-m braided nylon rope depending on deployment depth for retrieval purposes. Each receiver stand was deployed at its corresponding GPS coordinates using a rope to gently lower the stand to the lake bottom. The concrete block was then placed due north of the stand 18 to 30 m away depending on water depth and rope length.

Receiver monitoring and retrieval.—Receivers will be retrieved approximately every six months to download acoustic transmission data and perform routine maintenance. During each retrieval event, we will approach the receiver’s GPS coordinates by boat and place a weighted buoy at the GPS coordinates to ensure the receiver is re-deployed in the correct location. Using the GPS coordinates of the receiver and concrete block, we will deploy a metal grappling hook to snag the rope connecting the receiver and block. Once the rope is snagged, the concrete block will be lifted to the surface. The attached rope will be connected to an onboard pulley and winch system that will then raise the metal receiver base out of the water. Once out of the water, receiver transmission and temperature logger data will be downloaded to a laptop computer, and batteries in the receiver and temperature loggers will be replaced as necessary. Each base will then be re-deployed at the original GPS coordinates using the original deployment techniques. Additional monitoring of fish and receivers will be periodically collected with a VEMCO VR100 active tracking receiver. Using the VHTx-69k omnidirectional Transponding Hydrophone, we will be able to locate fish throughout the lake and in the tailrace via their acoustic tags. We will also be able to check the health of our VR2Tx receivers, receiving information such as battery life, number of acoustic transmissions, as well as the tag ID number of the acoustic transmissions.

Fish collection.—Walleye were collected during the first two weeks of April 2019 during nighttime broodstock gill netting collection by Iowa DNR biologists. Gill nets were set for 4-h intervals using a bottom-set technique, with multifilament nylon nets (30.5 m long x 1.8 m deep; 64-mm bar mesh). Because of the large bar mesh used, catch was limited to individuals >432 mm. Walleye were collected from two locations where they are known to spawn, down-lake by the dam and up-lake at the Bridgeview recreation area. After capture, all Walleye were taken to the Rathbun Fish Hatchery where they were artificially spawned and held in raceways for one to two days before tagging. Walleye were sorted into four groups in the raceways based on size, sex, and collection location. Thirty Walleye were collected from near Rathbun Dam, comprised of 15 males and 15 females. Similarly, 30 Walleye were collected from the Bridgeview recreation area, comprised of 15 males and 15 females. Each of the four groups were comprised of five fish between 381-457 mm total length and 10 fish >482 mm total length.

Fish tagging.—A total of 60 Walleye were initially implanted with VEMCO V13P-1L or V16P-4L coded pressure-sensing acoustic transmitters. Additional Walleye will be implanted with acoustic transmitters in subsequent years as fish are lost to escapement and mortality. Transmitters were implanted into the coelomic cavity via surgery. Walleye were measured for total length (mm) and wet weight (g), placed into a surgery cradle, and anesthetized with electroanesthesia (TENS 7000 unit). Electrodes were placed inside cotton gloves, with the anesthetizer wearing rubber gloves underneath to prevent minor electrocution. The anesthetizer would then hold the fish secure against the surgery cradle, applying electricity to the fish. This process caused electro-paralysis of the fish, allowing for the surgery process to commence with little to no fish movement. A tube was inserted into the mouth of the fish and water was pumped over the gills to provide sufficient oxygen to the fish during surgery. An approximately 25 mm incision was cut in the body cavity of the fish and the transmitter was placed inside the fish. The cavity of the fish was closed using 1-2 cruciate or single sutures with 2-0 monofilament absorbable suture. Fish were then individually identified with a Floy FT-4 cinch up tag to estimate harvest mortality. Tags were implanted through the dorsal musculature of each fish between the first and second dorsal fins. Fish were also implanted with stainless steel jaw tags as another form of external identification. Finally, all individuals were implanted with a Passive Integrated Transponder (PIT) tag in the dorsal musculature near the operculum. Surgeries and external tagging procedures were completed in approximately 6-8 minutes and fish were returned to the raceways post-surgery for recovery. Fish were held in the raceways seven days to ensure no post-surgery mortality. After seven days, fish were returned to Rathbun Lake and released according to their collection location. Fish collected in gill nets near Rathbun dam were released at Buck Creek Marina, while fish collected from the Bridgeview recreation area were released further up-lake in the South Fork arm of the Chariton River (Figure 1).

Data analysis.—Raw data downloaded from the acoustic receivers will be analyzed using the VEMCO VUE software platform. VUE software creates database files for each receiver and displays all detections and other information collected during the study period. VUE software also has the capability to correct for any time discrepancies among receivers, analyze for false or incorrect animal detections, and filter repeat or unneeded entries. Once the database files have been analyzed in VUE, they can be exported in spreadsheet format for use in other analyses. We will fully analyze data in VUE to ensure that all data are correct and correspond to the correct individuals (i.e., only adult Walleye).

We used a field study design relying on fixed acoustic receivers and external tag returns to determine the fate of individuals described by Hightower and Harris (2017). This study design allows us to estimate survival and separate total loss (Z) into three components: harvest mortality (F), natural mortality (M), and emigration (E). In this design, the fixed acoustic receiver array will detect individuals to inform models about survival and emigration. Likewise, the external high reward tags will be used to inform models about harvest mortality. One hundred percent tag reporting is necessary in modeling situations to accurately estimate fishing mortality. Pollock et al. (2001) found that rewards >$50 were sufficient to obtain a 100% tag return rate. In this study, we chose $200 high reward external tags to ensure total tag reporting by anglers. To analyze the components of F, M, and E, we will use a multistate capture-recapture model using state-space likelihood (Kery and Schaub 2012) similar to methods used by Scheffel et al. (2019). Using this approach, we will be able to determine monthly survival and relocation probabilities by analyzing the probabilities of Walleye remaining or transitioning states (s) from one sampling time period (t) to the next (t+1). In this model, there will be four possible states for Walleye to occupy: 1) survival, 2) harvest, 3) emigration, or 4) natural death. We assume all individuals are alive (s=1) at the beginning of the study, and that the estimated true state of individuals is dependent on the true state of the individuals in the previous month. This ensures impossible transition probabilities are not estimated. Walleye cannot transition from mortality to survival and cannot transition from the emigrated state because escaped individuals cannot re-enter the lake. Similar to the true state of Walleye individuals, there are four observed states that Walleye can occupy: 1) detected alive (true state = alive), 2) reported harvest (true state = harvest), 3) detected or assigned emigrant (true state = emigrated), or 4) not detected (possible true states = alive, harvested, natural death). Due to the assumptions of the multi-state model framework, harvest as a true state is only possible for observed non-detections, if the individual lost external tags, because we assume 100% reporting rate for harvested fish. Other assumptions include: 1) all initially marked fish have the same probability of being detected, 2) all marked fish have equal probability of surviving to the next sampling period, 3) transmitter failure is negligible, 4) marked and unmarked fish have equal survival rates, 5) fate of marked individuals is independent from each other, and 6) emigrating fish are detected with a 1.00 probability.

Determination of observed states will be based on our study design methods. Individuals will be considered alive if they are detected within the in-lake telemetry receiver array. Because natural death is an unobserved state in the model, a dead Walleye may still appear as an unmoving detection in the receiver array. To combat this issue, Walleye that are consistently recorded on the same receiver for several months will be assumed naturally dead. Additionally, investigation with the VR100 active tracking device will allow us to better estimate the survival of a non-moving individual. An individual will be classified as harvested with the verified return of external reward and acoustic transmitting tags. We assume that the reporting rate for harvests is 100% and we assume that the presence of the external tag will not influence on whether the fish is harvested or released. Individuals will be considered emigrated if they are detected on the receivers in the tailrace.

Estimates of F, M, and E and detection probability (p) will be calculated using multi-state capture-recapture models. The models will be fit in a Bayesian framework using OpenBUGS software (Lunn et al. 2009). Uninformative uniform prior distributions will be used for the natural logs of F, M, and E, and posterior distributions will be estimated using Markov chains of 10,000 samples, with the first 5,000 samples excluded to remove bias associated with initial parameters. Chain convergence will be determined by visually inspecting time-series plots of parameter values and calculation of the Brooks-Gelman Robin statistic. Models will provide parameter estimations for F, M, and E. In addition to base models, we will include multiple covariates to help explain F, M, and E rates. Walleye will be separated into groups based on sex, collection location, and size. These group effects will be run in models to determine differences in parameter estimation. We will also add environmental covariates such as water temperature and discharge into the models. These covariates will be measured at the same timestep intervals as the fish detections to maintain consistency. Combinations of covariates and groups will be turned into a set of candidate models. Once models are run, the candidate models will be ranked using lowest model deviance and top models will be selected.

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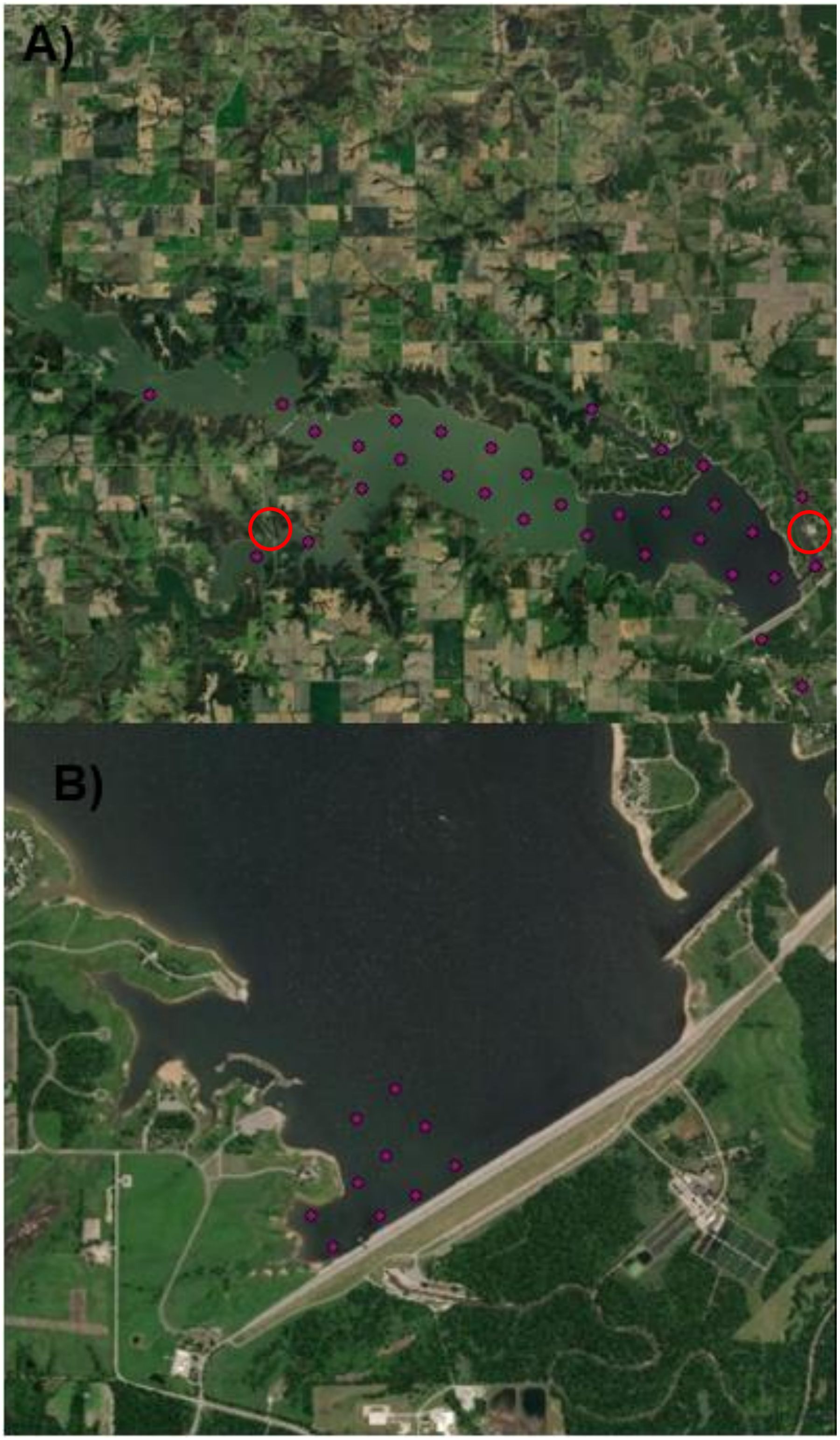

Figure 1. A) Map of acoustic receiver locations across Lake Rathbun. Receivers are denoted by purple dots. Walleye release locations are denoted by red circles B) Acoustic receiver locations of fine-scale VPS array near Rathbun Dam intake tower. Receivers are denoted by purple dots.

CHAPTER 2: SURVIVAL, MOVEMENT, AND ESCAPEMENT OF STOCKED FINGERLING WALLEYE

Introduction

Stocking of hatchery-raised fishes is a common practice across the United States (Lorenzen 2005). Species are often stocked to augment wild fish populations for restoration or recreational fishing purposes (Cowx 1994; Trushenski et al. 2010). Recreational fisheries can provide substantial economic benefits both locally and regionally (Garlock et al. 2019). However, management of recreational fisheries is important, as population declines can quickly lead to a loss of resources and associated benefits (Lewin et al. 2006). As such, survival of stocked fishes is critical so that populations can remain viable through recreational angling pressure. Survival of stocked fishes is highly variable, with both density-dependent and density-independent factors potentially affecting survival rates (Scharf 2000). Fishes are commonly stocked at the juvenile stage as fingerlings. Studies have demonstrated the effect of juvenile survival on the success of year-class strength (Bailey 1994; Campana 1996). Stocking of advanced stage juveniles may be especially effective, as these larger fish may bypass density-dependent mortality factors associated with recruitment (Garlock et al. 2019). However, success of juvenile stocking is not guaranteed to enhance overall population abundance (Scharf 2000; Porak et al. 2002).

One of the most commonly stocked fishes in North America is Walleye *Sander vitreus*. In their native range, Walleye inhabit natural lakes and rivers in the central United States and Canada (Billington et al. 2011). However, Walleye have been introduced into reservoirs across North America as they are an extremely prized sportfish (Rahel 2000; Eby 2006). Recent habitat changes have altered the reproductive capability of Walleye populations, as reservoirs have begun to mature and natural lakes have been altered by human activities, becoming less suitable for Walleye reproduction (Ellison and Franzin 1992; Mitzner 2002). With its highly regarded sportfish status and lack of natural reproduction, Walleye stocking is necessary to maintain harvestable populations (Santucci and Wahl 1993; Nate et al. 2003; Kerr 2011). In 2004, over 1 billion Walleye were stocked, making up almost 60% of the total number of fishes stocked across the United States (Halverson 2008). Stocking success of Walleye is variable, with examples of both successful and unsuccessful advanced stage juvenile stockings (Fielder 1992; McWilliams and Larscheid 1992; Santucci and Wahl 1993). In many cases, survival of stocked individuals is thought to determine overall year-class strength and ultimately drive population abundance. However, in addition to survival of individuals, loss of individuals through emigration may affect stocking success.

Emigration is common in riverine systems where species can move freely between habitats. Juvenile fishes in particular have been shown to emigrate throughout riverine systems. Fishes such as White Sturgeon *Acipenser transmontanus*, Pallid Sturgeon *Scaphirhynchus albus*, and Chinook Salmon *Oncorhynchus tshawytscha* can emigrate at the juvenile stage (Boysen and Hoover 2009; Hoover et al. 2011; Mussen et al. 2013). In addition to riverine systems, emigration of fishes from reservoirs is also possible. Reservoir emigration happens mainly through escapement of non-migratory fishes over or through the downstream dam. Native and introduced sportfish such as sunfishes *Lepomis* spp., Kokanee *Oncorhynchus nerka*, and Rainbow Trout *Oncorhynchus mykiss* have been documented escaping from reservoirs across the United States (Stober et al. 1983; Rischbieter 1998; Paller et al. 2006). Walleye is another sportfish that have been documented emigrating from reservoirs (Weber et al. 2013; Weber and Flammang 2019) and emigration has been indirectly associated with Walleye stocking success, recruitment, and population density (Willis and Stephen 1987). In connected riverine systems, emigration in not problematic as individuals can immigrate back into the population. However, this is not possible in reservoir systems after fish pass the downstream dam. In such cases, emigration may be interpreted as a form of fish loss and population mortality. This added population loss potential, combined with poor survival of stocked individuals, may be regulating reservoir Walleye population densities (Willis and Stephen 1987). For example, Weber et al. (2013) found that 25% of the Walleye population emigrated out of Rathbun Lake, Iowa during a two-year period. This artificial mortality combined with low survival of stocked individuals may have detrimental effects on Walleye populations, especially in systems with no natural reproduction.

While survival of individuals has thought to be the main driver of stocking success, behavior and movement patterns, especially through emigration, may also be important factors in determining the success of stocking programs. As such, we have developed an acoustic telemetry study to track survival and movement of age-0 advanced fingerling Walleye in Rathbun Lake, Iowa. Telemetry studies are common for estimating survival (Welch et al. 2009; Steig and Holbrook 2012; Faust et al. 2019) and movement patterns (Baldwin et al. 2002; Hayden et al. 2014; Brooks et al. 2019) of fishes. Our specific objectives are to determine movement, behavior, survival, and escapement rates of age-0 advanced fingerling Walleye in Rathbun Lake. Using this approach, we will be able to provide insight into the stocking success of Walleye at Rathbun Lake and provide fisheries managers the information to best use their expensive hatchery resources.

Methods

Study Area.—Rathbun Lake is a 4,672-ha reservoir located in Appanoose, Lucas, Monroe, and Wayne counties in south-central Iowa. Rathbun Lake is part of the Chariton River basin, which spans 5,980 km^2 between Iowa and Missouri, with 1,422 km^2 comprising the Rathbun Lake watershed. This results in a 29:1 ratio of watershed area to lake surface area. Currently, the Rathbun Lake watershed is classified as 37.7% grassland, 36.9% row crop, and 13.8% forested timber (Ikenberry 2017). Rathbun Dam construction began in the 1960s, and was operating as a flood control reservoir by 1970. The dam itself is an earth-filled embankment measuring over 3,230 m in length, with the top of the dam sitting over 30 m above the Chariton River downstream. Rathbun Lake has a bottom-draw outlet with 3.7-m x 1.8-m wide gates to control discharge. Normal operational discharge varies between less than 1 to 34 m^3/s. However, maximum allowable discharge for the reservoir is 142 m^3/s. At conservation pool (mean sea elevation of 275 m), the mean depth of the lake is 5.3 m and the maximum depth is 44.2 meters. There are 190 km of shoreline, with a fairly irregular shape; however, there has been a recent loss of irregularity and embayments due to shoreline erosion. Currently the shoreline development index = 1.4 (Ikenberry 2017). The lake is also one of the main sources of Walleye broodstock used by the Iowa Department of Natural Resources (DNR) for stocking fish throughout Iowa and is home to the Rathbun Fish Hatchery. Walleye in Rathbun Lake experience no natural reproduction and are sustained only through the stocking of fry and advanced fingerling raised in the Rathbun Hatchery.

Receiver Deployment.—Forty-two VEMCO acoustic receivers were deployed throughout Rathbun Lake and in the tailrace in March 2019. Prior to deployment, acoustic range testing was completed on Rathbun Lake to determine optimal distance between receivers. Based on range testing results, receivers could process high powered acoustic transmissions reliably at a 600 m radius; however, less powerful transmitters in juveniles will have a lower transmission range. We will conduct further range testing to determine the reliable transmission range of these lowered powered transmitters. Thirty receivers were placed in a grid pattern approximately 1200 m apart to minimize receiver overlap and maximize coverage across the entire lake. Two additional receivers were placed in the Chariton River below Rathbun Dam. The first was placed 70 m downstream of the outlet and the second 775 m downstream of the outlet. The remaining 10 receivers were placed in a tight grid pattern in close proximity to the dam intake tower to monitor individual fish movement and behavior patterns as another part of the study. All receivers were variants of the VEMCO VR2 product line (VR2W, VR2Tx, VR2AR) and all operate at the 69 kHz frequency level. Receivers were housed in large metal stands to ensure proper orientation and no movement of receivers during the study period. Each receiver was bolted into the metal stand and an ONSET HOBO Pendant Temperature Logger was attached to stands with receivers that could not log temperature internally. A large concrete block was attached to each metal stand with 18 to 30-m braided nylon rope depending on deployment depth for retrieval purposes. Each receiver stand was deployed at its corresponding GPS coordinates using a rope to gently lower the stand to the lake bottom. The concrete block was then placed due north of the stand 18 to 30 m away depending on water depth and rope length.

Receiver monitoring and retrieval.—Receivers will be retrieved approximately every six months to download acoustic transmission data and perform routine maintenance. During each retrieval event, we will approach the receiver’s GPS coordinates by boat and place a weighted buoy at the GPS coordinates to ensure the receiver is re-deployed in the correct location. Using the GPS coordinates of the receiver and concrete block, we will deploy a metal grappling hook to snag the rope connecting the receiver and block. Once the rope is snagged, the concrete block will be lifted to the surface. The attached rope will be connected to an onboard pulley and winch system that will then raise the metal receiver base out of the water. Once out of the water, receiver transmission and temperature logger data will be downloaded to a laptop computer, and batteries in the receiver and temperature loggers will be replaced as necessary. Each base will then be re-deployed at the original GPS coordinates using the original deployment techniques. Additional monitoring of fish and receivers will be periodically collected with a VEMCO VR100 active tracking receiver. Using the VHTx-69k omnidirectional Transponding Hydrophone, we will be able to locate fish throughout the lake and in the tailrace via their acoustic tags. We will also be able to check the health of our VR2Tx receivers, receiving information such as battery life, number of acoustic transmissions, as well as the tag ID number of the acoustic transmissions.

Fish Tagging.—A total of 30 advanced fingerling Walleye will be implanted with VEMCO V7-4L coded acoustic transmitters. All Walleye will be hatchery raised to advanced fingerling size (~240 mm) over the summer and will be implanted with acoustic transmitters prior to autumn dispersal into the lake. Additional Walleye will be implanted with acoustic transmitters in the following year. Transmitters will be implanted into the body cavity via surgery. Surgeries will comprise of initial measurement of total length (mm) and wet weight (g). Fish will then be placed into a surgery cradle and anesthetized with electricity from a handheld TENS 7000 unit. Electrodes from the TENS unit will be placed inside cotton gloves, with the anesthetizer wearing rubber gloves underneath to prevent minor electrocution. The anesthetizer will then hold the fish secure against the surgery cradle, applying electricity to the fish. This process causes electro-paralysis of the fish, allowing for the surgery process to commence with little to no fish movement. A tube will be inserted into the mouth of the fish and water was pumped over the gills to provide sufficient oxygen to the fish during surgery. An approximately 1/2-inch incision will be cut in the body cavity of the fish and the transmitter will be implanted inside the fish. The cavity of the fish will closed using 1-2 cruciate or single sutures with 2-0 monofilament absorbable suture. Fish will also be implanted with a Passive Integrated Transponder (PIT) tag in the dorsal musculature near the operculum. Surgeries will be completed in approximately 4-5 minutes and fish will be returned to hatchery raceways post-surgery for recovery. Fish will be held in the raceways 3 to 5 days to ensure no post-surgery mortality. After the holding period, fish will be released into Rathbun Lake at the Buck Creek marina.

Data Analysis.—Raw data downloaded from the acoustic receivers will be analyzed using the VEMCO VUE software platform. VUE software creates database files for each receiver and displays all detections and other information collected during the study period. VUE software also has the capability to correct for any time discrepancies among receivers, analyze for false or incorrect animal detections, and filter repeat or unneeded entries. Once the database files have been analyzed in VUE, they can be easily exported in spreadsheet format for use in other analyses. We will fully analyze data in VUE to ensure that all data are correct and correspond to the correct individuals (i.e., only age-0 Walleye).

We used a field study design relying on fixed receiver acoustic telemetry to determine the fate of individuals, as described by Hightower and Harris (2017). This study design allows us to estimate survival and separate total loss (Z) into two components: natural mortality (M), and emigration (E). To analyze the components of M and E, we will use a multistate capture-recapture model using state-space likelihood (Kery and Schaub 2012; Scheffel et al. 2019), although multistate capture-recapture modeling could also be done using program MARK

(White and Burnham 1999) similar to methods described in Weber et al. (2013) and Weber and Flammang (2019). Using a state-space approach, we will be able to determine monthly survival and relocation probabilities by analyzing the probabilities of Walleye remaining or transitioning states (s) from one sampling time period (t) to the next (t+1). In this model, there will be three possible states for age-0 Walleye to occupy: 1) survival, 2) emigration, or 3) natural death. We assume all individuals are alive (s=1) at the beginning of the study, and that the estimated true state of individuals is dependent on the true state of the individuals in the previous month. This ensures impossible transition probabilities are not estimated. Walleye cannot transition from mortality to survival, and cannot transition from the emigrated state because escaped individuals cannot re-enter the lake. In addition to the true state of Walleye individuals, there are three observed states that Walleye can occupy: 1) detected alive (true state = alive), 2) detected or assigned emigrant (true state = emigrated), or 3) not detected (possible true states = alive, harvested, natural death). Our assumptions for this framework include: 1) all initially marked fish have the same probability of being detected, 2) all marked fish have equal probability of surviving to the next sampling period, 3) transmitter failure is negligible, 4) marked and unmarked fish have equal survival rates, 5) fate of marked individuals is independent from each other, and 6) emigrating fish are detected with a 1.00 probability.

Determination of observed states will be based on our study design methods. Individuals will be considered alive if they are detected within the in-lake telemetry receiver array. Because natural death is an unobserved state in the model, a dead Walleye may still appear as an unmoving detection in the receiver array. To combat this issue, Walleye that are consistently recorded on the same receiver for several months will be assumed naturally dead. Additionally, investigation with the VR100 active tracking device will allow us to better estimate the survival of a non-moving individual. We also assume that harvest of age-0 advanced fingerling Walleye is nonexistent and that non-detection within the array is due to natural mortality. Individuals will be considered emigrated, if they are detected on the receivers in the tailrace.

Estimates of M and E and detection probability (p) will be calculated using multistate capture-recapture models. The models will be fit in a Bayesian framework using OpenBUGS software (Lunn et al. 2009). Uninformative uniform prior distributions will be used for the natural logs of M and E, and posterior distributions will be estimated using Markov chains of 10,000 samples, with the first 5,000 samples excluded to remove bias associated with initial parameters. Chain convergence will be determined by visually inspecting time-series plots of parameter values and calculation of the Brooks-Gelman Robin statistic. Models will provide parameter estimations for M and E. In addition to base models, we will also add environmental covariates such as temperature and discharge into the models. These covariates will be measured at the same timestep intervals as the fish detections to maintain consistency. Combinations of covariates and will be turned into a set of candidate models. Once models are run, the candidate models will be ranked using lowest model deviance and top models will be selected.

In addition multi-state modeling for survival, we will also analyze movement trends of advanced fingerling Walleye. We will use detections from acoustic receivers to track individual movements around the lake. Using our detections, we can gain a coarse approximation of exact location for movement and behavior analyses. Fish locations will be entered and analyzed using ArcMap 10.5.1 software (ESRI, Redlands, CA). Movement of individual fish will be measured as the GPS coordinates of the receiver on which the individual was detected. These data will be used to calculate dispersal behavior and home range sizes of individuals. Home range sizes will be calculated using Home Range Tools extension in ArcGIS or Reproducible Home Ranges package statistical software program R (Signer and Balkenhol 2015; R Core Team 2018). Once home range sizes have been calculated, the data will be run through a multiple regression model. The multiple regression analysis will be used to determine if movement rates are affected by water temperature and discharge. Covariates that are significant at the $p = 0.05$ level will indicate that movement rates are dependent such factors. We will also determine seasonal movement patterns of Walleye using analysis of variance (ANOVA). For seasonal movement, home range size data will be separated into the four seasons: spring (March 1-May 31), summer (June 1-August 31), fall (September 1-November 30), and winter (December 1-February 28). ANOVA analysis in statistical software R will show significant differences at the 0.05 level among the four seasons.

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CHAPTER 3: MOVEMENT PATTERNS OF RESERVOIR WALLEYE

Introduction

Movement of fishes around their environment is necessary to meet their life history needs (Baldwin et al. 2002). These can be small-scale movements as fish chase prey or find suitable habitat, but can also be long-distance migrations as part of the fish's reproductive life cycle. Movement of fishes is well studied in riverine and lake systems, as fisheries managers use movement and behavior information to make management decisions. For example, Walleye *Sander vitreus* and Muskellunge *Esox masquinongy* movements have been studied in the Midwestern United States and in the Great Lakes to determine distinct geographic spawning populations and behavior, altering management and stocking strategies (Rasmussen et al. 2002; Weeks and Hansen 2009; Hayden et al. 2014; Brooks et al. 2019). However, movement of Walleye is not commonly studied in reservoir systems.

Reservoirs are complex systems that are common across North America. The main function of many reservoirs is to regulate and supply water to local communities, but irrigation, power generation, and recreation are also important functions (Allen et al. 2008). Reservoirs are also highly variable, with many different habitat types, water temperatures, and water levels. Given the complexity and variability of reservoir systems, a broad spectrum of fisheries management challenges exist, often with socioeconomic implications (Allen et al. 2008). For example, alterations in reservoir operation may alter the fishery, which can impact management strategies (Niemi and Raterman 2008). However, such operational alterations can be expensive and have social, economic, and legal repercussions (Jones 2008).

Rathbun Lake is a flood-control reservoir located in southcentral Iowa, USA that supports an important Walleye fishery and serves as broodstock source for stocking operations across the entire state. Additionally, Walleye in Rathbun Lake do not naturally reproduce and are maintained only by stocking (Mitzner 2002). The Walleye population in Rathbun Lake has been declining in recent years, and studies have shown downstream escapement of Walleye through the bottom-draw control structure dam (Weber et al. 2013; Weber and Flammang 2019. As an artificial reservoir system, Walleye movement and behavior in Rathbun Lake may vary from natural systems, especially as the reservoir undergoes environmental fluctuations throughout the year as flood control operations are implemented.

In natural systems, Walleye is a wide-ranging species and have been documented making large movements across lakes (Eschmeyer 1950; Holt et al. 1977; Weeks and Hansen 2009). Movement is greatest before and after spawning activities in the spring (Holt et al. 1977; Rasmussen et al. 2002). While spawning movement can be large, Walleye may be sedentary most of the rest of the year (Forney 1963; Olson et al. 1978; Weeks and Hansen 2009). However, Walleye will make movements to forage for prey species or to find more favorable environmental conditions (Holt et al. 1977; Colby et al. 1979). Walleye naturally inhabit the bottoms of lakes and rivers with clean, hard substrate and cover consisting of boulders, submerged aquatic vegetation, trees, and logs (Holt et al. 1977; Kerr et al. 1997; Bozek et al. 2011). Walleye are light sensitive and as such, are more active in low light conditions, often increasing activity at dusk to feed and continue high activity throughout nighttime hours (Ryder 1977; Kelso 1978; Bozek et al. 2011).

While much is known about the general movement patterns and behavior of Walleye in natural systems, there is little knowledge on movement patterns and behavior of Walleye in reservoirs. As such, we have developed an acoustic telemetry study to monitor Walleye movement patterns and behavior in Rathbun Lake, Iowa. Movement and behavior may be different in an artificial system like Rathbun Lake where quality habitat is not available due to high sediment loads compared to natural systems. Spawning movement and behavior may also be altered in reservoir systems, as lack of spawning habitat and success is common in reservoirs. Changes is reservoir operation, especially discharge from flood control reservoirs, may cause acute changes in movement and behavior of Walleye. Given this wide potential of variability from natural systems, our specific objectives are to 1) determine the movement patterns and behavior of Walleye on Rathbun Lake and 2) determine the factors that may be influencing these patterns and behaviors. Results from this study will allow managers to better understand movement and behavior patterns of reservoir Walleye that will then permit them to alter management and stocking strategies or alter reservoir operation to minimize escapement and maintain viable populations.

Methods

Study Area.—Rathbun Lake is a 4,672-ha reservoir located in Appanoose, Lucas, Monroe, and Wayne counties in south-central Iowa. Rathbun Lake is part of the Chariton River basin thatspans 5,980 km^2 between Iowa and Missouri, with 1,422 km^2 comprising the Rathbun Lake watershed. This results in a 29:1 ratio of watershed area to lake surface area. Currently, the Rathbun Lake watershed is classified as 37.7% grassland, 36.9% row crop and 13.8% forested timber (Ikenberry 2017). Rathbun Dam construction began in the 1960s, and was operating as a flood control reservoir by 1970. The dam itself is an earth-filled embankment measuring over 3,230 m in length, with the top of the dam sitting over 30 m above the Chariton River downstream. Rathbun Lake has a bottom-draw outlet with 3.7-m x 1.8-m wide gates to control discharge. Normal operational discharge varies between less than 1 to 34 m^3/s. However, maximum allowable discharge for the reservoir is 142 m^3/s. At conservation pool (mean sea elevation of 275 m), the mean depth of the lake is 5.3 m and the maximum depth is 44.2 meters. There are 190 km of shoreline, with a fairly irregular shape; however, there has been a recent loss of irregularity and embayments due to shoreline erosion. Currently the shoreline development index = 1.4 (Ikenberry 2017). Habitat in the lake is generally lacking, with little suitable firm substrate for fishes to spawn (Krogman 2015). Turbidity is also high in the lake, with an estimated 377,308 tons of sediment delivered from watershed inputs in 2010 (Downing and Balmer 2011). The lake also experiences internal sediment loading from shoreline erosion. The Rathbun Dam is covered with hard riprap cover, which may be suitable spawning area for Walleye (Eschmeyer 1950).

Receiver Deployment.—Forty-two VEMCO acoustic receivers were deployed throughout Rathbun Lake and in the tailrace in March 2019. Prior to deployment, acoustic range testing was completed on Rathbun Lake to determine optimal distance between receivers. Based on range testing results, receivers could process acoustic transmissions reliably at a 600 m radius. As such, 30 receivers were placed in a grid pattern approximately 1200 m apart to minimize receiver overlap and maximize coverage across the entire lake. All receivers were variants of the VEMCO VR2 product line (VR2W, VR2Tx, VR2AR) and all operate at the 69 kHz frequency level. Receivers were housed in large metal stands to ensure proper orientation and no movement of receivers during the study period. Each receiver was bolted into the metal stand and an ONSET HOBO Pendant Temperature Logger was attached to stands with receivers that could not log temperature internally. A large concrete block was attached to each metal stand with 18 to 30-m braided nylon rope depending on deployment depth for retrieval purposes. Each receiver stand was deployed at its corresponding GPS coordinates using a rope to gently lower the stand to the lake bottom. The concrete block was then placed due north of the stand 18 to 30 m away depending on water depth and rope length.

Receiver monitoring and retrieval.—Receivers will be retrieved approximately every six months to download acoustic transmission data and perform routine maintenance. During each retrieval event, we will approach the receiver's GPS coordinates by boat and place a weighted buoy at the GPS coordinates to ensure the receiver is re-deployed in the correct location. Using the GPS coordinates of the receiver and concrete block, we will deploy a metal grappling hook to snag the rope connecting the receiver and block. Once the rope is snagged, the concrete block will be lifted to the surface. The attached rope will be connected to an onboard pulley and winch system that will then raise the metal receiver base out of the water. Once out of the water, receiver transmission and temperature logger data will be downloaded to a laptop computer, and batteries in the receiver and temperature loggers will be replaced as necessary. Each base will then be re-deployed at the original GPS coordinates using the original deployment techniques. Additional monitoring of fish and receivers will be periodically collected with a VEMCO VR100 active tracking receiver. Using the VHTx-69k omnidirectional Transponding Hydrophone, we will be able to locate fish throughout the lake and in the tailrace via their acoustic tags. We will also be able to check the health of our VR2Tx receivers, receiving information such as battery life, number of acoustic transmissions, as well as the tag ID number of the acoustic transmissions.

Fish collection.—Walleye were collected during the first two weeks of April 2019 during nighttime broodstock gill netting collection by Iowa DNR biologists. Gill nets were set for 4-h intervals using a bottom-set technique, with multifilament nylon nets (30.5 m long x 1.8 m deep; 64-mm bar mesh). Because of the large bar mesh used, catch was limited to individuals >432 mm. Walleye were collected from two locations where they are known to spawn, down-lake by the dam and up-lake at the Bridgeview recreation area. After capture, all Walleye were taken to the Rathbun Fish Hatchery where they were artificially spawned and held in raceways for one to two days before tagging. Walleye were sorted into four groups in the raceways based on size, sex, and collection location. Thirty Walleye were collected from near Rathbun Dam, comprised of 15 males and 15 females. Similarly, 30 Walleye were collected from the Bridgeview recreation area, comprised of 15 males and 15 females. Each of the four groups were comprised of five fish between 381-457 mm total length and 10 fish >482 mm total length.

Fish tagging.—A total of 60 Walleye were initially implanted with VEMCO V13P-1L or V16P-4L coded pressure-sensing acoustic transmitters. Additional Walleye will be implanted with acoustic transmitters in subsequent years as fish are lost to escapement and mortality. Transmitters were implanted into the coelomic cavity via surgery. Walleye were measured for total length (mm) and wet weight (g), placed into a surgery cradle, and anesthetized with electroanesthesia (TENS 7000 unit). Electrodes were placed inside cotton gloves, with the anesthetizer wearing rubber gloves underneath to prevent minor electrocution. The anesthetizer would then hold the fish secure against the surgery cradle, applying electricity to the fish. This process caused electro-paralysis of the fish, allowing for the surgery process to commence with little to no fish movement. A tube was inserted into the mouth of the fish and water was pumped over the gills to provide sufficient oxygen to the fish during surgery. An approximately 25 mm incision was cut in the body cavity of the fish and the transmitter was placed inside the fish. The cavity of the fish was closed using 1-2 cruciate or single sutures with 2-0 monofilament absorbable suture. Surgery procedures were completed in approximately 6-8 minutes and fish were returned to the raceways post-surgery for recovery. Fish were held in the raceways 7 days to ensure no post-surgery mortality. After 7 days, fish were returned to Rathbun Lake and released according to their collection location. Fish collected in gill nets near Rathbun dam were released at Buck Creek Marina, while fish collected from the Bridgeview recreation area were released further up-lake in the South Fork arm of the Chariton River.

Data analysis.—Raw data downloaded from the acoustic receivers will be analyzed using the VEMCO VUE software platform. VUE software creates database files for each receiver and displays all detections and other information collected during the study period. VUE software also has the capability to correct for any time discrepancies among receivers, analyze for false or incorrect animal detections, and filter repeat or unneeded entries. Once the database files have been analyzed in VUE, they can be easily exported in spreadsheet format for use in other analyses. We will fully analyze data in VUE to ensure that all data are correct and correspond to the correct individuals (i.e., only adult Walleye).

We will use detections from acoustic receivers to track general Walleye movement patterns around the lake. Using our detections, we can gain a coarse approximation of exact location for movement and behavior analyses. Fish locations will be entered and analyzed using ArcMap 10.5.1 software (ESRI, Redlands, CA). Locations will be entered as the GPS coordinates of the receiver on which the fish was detected. These data will be used to calculate home ranges of individual fish. Home ranges will be calculated using Home Range Tools in ArcGIS or Reproducible Home Ranges package in statistical software R (Signer and Balkenhol 2015; R Core Team 2018) using kernel density and minimum convex polygon approaches. Differences in home range sizes among groups of Walleye will be calculated using analysis of variance (ANOVA). Walleye groups will be separated among sex (male, female), collection location (Bridgview recreation area, Rathbun Dam), and age (0-2, 3-5, 6-8, 9+). Similarly we can use ANOVA analysis to determine seasonal movement patterns. For seasonal movement, home range data will be separated into the four seasons: spring (March 1-May 31), summer (June 1-August 31), fall (September 1-November 30), and winter (December 1-February 28). ANOVA analysis in statistical software R will show significant differences at the 0.05 level among the four seasons.

To analyze the large-scale movement of Rathbun Lake Walleye, we will use a multi-state mark-recapture model similar to Hayden et al. (2014). With this approach, we will be able to calculate the probability of a Walleye making a large-scale movement around the lake. We will divide the lake into three geographic locales: up-lake, mid-lake, down-lake and the receivers in each physical location will be used to create individual fish detection histories. For each timestep, individuals will have a probability of transitioning from a physical state or staying in the same physical state. For example, a fish originally detected in the up-lake portion of the array can then transition into the mid-lake portion of the array or can stay in the up-lake portion of the array. To estimate the movement probabilities, we will use software program MARK (White and Burnham 1999) using the model described by Hestbeck et al. (1991) and Brownie et al. (1992). We will follow the assumptions of the multi-state mark-recapture model as described by Burnham et al. (1987). A set of candidate models will be developed to evaluate the effects of sex, age, season, collection location, water temperature, and discharge on movement probabilities. Model fit will be assessed using Akaike's Information Criterion (AIC) values, with lowest AIC values representing better supported models.

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CHAPTER 4: FINE-SCALE MOVEMENT AND BEHAVOIR OF WALLEYE NEAR A RESERVOIR INTAKE TOWER

Introduction

Knowledge of fish movement and behavior is essential for fisheries scientists to better manage and conserve fisheries populations (Cooke et al. 2004). Movement of fishes is often studied to determine long distance migration patterns and spawning stock structure (Pracheil et al. 2015; Brooks et al. 2019). On a smaller-scale, fish movement and behavior are studied to determine habitat selection and activity patterns (Guy et al. 1992; Sammons and Maceina 2005). Recently, fine-scale analysis of fish position data have been used to explain fish movement and behavior patterns (McMahan et al. 2013; Dance and Rooker 2015; Binder et al. 2018).

One important application of fine-scale fish position analysis is to study fish movement and behavior in relation to possible entrainment. Entrainment can be defined as the displacement of individuals from reservoirs to downstream waters by way of water diversion through turbines or other water releasing structures (Johnson et al. 2004). Entrainment can negatively affect fish populations through direct mortality during entrainment, as well as decreasing the abundance of individuals from the upstream system (Coutant and Whitney 2000; Weber et al. 2013). Entrainment is especially important in species that make long-distance migrations through fragmented systems to complete their life cycles. In particular, entrainment of Pacific Salmonids (*Oncorhynchus* spp.) has been studied to prevent further population losses through creation of bypass structures around dams (Coutant and Whitney 2000; Mathur et al. 2000; Boggs et al. 2004). However, migratory species are not the only species vulnerable to entrainment. Resident species that normally do not emigrate can also experience entrainment if they use habitats close to the water intake structures, which can alter the upstream fish population, leading to management problems and decreased angler satisfaction (Jensen 1982). This is especially true in recreationally important species, where the loss of large, highly fecund adults can reduce the growth and viability of the population (Martins et al. 2014).

One such recreationally important species is Walleye *Sander vitreus*. Walleye are vulnerable to downstream entrainment from dams and entrainment has been shown to be the cause of substantial mortality to Walleye populations (Kerr et al. 1997; Navarro et al. 2006). Walleye have also been shown to escape reservoir systems that do not have hydroelectric turbines (Weber et al. 2013; Weber and Flammang 2019). Entrainment or escapement of Walleye can be detrimental fisheries management strategies, especially as Walleye are a commonly stocked fish across North America (Rahel 2000, Eby 2006). In reservoir systems, Walleye spawning success is variable, and many populations are maintained through stocking (Santucci and Wahl 1993; Kerr 2011). As such, escapement of Walleye can reduce the effectiveness of such stocking programs and exacerbate reservoir population troubles.

While entrainment and escapement of Walleye has been well studied, there are few studies on Walleye movement and behavior in relation to escapement. Walleye are generally considered a mobile species and make long distance migrations in natural systems (Weeks and Hansen 2009). Movement of Walleye is closely related to spawning events, during which time individuals will move to lake shorelines or other shallow areas of gravel, cobble, or rubble substrate to reproduce (Eschmeyer 1950; Johnson 1961). Walleye have also have been shown to exhibit high activity and movement levels during high flow events and flows >55 m/s^3 can result in significant displacement of Walleye populations (Groen and Schroder 1978; Murchie and Smokorowski 2004). Although these movement and behavior patterns have been studied, their role in escapement is unknown.

Given the current knowledge on Walleye movement and behavior, the potential for Walleye escapement may be high. This may be especially so in reservoir systems, where riprap dams can provide suitable Walleye spawning habitat, and high flow events are likely during heavy rain or flood-control operations. To help combat potential escapement, knowledge of movement and behavior around reservoir dams and intake towers is important. For example, many mechanisms to reduce downstream escapement have been studied, including both physical and non-physical barriers at dams (Taft et al. 2001; Noatch and Suski 2012; Flammang et al. 2014). Knowledge of fine-scale movement and behavior may help improve efficiency of such barriers. Movement and behavior around the intake tower may also help explain particular environmental conditions that increase potential for escapement, and allow reservoir operators to control dam operation accordingly.

With the importance of fine-scale movement and behavior patterns of Walleye in relation to possible entrainment and the lack of current information, we have designed a fine-scale movement and behavior study using acoustic telemetry technology to track and analyze movement and behavior patterns of Walleye in Rathbun Lake, Iowa. Rathbun Lake is a model system to study Walleye movement and behavior in relation to escapement, as it is a large flood-control reservoir that has a bottom-drawn control dam and supports an important Walleye fishery. Suitable Walleye spawning habitat occurs along the dam, and water flow fluctuates as flood-control operations change. High levels of Walleye escapement have also been documented (Weber et al. 2013; Weber and Flammang 2019). Escapement of Walleye is especially detrimental in Rathbun Lake because no natural reproduction occurs in the lake, and is totally supported through hatchery-raised individuals (Mitzner 2002). The specific objectives of our study are to 1) determine fine-scale movement and behavior patterns of Walleye individuals preceding downstream escapement and 2) determine fine-scale movement and behavior patterns of Walleye in relation to biotic and abiotic factors such as age, sex, collection location, temperature, season, time of day, and reservoir discharge. The results of this study will allow managers to better understand the behavior of Walleye around reservoir intake towers and allow them to change reservoir operation procedures to minimize Walleye escapement potential and create more efficient barriers against escapement.

Methods

Study Area.—Rathbun Lake is a 4,672-ha reservoir located in Appanoose, Lucas, Monroe, and Wayne counties in south-central Iowa. Rathbun Lake is part of the Chariton River basin, which spans 5,980 km^2 between Iowa and Missouri, with 1,422 km^2 comprising the Rathbun Lake watershed. This results in a 29:1 ratio of watershed area to lake surface area. Currently, the Rathbun Lake watershed is classified as 37.7% grassland, 36.9% row crop, and 13.8% forested timber (Ikenberry 2017). Human impacts are minimal, with major pollutants coming from agricultural runoff. Rathbun Dam construction began in the 1960s, and was operating as a flood control reservoir by 1970. The dam itself is an earth-filled embankment measuring over 3,230 m in length, with the top of the dam sitting over 30 m above the Chariton River downstream. Rathbun Lake has a bottom-draw outlet with 3.7-m x 1.8-m wide gates to control discharge. Normal operational discharge varies between less than 1 to 34 m^3/s. However, maximum allowable discharge for the reservoir is 142 m^3/s. At conservation pool (mean sea elevation of 275 m), the mean depth of the lake is 5.3 m and the maximum depth is 44.2 meters. There are 190 km of shoreline, with a fairly irregular shape; however, there has been a recent loss of irregularity and embayments due to shoreline erosion. Currently the shoreline development index = 1.4 (Ikenberry 2017). Habitat in the lake is generally lacking, with little suitable firm substrate for fishes to spawn (Krogman 2015). Turbidity is also high in the lake, with an estimated 377,308 tons of sediment delivered from watershed inputs in 2010 (Downing and Balmer 2011). The lake also experiences internal sediment loading from shoreline erosion. The Rathbun Dam is covered with hard riprap cover, which may be suitable spawning area for Walleye (Eschmeyer 1950; Weber et al. 2013).

Receiver deployment—Ten VEMCO acoustic receivers were deployed around the intake tower at the Rathbun dam using VEMCO VPS array design. VPS technology uses standard VEMCO acoustic coded tags and VR2 family receivers, but are arranged in a specific pattern to meet study goals. To obtain exact two-dimensional locations of individuals, an acoustic transmission must be detected by at least three different receivers. VEMCO uses time offsets from the detection on the multiple receivers to triangulate the location of the individual. For a VPS study to be successful, proper placement of the receivers is essential to ensure that receivers are not too far apart to determine fish locations. Prior to deployment, acoustic range testing was completed on Rathbun Lake and sent to VEMCO personnel to determine optimal distance between receivers for VPS array performance. Two additional receivers were placed in the Chariton River below Rathbun Dam. The first was placed 70 m downstream of the outlet and the second 775 m downstream of the outlet. All receivers in the VPS array are VEMCO VR2Tx and operate at the 69 kHz frequency level. Receivers are housed in large metal stands to ensure proper orientation and no movement of receivers during the study period. Each receiver was bolted into the metal stand. A large concrete block was attached to each metal stand with 18 to 30-m braided nylon rope depending on deployment depth for retrieval purposes. Each receiver stand was deployed at its corresponding GPS coordinates using a rope to gently lower the stand to the lake bottom. The concrete block was then placed due north of the stand 18 to 30 m away depending on water depth and rope length.

Receiver monitoring and retrieval.—After deployment of the VPS array, study design was analyzed to ensure proper performance of the array. A VEMCO range test tag was dragged by boat through the study array and the receivers were retrieved and data offloaded onto a laptop computer. Detection information from the receivers was sent to VEMCO personnel for analysis, and any recommended changes were made to the study array. Additional retrievals will be made approximately every 6 months to download acoustic transmission data and perform routine maintenance. During each retrieval event, we will approach the receiver's GPS coordinates by boat and place a weighted buoy will be placed at the GPS coordinates to ensure the receiver is re-deployed in the correct location. Using the GPS coordinates of the receiver and concrete block, we will deploy a metal grappling hook to snag the rope connecting the receiver and block. Once the rope is snagged, the concrete block will be hauled to the surface. The attached rope will be connected to an onboard pulley and winch system that will then raise the metal receiver base out of the water. Once out of the water, receiver transmission data will be downloaded to a laptop computer, and batteries in the receivers will be replaced as necessary. Each base will then be re-deployed at the original GPS coordinates using the original deployment techniques.

Fish collection.—Walleye were collected during the first 2 weeks of April 2019 during nighttime broodstock gill netting collection by Iowa DNR biologists. Gill nets were set for 4-h intervals using a bottom-set technique, with multifilament nylon nets (30.5 m long x 1.8 m deep; 64-mm bar mesh). Because of the large bar mesh used, catch was limited to individuals >432 mm. Walleye were collected from two locations where they are known to spawn, down-lake by the dam and up-lake at the Bridgeview recreation area. After capture, all Walleye were taken to the Rathbun Fish Hatchery where they were artificially spawned and held in raceways for 1 to 2 days before tagging. Walleye were sorted into four groups in the raceways based on size, sex, and collection location. Thirty Walleye were collected from near Rathbun Dam, comprised of 15 males and 15 females. Similarly, 30 Walleye were collected from the Bridgeview recreation area, comprised of 15 males and 15 females. Each of the four groups were comprised of five fish between 381-457 mm total length and 10 fish >482 mm total length.

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Data analysis—Raw data downloaded from the acoustic receivers will be sent to VEMCO personnel for fine-scale movement analysis through the VPS array. Currently, VEMCO recommends sending all VPS data to their personnel to analyze exact two-dimensional locations. VEMCO will provide exact GPS tracked locations of all detected fish within the array in spreadsheet format for easy use in future analyses. Additionally, regular presence/absence detection data from the VPS receivers could be analyzed using the VEMCO VUE software platform, if necessary. VUE software creates database files for each receiver and displays all detections and other information collected during the study period. VUE software also has the capability to correct for any time discrepancies among receivers, analyze for false or incorrect animal detections, and filter repeat or unneeded entries. Once the database files have been analyzed in VUE, they can be easily exported in spreadsheet format for use in other analyses.

Fine-scale movement and behavior analyses will be based on two and three-dimensional locations of individuals provided by VPS array data. Fish GPS locations will be entered and analyzed in ArcMap 10.5.1 (ESRI, Redlands, CA). We will provide an introductory quantitative analysis to explain general trends of fine-scale movement and behavior patterns of Walleye near the intake tower. Such measurements will include, time spent in the array, average depth in the array, depth at entry into the array, and number entries into the array. These variables will be calculated for each individual in the array and will then be grouped together for comparative analyses. Analysis of variance (ANOVA) will be used to test for differences among the groups in the statistical software R (R Core Team 2018). Individuals will be grouped by fish sex, collection location, and age. We will also calculate fine-scale movement rates using the GPS locations of the Walleye in the array. With exact locations and continuous monitoring in the array we will be able to calculate movement rates at the m/hour or m/minute temporal scale. We will compare movement rates among groups of Walleye as well as comparing movement rates using environmental factors such as discharge and water temperature. Similarly we can compare movement rates across diel time periods and seasons. All comparative analyses will be completed using ANOVA testing.

To investigate reservoir operation in relation to fine-scale movement and escapement, we will provide quantitative analyses to explain movement and behavior prior to escaping. We will use a regression analysis approach to determine if discharge is associated with movement toward the intake tower. To run the regression, we will calculate the closest distance each Walleye comes to the intake tower during a detection occasion. Discharge data will be added to each individual's distance datapoint and probability predictions will be calculated through the regression. The regression analysis will allow us to determine if discharge affects how close Walleye swim toward the intake tower. We will also calculate the number of challenges or attempts at escaping individuals make before actually escaping. Number of approaches will be calculated by determining if the GPS location of the individual comes within a certain distance of the intake tower. The number of approaches can then be grouped for ANOVA testing, with similar groups to those mentioned above. We will also group the number of approaches in relation to discharge, using low discharge (0-500 cfs), medium discharge (500-1500 cfs), and high discharge (>1500 cfs) as the groupings. ANOVA testing will show significant differences in approach behavior based on dam discharge.

We will also explore modeling options to help explain actual Walleye escapement similar to methods used by Bacheler et al. (2018), who used generalized additive modeling (GAM) to determine if predictor variables were correlated with Gray Triggerfish *Balistes capriscus* response to traps. They used binary GAMs due to the binary nature of the response variable, Gray Triggerfish either responded or did not respond to traps. In our application, we will use binary GAMs to determine if predictor variables are correlated to downstream escapement by Walleye. For example individuals will receive a value of 0 if they did not escape and will receive a value of 1 if they did escape. We will then add discharge, time-of-day, season, water temperature, sex, collection location, and age to each escapement data point. Combinations of predictor variables will be used to create a suite of candidate models. Models will be run in the statistical software R. Model fit will be assessed using Akaike's Information Criterion (AIC), with lower AIC values representing better model support. Predictor variables that are significant at the 0.05 level in each GAM will also be indicative of association to escapement.

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