

## ABSTRACT

WALLEYE AGE VALIDATION USING KNOWN-AGE FISH AND IMPACTS  
OF TAG LOSS AND AGING ERROR ON WALLEYE MANAGEMENT

By Ryan P. Koenigs

Sport fishing on the Lake Winnebago System in east-central Wisconsin annually contributes US\$234 million to the local economy, and walleye *Sander vitreus* are one of the most heavily targeted sport fish in the system. Use of accurate data when estimating population abundances and rates of exploitation, somatic growth, and mortality is essential to effective management of the walleye fishery. Previous to this study, Wisconsin DNR fisheries biologists were utilizing mark-recapture methods and angler tag returns to estimate population abundances and exploitation rates without accounting for tag loss. Further, age estimates from dorsal spines were being used to estimate rates of somatic growth and mortality without completely understanding the accuracy of age estimates or the impacts that potential aging error had on management practices. Walleye tagged during 2010 April spawning assessments were secondarily marked with an upper caudal clip in order to estimate tag loss occurring within three time periods (0-11 days post tagging, 0-90 days post tagging, and one year post tagging). Additionally, otoliths and dorsal spines were collected from 331 known-age walleye: 155 that were assigned ages via progression of discrete length modes following an individual strong year class (ages-0-3), and 176 (ages-4-10, 16) that were initially tagged at lengths small enough to accurately assign age  $\pm 1$  year ( $< 381$  mm) and later recaptured where assigned age at tagging plus number of years at liberty was a reasonable approximation of true age. Paired aging structures were also collected during April spawning assessments and June tournament monitoring to better understand the relationship between age estimates from dorsal spines and otoliths and to determine the impacts that aging error has on estimated age distributions and rates of somatic growth and mortality. Tag loss that occurred within the first 11 days post tagging was negligible ( $< 0.3\%$ ), but increased with time, 4.7% within the first 90 days post tagging, 21.9% after one year post tagging. After correcting for tag loss that occurred within the first 90 days, population abundance estimates decreased (5.4% for female and 5.3% for male walleye) and exploitation estimates increased (5.0% for female and 4.9% for male walleye). Otolith age estimates from known-age fish were accurate for walleye ages-0-10, while dorsal spine age estimates were relatively accurate for walleye ages-1-9, but underestimated the age of walleye 10 years of age and older. Paired age estimates followed similar trends, where age estimates from both structures showed close agreement for walleye ages-0-6, but dorsal spines underestimated age of walleye age-7 and older relative to otoliths (up to 5.0 years for female walleye and 7.4 years for male walleye). Age distributions derived from otolith age estimates correlated well with year class strength, accurately portraying highly

variable recruitment and providing strong corroboratory evidence that otolith age estimates are accurate for all ages of walleye. Estimated age distributions from dorsal spine age assignments did not correlate well with year class strength data, supporting the conclusion that dorsal spines are inaccurate for estimating the age of older walleye. Mean estimates of conditional total annual mortality were greater when constructing catch curves from dorsal spine age estimates (39.9% for male walleye and 38.8% for female walleye) relative to when incorporating otolith age estimates (29.3% for male walleye and 32.6% for female walleye). von Bertalanffy growth models constructed from otolith age estimates were not significantly different from those based on dorsal spine age estimates for either male or female walleye ( $P > 0.05$ ), meaning that aging error had little impact on estimated growth parameters of length infinity ( $L_{\infty}$ ) or Brody growth coefficient ( $K$ ). Mean dorsal spine and otolith age estimates were similar for male walleye <457 mm and female walleye <508 mm, but age estimates from otoliths were significantly older than those from dorsal spines for fish of larger sizes. I recommend tag loss be estimated and accounted for in all mark-recapture studies, in order to provide more accurate data. Due to the accuracy and precision of age estimates from otoliths, I also recommend use of otoliths to estimate walleye age and rates of growth and mortality.

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by

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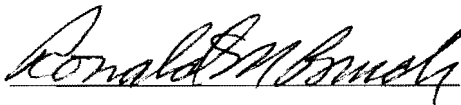
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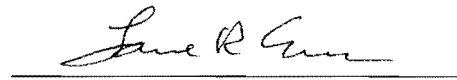
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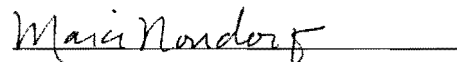
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## Chapter I

### Introduction

Knowledge of fish population dynamics is essential when developing management plans and evaluating whether management objectives are being met. Different fish species exhibit varying life history traits, and thus must be managed differently. For example, lake sturgeon *Acipenser fulvescens* are long lived, mature later in life, and do not reproduce every year (Bruch et al. 2001), whereas freshwater drum *Aplodinotus grunniens* are long lived, mature earlier in life, and spawn annually (Davis-Faust et al. 2009). Management strategies for these two fish species should be different as freshwater drum are able to withstand much higher levels of exploitation than lake sturgeon. Cultural, sociological, and economic factors also affect the management practices of different fish populations. For example, lake sturgeon are generally highly revered by anglers and the public, while freshwater drum, although often an important component of the fish communities, are viewed as a rough fish with little public interest. Regardless of the fish species, effective fisheries management hinges on an accurate understanding of the population dynamics of the fish population in question.

Estimates of exploitation rates and population densities are two major components of fisheries population dynamics. Exploitation, the percent of the fish stock harvested by anglers over a given time period, is typically estimated by marking a sample of fish and monitoring the harvest of those fish through time. Some management programs mark fish with external tags (anchor tags, jaw tags, monel tags, Carlin tags, etc.) that contain a

unique alpha-numeric number sequence. Anglers are then encouraged to notify fisheries managers when they harvest a tagged fish, and recapture data are used to estimate exploitation rates. Other management programs mark fish with internal tags, and then investigate harvested fish for tags during harvest assessments and creel surveys. The method of marking fish to estimate exploitation relies on a number of assumptions including: no loss of tags, no death induced from tagging, no emigration or immigration of tagged or untagged fish, no differential mortality between marked and unmarked fish, and equal vulnerability of marked and unmarked fish to harvest (Ricker 1975; Miranda et al. 2002). Population densities are typically estimated by marking a sample of fish, similar to marking fish to estimate exploitation rates, and then collecting a recapture sample after marked fish have evenly dispersed throughout the water body. The numbers of marked and unmarked fish in the recapture sample, along with the number of marks at large, are used to estimate population abundance. Assumptions described above are also made when using these methods to estimate population densities.

Some of the most important population dynamic characteristics estimated to effectively manage fish populations, such as mortality, growth, recruitment, and age structure, require age data. Fish age is estimated by counting the number of growth rings or annuli present on hard structures such as scales, spines, fin rays, and otoliths, similar to counting the number of growth rings when estimating the age of a tree. The mechanism for annulus formation is related to changes in growth rates during alternating periods of relatively fast growth (spring and summer) and relatively slow growth (fall and winter) (Devries and Frie 1996). Since fish are poikilothermic, their metabolic rates, and



corresponding growth rates, vary with changing water temperatures (Smith and Pycha 1960; Staggs and Otis 1996). Rapid growth during spring and summer corresponds with wider growth increments that appear transparent on aging structures, while slowed growth during late fall and winter correspond to narrower growth increments that appear opaque on aging structures. Fish age can be estimated by observing the banding patterns on aging structures and counting the number of opaque bands present.

Of the different population parameters developed from age data, mortality is probably the most important factor driving fisheries population dynamics. Estimates of total annual mortality can be parceled into components of natural mortality and fishing mortality; natural mortality refers to fish succumbing to natural causes of death (starvation, predation, disease, etc.) and fishing mortality refers to death due to harvest (Van Den Avyle and Hayward 1999). Exploitation estimates are typically used to estimate fishing mortality rates from total annual mortality, with the remaining mortality attributable to natural causes. Age composition of a fish population is driven by mortality, specifically by fishing mortality within exploited populations. Heavily exploited fish populations generally contain higher percentages of younger fish, while populations experiencing lower exploitation rates tend to contain higher percentages of older fish. Erickson (1983) described how walleye *Sander vitreus* in Lakes Winnipeg and Winnipegosis, Manitoba, experienced heavy exploitation, and were thus dominated by walleye age-9 and younger; while Lakes Eardley and Obukowin, Manitoba, experienced little to no exploitation and contained higher percentages of older walleye.

Age estimates are also used to estimate somatic growth rates, which are heavily influenced by both biotic (prey availability, population density, etc.) and abiotic (temperature, trophic status) conditions (Devries and Frie 1996). Growth rates are also affected by exploitation and mortality rates, with higher mortality rates corresponding to faster growth rates due to less competition for available resources (Belanger and Hogler 1982; Frie et al. 1989; Robillard and Marsden 1996; Kocovsky and Carline 2000). Therefore, estimating somatic growth rates is a reliable method for monitoring population dynamic trends within a fish population.

The accuracy of all of these estimated population parameters hinges on the use of accurate data, and the use of inaccurate data reduces the effectiveness of fisheries management practices. When not accounted for, tag loss causes inflated estimates of population abundance and underestimates of exploitation rates (Kallemeyn 1989; Isermann and Knight 2005). Use of inaccurate age data can also have major impacts on estimated rates of growth, mortality, and recruitment, in turn reducing the accuracy of these estimates (Bradford 1991; Mertz and Meyers 1997). Somatic growth, mortality, and recruitment impact the dynamics of a fish stock the most. These parameters are used extensively in population dynamics models, including catch-at-age models and cohort analyses, which are becoming more common in fisheries management and research (Ricker 1975; Beverton 1987; Colvin 1991; Maceina et al. 1998; Quist et al. 2004). Models provide results that are only as accurate as the data that are input into them, underlining the critical importance of collecting accurate age data for producing reliable and meaningful results (Mertz and Meyers 1997).

Although extensive research has demonstrated the importance of using accurate data to estimate dynamics of fish populations, the results of this research have not been systematically incorporated into many fisheries management programs. For example, tag loss has been evaluated for many freshwater game-fish species, but not all management programs estimate rates of tag loss and account for those rates when estimating population densities and rates of exploitation. Additionally, many resource managers use inaccurate age data to estimate growth and mortality rates of exploited fish populations. Maceina et al. (2007) surveyed 45 state and 6 provincial agencies, inquiring about their aging practices and the relative confidence they place in age estimates. Responses showed that the agencies estimated age of percids using mostly scales (25 agencies, 8 exclusively) and otoliths (29 agencies, 10 exclusively), with 8 agencies reporting using spines and 1 using fin rays (Maceina et al. 2007). Only 27% of the respondents felt that scale age estimates were accurate for estimating the age of older fish of any species, while most agencies felt that otoliths provided the most accurate age estimates (Maceina et al. 2007). Despite these results, many agencies continue to use aging techniques that the majority of fisheries managers perceive to yield inaccurate age estimates. The negative impacts of using inaccurate age data to estimate population metrics may not be well known by many fisheries managers. In addition, some fisheries managers knowledgeable about the implications of inaccurate aging data may be content to continue to use inaccurate aging techniques due to historical precedents and resistance to changing management procedures. In any event, it is imperative that fisheries management agencies and biologists earnestly investigate the accuracy of the age data

they are collecting for their management programs and strive to utilize the most accurate data possible.

Walleye are one of the most popular and heavily-researched recreational and commercial freshwater sport fish species in North America. Walleye fisheries are present in seven Canadian provinces, with an estimated 20 million walleye being harvested in 1990 (16.3% of all fish harvested) (Fenton et al. 1996). Recreational walleye fisheries are also present in 34 American states, and anglers spent 51 million hours targeting walleye in 1991, contributing to an overall economic impact of US\$2.7 billion (U.S. Fish and Wildlife Service 1993). Due to the economic importance of walleye fisheries, it is imperative to use accurate data to estimate population metrics such as relative abundance and rates of exploitation, somatic growth, mortality, and recruitment. These population characteristics are used to effectively set harvest regulations and quotas that maintain sustainable harvest opportunities.

Walleye are also a very important sport fish in the Winnebago System fishery in east-central Wisconsin, a fishery that annually contributes \$234 million to the local economy (Cook and Neiswender 2007). The Winnebago System walleye fishery is nationally recognized and heavily targeted by anglers, while also contributing the greatest economic value to the overall fishery in the Winnebago System. Management practices for walleye in the Winnebago System date back to the early 1960s when Gordy Priegel observed and documented age (with scales), growth, fecundity, and life histories of walleye (Priegel 1969, 1970). Priegel (1970) identified locations and described behavior of Winnebago System walleye spawning in the Upper Fox and Wolf Rivers, while also

quantifying harvest that occurred pre-spawn and post-spawn to address over-harvest concerns expressed by anglers around the Winnebago System. Marsh maintenance and improvement projects were also begun during this time to improve the quantity and quality of spawning habitat for walleye inhabiting the Winnebago System (Priegel 1970).

The extensive period of studying Winnebago System walleye during the 1960s was followed by two decades of relatively-passive walleye management (1970-1988). The focus of fisheries managers had largely shifted to lake sturgeon research and management, and daily catch reports from freshwater drum removal projects provided relative abundance of adult and young of year walleye during this time period. Due to high exploitation, a decrease in forage abundance, and poor recruitment during the mid to late 1980s, the Winnebago System walleye population decreased substantially. This decrease led to the implementation of an intensive walleye tagging program in 1989 and a walleye management plan in 1991. Actions stemming from the walleye management plan included reducing carbon monoxide emissions from the Mercury Marine testing facility located on the Fox River in Oshkosh (which was thought to kill walleye fry dispersing to Lake Winnebago), implementing a 381 mm size limit (1992-1997) to help protect walleye to maturity, creating no-entry zones in walleye spawning marshes, habitat improvement projects, and conducting fall young-of-the-year walleye assessments. The intensive tagging program was implemented to enable fisheries managers to estimate population densities and exploitation rates, while also observing size and age distributions, growth rates, and mortality rates of adult male and female walleye. Floy anchor tags were used to mark spawning walleye, and ages were estimated with dorsal

spines rather than scales. The combination of these management practices led to the rehabilitation of the Winnebago System walleye population.

Currently, the Winnebago walleye fishery is a recreational fishery that is open year-round with a daily bag limit of 5 fish and no size limits. Size and daily bag limits are the primary tools for controlling exploitation of walleye and are the means for maintaining exploitation rates at or below sustainable levels. Therefore, it is imperative to collect accurate data to estimate population densities and rates of exploitation, mortality, and growth; estimates which are used to implement appropriate size and daily bag limits to effectively manage the exceptional walleye fishery in the Winnebago System.

### *Objectives*

The purpose of my research was to assess the accuracy of data currently being collected and used for the Winnebago System walleye management program. Specifically, I estimated Floy anchor tag retention rates and the accuracy of age estimates from dorsal spines and otoliths for walleye from the Winnebago System to assess the accuracy of estimated population densities and rates of exploitation, mortality, and somatic growth.

Currently, Floy anchor tags (FD-94, Floy Tag and Manufacturing Inc.) are used to mark adult male and female walleye on the Winnebago System. Angler tag return data from these marked samples of fish are used to estimate annual exploitation rates of the adult stock, and walleye registered during select June walleye tournaments represent the

recapture sample used to estimate population abundances. Before this study, estimates of population abundance and exploitation did not account for anchor tag loss rates. Further, age estimates dating back to the implementation of the Winnebago System walleye management plan in 1989 were derived from dorsal spines and were used to estimate walleye age distribution and rates of growth and mortality. My primary objectives were 1) to estimate instantaneous tag loss (loss occurring within the first 11 days), tag loss occurring between time of tagging and summer tournaments (0-90 days post tagging), and tag loss occurring within the first year following tagging (annual tag loss); 2) to examine the impact of tag loss on estimates of exploitation and population abundances; 3) to evaluate the accuracy and precision of dorsal spine and otolith age estimates for walleye in the Winnebago System; and 4) to evaluate impacts that potential aging error with dorsal spines has on walleye management (particularly estimates of age distribution and rates of growth and mortality).

### *Study Area*

The Winnebago System is a large, shallow, eutrophic ecosystem in east-central Wisconsin that is composed of Lake Winnebago and three upriver lakes (Butte des Morts, Winneconne, and Poygan), which collectively comprise 668 km<sup>2</sup> of surface water. The Upper Fox River and the Wolf Rivers (along with their major tributaries) flow into the lakes, draining a 15,540 km<sup>2</sup> watershed. The floodplain of the lower 60 km of the Upper Fox River and the lower 200 km of the Wolf River above the lakes contain an extensive network of old channels and oxbows, which in most springs carry flowing water over wet

meadows, providing ideal spawning habitat for Winnebago System walleye. Walleye are abundant in the Winnebago System and are the primary focus of a high-profile, year-round recreational fishery that has an annual regional economic impact of \$234 million (Cook and Neiswender 2007).



## Chapter II

### Loss of Anchor Tags in Walleye Inhabiting the Winnebago System and Impacts of Tag Loss on Walleye Management

#### *Introduction*

Fish tagging and marking techniques are utilized by fisheries managers to determine population characteristics including abundance, exploitation, movement, somatic growth, and mortality (Pegg et al. 1996). External tags such as anchor tags, Carlin tags, and jaw tags are commonly used due to their easy detection during recaptures by anglers and fisheries personnel. Rates of tag loss must be calculated and accounted for to prevent underestimating exploitation rates (Ebener and Copes 1982; Kallemeyn 1989; Isermann and Knight 2005) and overestimating population abundances (Kallemeyn 1989).

Tag loss studies have been conducted on multiple species of fish including: largemouth bass *Micropterus salmoides* (Tranquilli and Childers 1982; Hartman and Janney 2006), lake trout *Salvelinus namaycush* (Fabrizio et al. 1996), brown trout *Salmo trutta* (Brewin et al. 1995), white sucker *Catostomus commersonii* (Franzin and McFarlane 1987), lake whitefish *Coregonus clupeaformis* (Ebener and Copes 1982), channel catfish *Ictalurus punctatus* (Greenland and Bryan 1974; Buckmeier and Irwin 2000), white bass *Morone chrysops* (Muoneke 1992), northern pike *Esox lucius* (Pierce and Tomcko 1993), and sauger *Sander canadensis* (Pegg et al. 1996). Estimated rates of tag loss have been extremely variable, ranging from 1.8% annual tag loss of anchor tags

in northern pike (Pierce and Tomcko 1993) to 57.1% tag loss of anchor tags after 403 days in largemouth bass (Hartman and Janney 2006). For this reason, Kallemeyn (1989) suggested that tag loss should be estimated whenever using a mark-recapture method of estimating population statistics.

Estimated rates of tag loss in walleye have been variable depending on tag type and water body. Annual jaw tag loss ranged from 23% to 50% in Lake Erie (Isermann and Knight 2005) and from 12.5% to 27.8% in Escanaba Lake, WI (Newman and Hoff 1998). Walleye in Kabetogama Lake, MN shed Carlin tags at an annual rate of 24.2% (Kallemeyn 1989). To my knowledge, Weeks and Hansen (2009) reported the only estimate of anchor tag loss in walleye that is present in the peer-reviewed literature, estimating mean annual tag loss rates of 2.9% for anchor tags in walleye from the Manitowish Chain, Wisconsin.

Floy anchor tags (FD-94) have been used to mark walleye on the Lake Winnebago System, WI since 1989. Tag returns from anglers fishing the Winnebago System are used to estimate rates of exploitation, and catches during June walleye tournaments are used as the recapture sample for estimating population abundances. My objectives were: 1) to estimate instantaneous tag loss (tag loss occurring within the first 11 days), tag loss occurring between time of tagging and summer tournaments (0-90 days post tagging), and tag loss occurring within the first year following tagging (annual tag loss); and 2) to examine the impacts of tag loss on estimates of exploitation and population abundances (metrics used to manage the Winnebago System walleye fishery).

### *Methods*

*Tag loss.*—Walleye were captured on the Upper Fox and Wolf Rivers in spring 2010 using a standard Wisconsin-style boom shocker with pulsed direct current (25% duty cycle, 50 pulses per second, conductivities of 330-370  $\mu\text{hmhos/cm}$ , typically producing an electrical field of 100 volts at 5 amps or less). Captured fish were observed for the presence of Floy anchor tags (FD-94, Floy Tag and Manufacturing Inc.), and all fish tagged previous to 2010 (as determined by the tag number) were treated as recaptures and released after tag number, total length to the nearest 2.5 mm, sex, and spawning stage (ripe for male walleye and either green (hard), ripe, or spent for female walleye; determined by extrusion of gametes) were recorded. All untagged walleye were tagged with Floy anchor tags (FD-94) using a Floy Mark II tagging gun (Floy Tag and Manufacturing Inc.) equipped with a 33-mm needle and fin clipped. Tags were inserted at an acute angle into the base of the posterior dorsal fin on the left side of the body, similar to methods described by Guy et al. (1996). Special care was taken to ensure that tags were inserted behind pterygiophores and then properly seated by gently tugging on the tag. The upper lobe of the caudal fin was removed at a 90° angle to the fin rays to provide an easily observable second mark to identify fish tagged in 2010 (Guy et al. 1996). All walleye captured during Winnebago walleye assessments are measured in total length to the end of the upper lobe of the caudal fin; therefore, missing or partially regenerated upper caudal lobes were readily recognized as clipped fish when measured. This clip was used throughout the study to identify fish that had shed or retained their anchor tag.

Three walleye recapture periods were included in the study: instantaneous tag loss (0-11 days post tagging), tag loss occurring before and during summer tournaments (0-90 days post tagging), and tag loss occurring within the first year following tagging (annual tag loss). Instantaneous tag loss was determined during the remainder of the 2010 spawning assessments (0-11 days post tagging). Tag loss occurring before and during June tournaments (0-90 days post tagging) was determined during three catch-hold-release walleye tournaments: the 2010 Cabela's Masters Walleye Circuit's Lake Winnebago Central Division Qualifier (MWC), the 2010 Mercury Marine National Walleye Tournament (Mercury), and the 2010 Otter Street Walleye Tournament (Otter Street). All three tournaments were held on the Winnebago System during consecutive weekends in June 2010. Each tournament was treated as a replicate to establish confidence intervals for mean tag loss rates observed during this time period. Annual tag loss was evaluated during spawning assessments conducted on the Wolf River in April 2011. In addition to electro-fishing, fyke nets (1 meter high, 19 mm bar mesh) were set in spawning marshes on the Wolf River during 2011 spawning assessments.

Similar methods were used to evaluate tag loss during all three time intervals. All fish were observed for the presence/absence of a caudal clip, and the presence or absence of a tag was recorded for those fish exhibiting clipped caudal fins. Captured walleye that were fin clipped but had shed their tag were secondarily marked by removing the sixth dorsal spine in April 2010, the ninth dorsal spine in June 2010, and the lower lobe of the caudal fin in April 2011. This demonstrated that tag loss had already been documented for that fish during that time period, and would not be counted an additional time. Data

collected during April 2011 spawning assessments were separated between the two gear types. Rate of tag loss ( $R_{TL}$ ) for each individual period was calculated with the equation:

$$R_{TL} = (N_L / N_T) * 100$$

where ( $N_L$ ) represents the number of clipped fish that had shed their tag and ( $N_T$ ) represents the total number of fish observed with fin clips.

*Management implications.*—Mark data from April spawning assessments, together with capture and recapture data from June walleye tournament monitoring, were used to estimate population abundances. A sample of walleye were marked during April spawning assessments and, after release, eventually moved back downstream and dispersed throughout the Winnebago System. Walleye caught by anglers in catch-hold-release tournaments held on the Winnebago System in June were then observed for presence or absence of tags. The tournaments monitored have traditionally imposed a 381-mm minimum size limit for participants; therefore, the Wisconsin DNR estimated the abundance of male and female walleye  $\geq 381$  mm using the Chapman variation of the Peterson estimator (Ricker 1975):

$$PE = (M + 1)(C + 1) / (R + 1)$$

where M represented the number of fish marked with total lengths  $\geq 381$  mm and was calculated by subtracting the number of tagged fish harvested between tagging and summer tournaments from the total number of fish marked during spring spawning assessments, C represented the catch or the number of walleye registered at June walleye tournaments, and R represented the number of recaptured marks (walleye tagged during spawning assessments conducted during that spring) in the sample. Adjusted population

estimates were calculated by correcting the number of marked fish within the population by incorporating the estimated rate of tag loss ( $R_{TL}$ ) that occurred between the time of tagging and summer walleye tournaments (0-90 days post tagging):

$$PE = (M(1-R_{TL}) + 1)(C+1) / (R+1)$$

Tag loss estimates were also incorporated into sex-specific estimates of exploitation rates of adult walleye. Standard Winnebago System walleye assessment protocols assume a 50% return rate of tagged fish harvested by anglers when estimating annual exploitation rates ( $u$ ). Past exploitation estimates ( $u$ ) were calculated using the equation:

$$u = (N_C/0.5)/(N_T)$$

where ( $N_C$ ) represents the number of tagged fish reported by anglers as harvested and ( $N_T$ ) represents the total number of fish tagged. Exploitation estimates incorporating tag loss that occurred between tagging and summer tournaments were calculated using the equation:

$$u = (N_C/0.5)/(N_T(1-R_{TL})),$$

### *Results*

*Instantaneous tag loss (0-11 days post tagging).*—In April 2010, spawning assessments were conducted for 11 days on the Upper Fox and Wolf Rivers, during which 10,750 walleye were tagged and fin clipped. An additional 953 walleye that had previously been marked and caudal clipped during 2010 spawning assessments were recaptured, 2 of which had shed their tag (0.2% tag loss). After accounting for some fish

that were recaptured multiple times during the survey period, known from multiple recaptures of the same tag number, a total of 887 individual walleye were recaptured following tagging and fin removal during 2010 spawning assessments. Tag retention was observed in 885 of these fish, while tag loss was observed for 2 fish (0.2% tag loss).

*Summer tag loss (0-90 days post tagging).*—A total of 3,896 walleye were observed over the course of three June walleye tournaments (1,345 at MWC, 1,257 at the Mercury, and 1,294 at Otter Street) (Table 1). During these three tournaments, 65 walleye were observed with caudal clips (26 at MWC, 19 at Mercury, and 20 at Otter Street), and one caudal clipped fish that had shed its anchor tag was observed at each of the three tournaments. All three fish that had shed their tag exhibited fresh, bright red tagging scars where the tag had been inserted. Estimated tag loss rates at individual tournaments were 3.8% at MWC, 5.3% at Mercury, and 5.0% at Otter Street, with a mean loss rate of 4.7% (SD = 0.008, 95% confidence intervals of 3.8% to 5.6%) (Table 1). Despite being catch-hold-release tournaments, handling mortality does occur, and all three fish that had shed their tag were deemed un-releasable.

*Annual tag loss (~ 1 year post tagging).*—Some regeneration of the top lobe of the caudal fin occurred after one year, but the clips were still clearly discernible as regenerated rays were distorted at a different angle from original fin rays. A distinct line of scar tissue was also observed and could be felt between fingers along the area between the original and regenerated rays of the caudal fin (Figure 1). A total of 165 walleye with caudal clips were collected during electro-fishing surveys conducted in April 2011, 4 of which were sampled multiple times, meaning that 161 individual caudal marked fish

were observed (Table 2). Of these fish, 123 retained their tags and 38 had shed their tag, for an annual loss rate of 23.6%. During fyke net surveys conducted in April 2011, 158 walleye with caudal clips were collected, 4 of which were sampled multiple times, resulting in 154 individual caudal marked fish being observed. Of these fish, 123 retained their tags, while 31 had shed their tag, for an annual loss rate of 20.1% (Table 2). Mean tag loss rate among the two gear types was 21.9% (SD=0.02).

*Management implications.*—June walleye tournament monitoring provides the tag recapture data used to estimate walleye abundances within the Winnebago System. Therefore, estimates of tag loss occurring before and during this time period (4.7%) need to be accounted for to more accurately estimate population abundances. Population estimates not correcting for tag loss and spanning 1993-2010 ranged from 49,287 to 574,555 female walleye  $\geq 381$  mm with a mean of 241,792 fish (omitting the 2006 population estimate as an outlier). After incorporating the estimated 4.7% tag loss rate, estimates of population abundance ranged from 46,110 to 542,677 female walleye  $\geq 381$  mm, with a mean of 228,662 female walleye. Correcting for tag loss resulted in a mean population estimate of female walleye that was 5.5% lower than the original estimate. Without correcting for tag loss, population estimates of male walleye  $\geq 381$  mm spanning the years 1993-2010 ranged from 25,297 to 235,766 fish, with a mean abundance of 131,340 male walleye  $\geq 381$  mm (omitting the 2006 population estimate as an outlier). Adjusting for tag loss resulted in a mean population estimate of male walleye  $\geq 381$  mm that was 5.4% less than the original mean estimate (range 23,872-224,328; mean = 124,415 walleye).



From 1993-2010, unadjusted annual rates of adult female walleye exploitation ranged from 10.7% to 31.3% (mean of 21.5%). Corrected rates of exploitation varied from 11.2% to 32.9% (mean of 22.6%). Failure to adjust for tag loss rates resulted in a 1.1% mean over-estimate of adult female walleye exploitation, which is a 5.0% proportional increase over unadjusted estimates. Estimates of exploitation of adult male walleye were lower than estimated exploitation rates for adult female walleye but followed a similar trend once corrected for tag loss; the mean exploitation rate before tag loss adjustment was 14.0%, and the mean exploitation estimate after adjusting for tag loss was 14.7%. Correcting for tag loss increased the mean estimate of adult male exploitation by 0.7%, which is a 4.9% proportional increase in exploitation relative to unadjusted estimates.

### *Discussion*

Improper attachment of the tag and failure to engage the t-bar anchor between pterygiophores are the most common causes of instantaneous tag loss of t-bar anchor tags (Muoneke 1992). For example, improper attachment of Floy anchor tags increased shedding rates up to 88% in brook trout *Salvelinus fontinalis* (Keller 1971). Greenland and Bryan (1974) studied loss rates of two different models of Floy anchor tags in channel catfish at 6 weeks and 12 weeks, finding better retention of FD-67F during both time periods (70% shedding by week 6 and 90% by week 12 of FD-67 tags, 5% shedding at week 6 and 19% shedding at week 12 of FD-67F tags). They attributed the different loss rates to the fact that FD-67F tags had longer tag anchors that could more effectively

be inserted behind the interneural spines of the dorsal fin, where the FD-67 tag had shorter anchors that were likely not engaging behind the interneural spines (Greenland and Bryan 1974). My results indicate that instantaneous tag loss (0-11 days post tagging) was negligible (<0.3%), suggesting that Floy anchor tags are rarely shed due to improper tag attachment or failure to engage between interneural bones. Prior experience with tagging fish may increase proper placement of the t-bar anchor, in turn minimizing the amount of instantaneous tag loss (Davis and Reid 1982; Muoneke 1992; Fabrizio et al. 1996). The Oshkosh fisheries management crew of the Wisconsin DNR has tagged 141,000 walleye during spawning assessments conducted from 1989-2010, and their experience ensured consistent engaging of tags and minimal estimates of instantaneous tag loss.

I observed a 4.7% mean tag loss rate during the first 90 days post tagging, and my results are comparable to those of previous studies. Pegg et al. (1996) determined that 4.4% of sauger that were double tagged on the lower Tennessee River had shed their tag after a 5 month period, and researchers on Mille Lacs in Minnesota concluded that 4.3% of double tagged walleye collected 31-90 days post tagging had shed one of their tags (Schwarz 2008). Walleye in the St. Louis River exhibited a 7.5% loss of anchor tags within the first 65 days post tagging (Osborn et al. 1991).

My estimates of annual tag loss were 23.6% for walleye captured from electro-fishing and 20.1% for walleye captured in fyke nets. Reported estimates of anchor tag loss during the first year have been variable for walleye. Weeks and Hansen (2009) reported a mean annual tag loss rate of 2.9% for walleye tagged with anchor tags in the

Manitowish Chain, Wisconsin. Schwarz (2008) reported that 28.5% of double tagged walleye on Mille Lacs, Minnesota had shed an anchor tag within the first 271-360 days post tagging. Osborn et al. (1991) reported loss rates of 7.0%-17.9% after 1 year in the St. Louis River, while a study on the Woman Lake Chain, MN estimated 49%-56% loss of anchor tags after one year (S. M. Shroyer, Minnesota DNR, personal communication). Although my results are comparable to some of those studies, there remains considerable variation among estimates of anchor tag loss from different walleye populations and tagging operations.

There are numerous factors that contribute to long-term tag loss and variability in tag retention, including algal growth on the tag, snagging of tags, fish behavior, and equipment failure (Muoneke 1992). Growth of filamentous algae on the tubing of the tag is commonly discussed as a factor suspected to contribute to tag loss (Carline and Brynildson 1972; Ebener and Copes 1982; Muoneke 1992). Algal growth may increase the drag of the tag, promoting irritation of adjacent tissue (Ebener and Copes 1982). Carline and Brynildson (1972) observed the growth of filamentous algae through time on Floy anchor tags placed in brook trout and noted that algal growth may reduce the usefulness of similar tags in nutrient-rich waters. The Winnebago System is a eutrophic water body, and observed tags from recaptured walleye that were tagged during previous assessments are usually coated with filamentous algae and occasionally zebra mussels.

Snagging may contribute to long-term tag loss, resulting from entanglement in sampling gear such as gill nets and fyke nets. Tag shedding as a result of entanglement in gill nets has been documented with white sucker, lake trout, and lake whitefish (Franzin

and McFarlane 1987; Ebener and Copes 1982; Fabrizio et al. 1996). Newman and Hoff (1998) observed higher rates of jaw tag loss in walleye that were captured in fyke nets than walleye observed in creel surveys. Tag loss due to entanglement in fyke nets probably did not contribute to tag loss in this study, as annual estimates of tag loss were numerically less for fish captured in fyke nets than fish captured with electro-fishing.

Fish behavior can influence tag shedding as well. As fish move, anchor tags tend to spin, creating an open wound that could promote tag loss; spinning could also be exacerbated by algae coating the tags (Muoneke 1992; Fabrizio et al. 1996). Adult walleye in the Winnebago System are also pelagic feeders during much of the year and make long, annual spawning migrations (up to 201 km upstream), both of which increase the distance that walleye move and may contribute to tag loss. Substantial numbers of adult walleye also spend time feeding in shallow, heavily vegetated areas, which may increase rates of tag loss over time from tags catching on vegetation. Largemouth bass (Wilbur and Duchrow 1973) and brown trout (Brewin et al. 1995) may remove tags from other fish, but this behavior has not been reported for walleye.

Equipment failure also can contribute to tag loss. For example, the plastic tubing on a Floy tag may harden, become brittle, and eventually break (Muoneke 1992). Malfunction of tags has also been observed where the cement bond between the vinyl tube and the nylon shaft breaks (Tranquilli and Childers 1982). This is frequently observed on previously tagged walleye in the Winnebago System, where only the nub from the nylon shaft of the tag remains and the remainder of the nylon shaft and the sheath containing the tag information are lost. The three fish observed at June

tournaments that had shed their tags had distinct wounds where the tags had been inserted in the spring, but none of them contained tag nubs. However, multiple tag nubs were observed on walleye that had shed their tag within the first year, suggesting that equipment failure is likely contributing more toward tag loss occurring within the first year than within the first few months.

Tag loss that occurs during the first 90 days is the most important to walleye management on the Lake Winnebago System. The majority of walleye tagging occurs before April 10, and most of the harvest by anglers occurs between the end of spawning (mid April) and the middle of July. The recapture event for population estimates also occurs during this time frame. These factors make it imperative to accurately estimate tag loss occurring during this time period to produce accurate estimates of abundance and exploitation. After correcting for tag loss that occurred within the first 90 days, my estimates of population abundance decreased by roughly 5%, which was comparable to results observed by Kallemeyn (1989), who documented a decrease in estimated walleye abundance of 8.5% after correcting for tag loss. My estimates of exploitation increased 5.0% for adult female walleye and 4.9% for adult male walleye. Other studies reported that correcting for tag loss resulted in estimates of exploitation of walleye increasing by 25-59% (Kallemeyn 1989; Isermann and Knight 2005). The impacts on exploitation estimates observed in this study were substantially lower than observed in other studies because of a lower observed rate of tag loss resulting from a narrower time window where tag loss could occur (2-3 months rather than one year). By accounting for tag loss when estimating exploitation and population abundance, fisheries managers observe

higher rates of exploitation of an overall smaller population than previously estimated. Any amount of tag loss affects the accuracy of population data and should be accounted for in mark-recapture studies. Due to the variability of estimates of tag loss with differing tag types, tagging protocols, tagging experience, and fish species, it is imperative that studies be conducted to determine tag loss rates for the population being managed.

## Chapter III

### Age Validation of Walleye in the Winnebago System Using Known-Age Fish

#### *Introduction*

Accurate age data are essential for estimating rates of somatic growth and mortality, which are required for effective management of exploited fisheries. Walleye are one of the most popular and actively-managed recreational and commercial freshwater game-fish species in North America. However, walleye age estimates have not been validated for the range of ages present in most walleye populations.

Historically, scales have been the most common structure used to estimate walleye age because they are easy to collect and removal does not cause long-term damage to the fish sampled. However, extensive peer-reviewed literature has documented that scales underestimate the age of older walleye (Campbell and Babaluk 1979; Erickson 1979, 1983; Belanger and Hogler 1982; Marwitz and Hubert 1995; Kocovsky and Carline 2000) and many other fish species including yellow perch *Perca flavescens* (Vandergoot et al. 2008), white crappie *Pomoxis annularis* (Boxrucker 1986), striped bass *Morone saxatilis* (Heidinger and Clodfelter 1987; Welch 1993; Secor et al. 1995), cutthroat trout *Oncorhynchus clarkii* (Hubert et al. 1987), smallmouth bass *Micropterus dolomieu* (Heidinger and Clodfelter 1987), freshwater drum (Davis-Foust et al. 2009), and white sucker (Beamish 1973). Two factors reduce the accuracy of scales for estimating age of older fish: 1) erosion of year marks because calcium from scales can be resorbed to meet other physiological requirements and 2) crowding of annuli on the

outer edge of the aging structure as somatic growth decreases with increasing age, making annuli enumeration difficult or impossible (Simkiss 1974; Heidinger and Clodfelter 1987; Casselman 1990).

Spine and fin rays have been considered an alternative to scales for estimating fish age because they display annuli that are easier to identify, resulting in more precise age estimates (Campbell and Babaluk 1979; Frie et al. 1989; Borkholder and Edwards 2001). Like scales, collection of spines or fin rays is quick and does not pose long-term negative impacts to the fish sampled. However, as with scales, crowding of annuli occurs on the edge of the aging structure when somatic growth decreases, leading to underestimates of true age for larger, older fish (Erickson 1979, 1983; Marwitz and Hubert 1995; Logsdon 2007).

In contrast to scale and spine growth, otolith growth is not proportional to fish growth. Otoliths grow more slowly than the body during periods of rapid body growth and more quickly than the body during periods of slow body growth, which reduces the crowding of annuli that occurs near the edge of the aging structure, resulting in annuli that are easier to identify (Simkiss 1974; Casselman 1990). For this reason, otoliths tend to yield older age estimates that are more accurate and precise than age estimates from any other calcified structure (Campbell and Babaluk 1979; Erickson 1979, 1983; Heidinger and Clodfelter 1987; Kocovsky and Carline 2000; Logsdon 2007; Vandergoot et al. 2008; Davis-Foust et al. 2009). Erickson (1983) determined that mean age estimates derived from dorsal spines were lower than estimates from otoliths for walleye older than 11 years in Eardley Lake and 10 years in Obukowin Lake, Manitoba.



Vandergoot et al. (2008) determined that anal spines underestimated the age of Lake Erie yellow perch older than age-6 relative to otoliths and suggested that otoliths be used to age individuals in populations with a high proportion of older fish.

Although numerous studies have compared age estimates from calcified structures for walleye (Campbell and Babaluk 1979; Erickson 1983; Heidinger and Clodfelter 1987; Kocovsky and Carline 2000), few have compared the accuracy of walleye age estimates from various structures. Otolith age estimates have been validated for many other fish species including freshwater drum up to age-52 (Davis-Foust et al. 2009), lake sturgeon up to age-53 (Bruch et al. 2009), striped bass ages-3-7 (Secor et al. 1995), and largemouth bass up to age-16 (Taubert and Tranquilli 1982; Buckmeier and Howells 2003). However, to my knowledge there are no studies from the peer-reviewed literature that have examined the accuracy of walleye age estimates derived from otoliths, or any aging structure, using known-age fish from a wide range of age classes. Erickson (1983) assessed the accuracy of age estimates derived from scales and otoliths from 100 known-age walleye from a single year class, age-3, and Heidinger and Clodfelter (1987) investigated the accuracy of various aging structures from 0 to 4 year old known-age walleye. Although these studies made valuable contributions to the fisheries literature and expanded the understanding of the accuracy of age estimates, they do not include the complete range of walleye age groups and thus do not meet the standards required for full age validation (Campana 2001). Validation of age estimates from all age groups is necessary for assessing age group bias and the impacts that aging error can have on management decisions (Buckmeier and Howells 2003).

Although most aging structures from younger fish are generally believed to yield relatively accurate age estimates (Frie et al. 1989), the accuracy of age estimates for older walleye is unknown and has not been addressed by previous studies. My study objective was to determine the accuracy and precision of age estimates derived from otoliths and dorsal spines for walleye in the Winnebago System. I addressed this objective by comparing dorsal spine and otolith age estimates to the known-age (ages-1-16) of walleye collected during fisheries assessments (2009-2011). Given my ability to assess accuracy of age estimates from a wide range of age classes, this study provides the most comprehensive evaluation of walleye age estimates to date.

### *Methods*

*Collection of known-age fish.*—Known-age walleye, ages-0-3, from the abundant 2008 year class were sampled monthly during August-October 2008, May-October 2009, April-October 2010, and April 2011 to monitor modal length progression of the year class (Campana 2001). The 2008 walleye year class was the second largest year class documented on the Winnebago System since 1986 and was preceded in 2007 and followed in 2009 by weak year classes (Figure 2). Growth of 0-3 year old walleye in the Winnebago System is very rapid, and the 2008 year class could be identified from length frequency plots from August 2008-April 2011 and were thus known-age fish (Appendix A). A sample size of at least 100 walleye  $\leq 381$  mm was collected and measured during nighttime electro-fishing surveys conducted on Lake Winnebago during May and June (2009-2010) and April 2010, daytime electro-fishing during spawning assessments on the

Wolf River in April 2011, and bottom trawling on Lake Winnebago during 1-2 days (10-15 total trawl hauls) in July (2009-2010) and five days (46 total trawl hauls) in each month of August-October (2008-2010). Electro-fishing was conducted with a standard Wisconsin-style boom shocker with pulsed D/C current (5-13 amperes, 50 pulses/second, duty cycle of 25). Trawling assessments were conducted with a balloon trawl, similar to that described by Davis-Foust et al. (2009), towed five minutes per haul at a speed of 6.6 kilometers per hour, resulting in a sampling area of 0.405 hectares per haul. Total length of all captured walleye was measured to the nearest 2.5 mm. A stratified random sample of five fish per 12.7 mm length class of walleye  $\leq 381$  mm was euthanized to collect dorsal spine and otolith samples in May 2009, August 2009, April 2010, and April 2011. Age estimates from dorsal spines and otoliths were compared to known-ages assigned from length-frequency plots to determine the accuracy of age estimates from each structure. Sex and maturity were determined for all euthanized fish by visual examination of the shape, color, and development of the gonads (WI DNR, Oshkosh, unpublished data).

Since 1989, the Wisconsin Department of Natural Resources has used Floy anchor tags (FD-94, Floy Tag Inc., Seattle WA) to annually mark spawning walleye on the Upper Fox and Wolf Rivers. Recaptured adult male walleye that were initially tagged at an age (ages-3-4) that could be reasonably approximated ( $\pm 1$  year) based on length were utilized as known-age fish (Campana 2001). Preliminary otolith and dorsal spine age estimates showed that adult male walleye  $< 343$  mm were typically 3 years of age, while adult male walleye 343-381 mm were 4 years of age. As stated earlier, previous

studies have determined that otolith age estimates from 0-4 year old known-age walleye were accurate (Erickson 1983; Heidinger and Clodfelter 1987) and that estimates from dorsal spines and otoliths correlate well for younger fish (Erickson 1983; Logsdon 2007). Therefore, age at tagging could be assigned with relative confidence ( $\pm 1$  year) to adult male walleye that were tagged at total lengths  $\leq 381$  mm. The known-ages of these larger walleye were determined by adding the number of years at large since tagging to the assigned age at tagging. A similar approach for establishing known-age fish was used for validating age estimates of lake sturgeon (Bruch et al. 2009), bluefin tuna *Thunnus thynnus* (Lee and Prince 1995), and yellow tail flounder *Limanda ferruginea* (Dwyer et al. 2003).

Known-age walleye older than age-3 were sampled during April spawning assessments (2009-2011) conducted in spawning marshes on the Upper Fox and Wolf Rivers using electro-fishing (3-6 amperes, all other settings as described earlier). Fyke nets (1 meter high, 19 mm bar mesh) were also set in spawning marshes to collect spawning walleye in 2011. Sex and reproductive stage (ripe for males; green (hard), ripe, or spent for females) were determined for each captured fish based on extrusion of gametes. Total length of all fish was measured to the nearest 2.5 mm, and the first 50 fish at each location were weighed to the nearest 9 grams. Presence or absence of a Floy anchor tag was observed, and all untagged fish were tagged using a Floy Mark II tagging gun (Floy Tag and Manufacturing Inc.) equipped with a 33-mm needle. Tags were inserted at an acute angle into the base of the left posterior dorsal fin, similar to methods described by Guy et al. (1996). Special care was taken to ensure that tags were inserted

behind pterygiophores and then properly seated by gently tugging on the tag. Tag numbers from recaptured walleye were read and referenced against a list of known-age fish (adult male walleye tagged in 2005 or later that were initially tagged with total lengths  $\leq 381$  mm). All recaptured walleye that were on the list were euthanized to collect aging structures which were used to estimate age as described below. Recaptured walleye that were tagged before 2005 were also euthanized to collect aging structures. These fish were considered known-age walleye if they were initially tagged at lengths  $\leq 381$  mm, known from past tagging history.

*Additional sampling of aging structures.*—Adult male and female walleye were captured during April spawning assessments (2009-2011) with electro-fishing and fyke netting methods described above. A trumpeted random sample of adult male walleye were euthanized during April spawning assessments (2009-2011) to obtain a representative aging sample of paired otoliths and dorsal spines for each 12.7 mm size class (8-16 fish per length class with increased sampling in larger size classes). These age estimates were used to construct sex-specific catch curves, as described below, and to better understand the relationship between ages assigned from dorsal spines and otoliths.

The Winnebago System hosts over 65 walleye tournaments annually, which provide an ideal opportunity to collect aging structures from walleye tournament mortalities. Wisconsin DNR personnel collect biological data from select tournaments held on the Winnebago System as part of standardized walleye management activities. Two tournaments, the 2009 Mercury Marine National Walleye Tournament (Mercury) and the 2009 Otter Street Walleye Tournament (Otter Street), were monitored in 2009

while three tournaments, the Cabela's Masters Walleye Circuit's Lake Winnebago Central Division Qualifier (MWC), the 2010 Mercury, and the 2010 Otter Street, were monitored in 2010. These tournaments follow self-imposed 381 mm minimum size limits, which allowed us to sample walleye  $\geq 381$  mm. After weigh in, angler-registered walleye were deemed releasable or un-releasable. All un-releasable fish were considered dead and were weighed to the nearest 9 grams and total length was measured to the nearest 2.5 mm. Sex and maturity of each dead fish was determined using established criteria based on color, shape, and development of the gonads used in the Winnebago walleye management program (WI DNR, Oshkosh, unpublished data). Dorsal spines and otoliths were removed from a trumpeted random sample of female walleye (8-16 fish per 13 mm length class with increased sampling in larger size classes), and these age estimates were used to construct sex-specific catch curves to better understand the relationship between ages assigned from dorsal spines and otoliths.

Dorsal spines and otoliths were also collected from walleye sampled during other research activities conducted on the Winnebago System throughout the study (2009-2011), including during disease testing and trawling assessments. Age estimates from fish sampled during these assessments supplemented age estimates collected from known-age walleye, fish sampled during April spawning assessments, and walleye sampled during June tournament monitoring. Collectively these age estimates were used to determine the relationship between age estimates derived from otoliths and dorsal spines for both male and female walleye. These age estimates were also used to calculate precision of age estimates derived from otoliths and dorsal spines.

*Fish age estimation from calcified structures.*—The second or third dorsal spine was removed from each walleye sampled by cutting the spine as close to the skin interface as possible with surgical nail nippers. Spine samples were placed in sample envelopes and allowed to dry for a minimum of two weeks. Excess dry tissue was removed before using a Buehler Isomet low speed saw to cut 0.30 - 0.50 mm sections, using glycerol as a blade lubricant. Reader 1, with 40+ years of aging experience, estimated the age of the spine sections (by counting the number of annual growth rings) using a Meiji microscope at 25-45X magnification with dark field transmitted light. Reader 2, with four years of experience, aged the sections with an Olympus SZX7 stereomicroscope at 25-56X magnification using dark field transmitted light, and archived the images with an Olympus DP 71 camera attached to the microscope. Age estimates from both readers were made without any knowledge of fish sex or size, and these data were used to calculate precision of dorsal spine age estimates. Age estimates from reader 1 were used to compare age estimates derived from dorsal spines and otoliths, because this reader had aged every spine collected since the walleye assessment and tagging program began on the Winnebago System in 1989, ensuring consistency between past and present aging techniques for error assessment.

After removal, otoliths were placed in sample vials to prevent breakage, and allowed to air dry for a minimum of one month. Otoliths were then embedded in Epo-Quick two-part epoxy for a minimum of 24 hours before 0.30 – 0.40 mm sections were cut using a South Bay Technology low speed diamond wheel saw, Model 650, using water as a blade lubricant. Otolith reader 1 (spine reader 2) estimated age from the cross

sections (by counting the number of annual growth rings) using an Olympus SZX7 stereomicroscope at 25-56X magnification with bright field transmitted light. Isopropyl alcohol (50%) was occasionally used to help clear sections, and no polishing was done. An Olympus DP 71 camera was used to archive photographs of the sections for age assignment from a second reader (otolith reader 2), with two years experience reading otolith cross sections. Otolith age estimates from both readers were determined without knowledge of fish sex and size and were used to calculate precision. Age estimates from otolith reader 1 were used for comparisons between otolith and dorsal spine age estimates.

*Assessing accuracy and precision of age estimates.*—Age bias plots provide the best method for detecting linear and nonlinear biases (Campana et al. 1995) and were constructed to assess accuracy of age estimates from otoliths and dorsal spines. Assigned ages from known-age walleye sampled during the progression of the length mode procedures and mark-recapture exercises represented the known-age, and were plotted against mean age estimates derived from dorsal spines and otoliths for each age class. Age estimates from all paired aging structures collected throughout the study (known-age fish, April spawning assessments, June tournament monitoring, and any additional sampling) were incorporated into age bias plots (otolith age plotted against mean dorsal spine age estimate) to determine whether systematic differences existed between age estimates derived from otoliths and dorsal spines for male and female walleye (Campana et al. 1995).



Coefficient of variation ( $CV = 100 * SD/mean$ ) and percent agreement were calculated to assess the precision of age estimates derived from dorsal spines and otoliths (age estimates from male and female walleye were analyzed independently). CV of age estimates derived from dorsal spines and otoliths were calculated for each individual fish collected throughout the study (as described above). These data were then used to calculate mean CV for the composite samples (male and female walleye independently analyzed); mean CV was also calculated for each age class (as aged by spine and otolith reader 1) to assess whether precision varied with increasing age. Percent agreement, percent of cases where age estimates were identical between the two readers, between dorsal spine and otolith age estimates derived from readers 1 and 2 were also calculated (male and female walleye analyzed independently) for each age class (as aged by spine and otolith reader 1) to assess whether precision of age estimates varied with increasing age.

*Age corroboration through catch curve analysis.*—Since I was unable to adequately sample known-age walleye older than age-10, I constructed sex-specific catch-curves to corroborate age estimates from older walleye by observing whether estimated strong age classes (age distributions derived from otolith and dorsal spine age estimates) corresponded with strong year classes from empirical catch per unit effort (CPUE) data (CPUE of age-1 walleye during fall trawling assessments) (Campana 2001). Otolith and dorsal spine age data from adult male walleye collected during April spawning assessments and adult female walleye collected during June tournament monitoring were incorporated into structure and sex-specific age-length keys to assign

ages to all fish sampled during April spawning assessments conducted in each year (2009-2011) (Ricker 1975). Ages were assigned to all fish collected during spawning assessments to observe the relative abundances of year classes within the sample. Due to the active involvement of citizens in the Winnebago System walleye management program and the high-profile fishery of the Winnebago System, I was unable to euthanize adequate sample sizes of adult female walleye during April spawning assessments. I was thus forced to collect age structures from female walleye sampled within length classes during June tournament monitoring and apply these age data through age-length keys to assign ages to female walleye captured during April spawning assessments. Assigned ages from age-length keys were then used to construct structure and sex-specific catch curves for adult male and female walleye collected during spawning assessments conducted on the Winnebago System in April of each year (2009-2011) (Robson and Chapman 1961). The first ages represented in catch curves were age-4 for male walleye and age-5 for female walleye (ages at which >85% of male walleye and >95% of female walleye are mature) (WI DNR, Oshkosh, unpublished data). Residual values from structure and sex-specific catch curves were calculated to represent relative strength of age classes within the samples. These values were calculated by subtracting the predicted value for each age class (calculated by inserting the age into the equation from the linear regression of the  $\log_e(\text{number of fish sampled})$  on the age class of walleye) from the observed value in the catch curve. CPUE values for age-1 walleye captured during standardized trawling assessments on Lake Winnebago (spanning 1986-2010) were used as a measure of year class strength. Residual values from the catch curves and trawling

CPUE of age-1 walleye were standardized and scaled to have a mean of 0 and a standard deviation of 1, and then plotted (age vs. standardized year class strength (CPUE age-1 walleye) and age vs. standardized estimates of age class strength (catch curve residuals)). Pearson product moment correlation coefficients ( $r$ ) were also calculated to determine the amount of agreement between the standardized CPUE values from trawling assessments and the standardized residual values from otolith and dorsal spine based catch curves. Strong correlation between standardized year class strength and age specific standardized catch curve residuals would provide corroboratory evidence that age estimates are accurate for ages included within the catch curves.

### *Results*

*Accuracy of age estimates.*—A total of 298 known-age walleye were collected during the study period, of which 297 were ages-1-10, and one walleye was age-16 (Table 3, Figure 3). Known-ages of 142 fish (ages-1-3) were assigned by following the modal growth of the 2008 year class (Appendix A), and known-ages (ages-4-16) were assigned to the remaining 156 walleye using mark recapture techniques (Campana 2001). Growth increments were distinct on otolith cross sections from walleye of all lengths and ages (Figure 4). Inner annuli on dorsal spines were clearly discernible for most fish, but outer annuli were difficult to identify with confidence for older fish due to crowding of annuli at the edge of the structure (Figure 4). Mean age estimates derived from dorsal spines significantly overestimated the known-age of 2 and 4 year old walleye, represented by the 95% confidence intervals around the mean dorsal spine age estimates

not overlapping with the 1:1 agreement line (Table 3, Figure 3). Conversely, mean dorsal spine age estimates were significantly lower than known-age for walleye 6, 7, and 10 years of age, represented by the 95% confidence intervals around the mean dorsal spine age estimates not overlapping with the 1:1 agreement line (Table 3, Figure 3). Mean spine age estimates from known-age walleye 8 and 9 years of age were younger than true age, but the 95% confidence intervals around the mean dorsal spine age estimate contained the 1:1 agreement line, meaning these age estimates were not significantly underestimated. Mean age estimates from dorsal spines underestimated known-age of walleye age-10 and older by more than 2 years, and the only 16 year old known-age walleye was estimated by dorsal spines to be 12 years old. Mean age estimates from otoliths corresponded well ( $\pm 1$  year) with known-age for all ages of walleye sampled (Table 3, Figure 3). The 95% confidence intervals around the mean otolith age estimates contained the known-age of all age classes of known-age fish sampled (except for ages-5 and 6), including the 16 year old known-age walleye (Figure 3).

*Age corroboration through catch curve analysis.*—Estimated age distributions of adult male and female walleye observed in catch curves constructed from otolith age estimates correlated well with empirical year class strength data from age-1 assessment trawling, while age distributions developed from dorsal spine age estimates correlated poorly (Table 4, Appendix B). Strong age classes observed in catch curves constructed from otolith age estimates correlated well with strong year classes of walleye from trawling data, while weaker age classes observed in catch curves correlated well with weaker year classes (Appendix B). These correlations were very poor when sex-specific

catch curves were built from dorsal spine age estimates (Table 4, Appendix B). Age distributions of female walleye derived from dorsal spine age estimates did agree well with year class strength up to age-8, but agreed poorly for older fish (Appendix B). When using otoliths to estimate fish age, the oldest walleye within the population were estimated to be age-18 in 2009, age-19 in 2010, and age-20 in 2011. These age classes all represent the 1991 year class, which was the first strong year class encountered after assessment trawling began in 1986 (Figure 2). No fish were estimated to be older than age-16 with dorsal spines. The close relationship between year class strength from trawling data and estimated year class strength observed within otolith-based catch curves corroborates otolith age estimates, suggesting that otolith age estimates are accurate for all ages of fish. This relationship was not observed when dorsal spines age estimates were used to construct catch curves, suggesting that dorsal spines were not yielding accurate age estimates for walleye.

*Additional sampling of aging structures.*—Paired aging structures were collected from 2,181 walleye (1,161 male walleye and 1,020 female walleye, known-age fish included). Estimated ages from otoliths ranged from 0-20 years for male walleye and 0-19 years for female walleye, while age estimates derived from dorsal spines ranged from 0-16 years for both male and female walleye (Figure 5). Age estimates from dorsal spines and otoliths correlated well for both male and female walleye ages-0-6, but otoliths yielded significantly older age estimates than dorsal spines for walleye age-7 and older (Figure 5). Discrepancies between mean age estimates derived from the two structures ranged from -0.31 years to 7.40 years for male walleye and -0.22 to 5.00 years

for female walleye. Discrepancies between structure-based age estimates increased with increasing age for both sexes (Figure 5).

*Precision of age estimates.*—Otolith age estimates were more precise than dorsal spine age estimates for both male (otolith CV = 0.92%, dorsal spine CV = 6.24%) and female walleye (otolith CV = 0.53%, dorsal spine CV = 6.08%) (Figure 6). There were no trends between age and estimated CV values (Figure 6). Percent agreement between readers was higher for otolith age estimates than dorsal spine age estimates for both male and female walleye (Figure 6). Percent agreement of otolith age estimates between readers was greater than 95% for 15 of the 17 age classes observed in female walleye and 13 of the 20 age classes observed in male walleye. Otolith age estimates from two age classes of male walleye had poor precision (age-17 and age-20), both of which contained small sample sizes. Percent agreement of dorsal spine age estimates decreased with increasing fish age, a trend not observed with percent agreement of otolith age estimates (Figure 6). Mean age estimates from spine reader 2 were in close agreement with age estimates from spine reader 1 for male walleye estimated to be ages-0-9 and female walleye estimated to be ages-0-11 (Figure 7). However, the less-experienced spine reader (reader 2) was estimating younger mean age estimates, relative to age assignments from reader 1, for male walleye estimated to be age-10 and older and female walleye estimated to be age-12 and older (Figure 7). No apparent bias was observed in reader agreement for otolith age estimates (Figure 7).

### *Discussion*

My age validation results using known-age walleye collected from the combination of monitoring the modal length progression of the 2008 year class and mark-recapture methods complement previous literature reporting that otolith age estimates were accurate for walleye up to age four (Erickson 1983; Heidinger and Clodfelter 1987). In fact, my results verified that otolith age estimates are accurate up to at least age-10, and strong corroboratory evidence from catch curve analyses suggests that otolith age estimates are accurate for older ages as well. These results add to the growing body of literature demonstrating that otolith-based age estimates are accurate, which has been reported for largemouth bass up to age-16 (Taubert and Tranquilli 1982; Buckmeier and Howells 2003), freshwater drum to age-52 (Davis-Foust et al. 2009), lake sturgeon to age-53 (Bruch et al. 2009), and 3 to 7 year old striped bass (Secor et al. 1995).

The strong correlation between year class strength and age-specific standardized catch curve residuals from otolith age data provide strong corroboratory evidence that age estimates from otoliths are accurate for walleye of all ages. Further, otolith age estimates accurately represent the age distribution of the spawning stock and that catch curves and the resultant estimates of total annual mortality are sound. Standardized residuals from catch curves developed using dorsal spine age estimates did not correlate well with standardized year class strength data, suggesting that spine age estimates, unlike otolith age estimates, were not accurately representing the age distribution of the spawning stock and subsequently provide inaccurate estimates of total annual mortality from catch curves. The persistent presence of fish from the strong 1991 year class in each sampling

year from 2009-2011 also corroborates the accuracy of otolith age estimates. Ultimately the Wisconsin DNR will gain important insight into the longevity of walleye in the Winnebago System as they continue to follow this year class through time via otolith age sampling. A similar phenomenon was observed for the 1983 year class of freshwater drum in Lake Winnebago, in which this year class was consistently represented in otolith age frequencies between 1986 and 2009 (Davis-Foust et al. 2009).

My extensive data set of otolith and dorsal spine age data (including fish of known and unknown ages) supported the observation, based on known-age fish, that age estimates from dorsal spines and otoliths diverge at older ages, with otoliths yielding older age estimates for walleye age-7 and older. Logsdon (2007) observed that age estimates from unsectioned dorsal spines were effective at replicating otolith ages of walleye younger than age-7 from Red and Mille Lacs Lakes in Minnesota, but were underestimating age of larger, older fish. Age estimates from scales tended to underestimate age of yellow perch in Lake Erie age-4 and older relative to otoliths, and although age estimates from anal spines were more precise than age estimates from scales, they still underestimated the age of older perch relative to otoliths (Vandergoot et al. 2008).

Younger fish are typically easier to age with all structures because growth is more rapid, resulting in wider growth increments that are easier to identify (Frie et al. 1989). However, following maturation fish begin to allocate more energy into gonadal growth and less into somatic growth. The result is smaller growth increments on the edge of bony structures that are more difficult to enumerate, which leads to age underestimation



of older fish (Borkholder and Edwards 2001; Logsdon 2007). Growth of otoliths continues throughout a fishes lifetime and annuli tend to be distinct regardless of life stage. Therefore, outer annuli are more readily identifiable, increasing the validity of age estimates derived from otoliths (Campana and Neilson 1985; Davis-Foust et al. 2009).

The differences between dorsal spine and otolith age estimates were more pronounced for male walleye than female walleye. Kocovsky and Carline (2000) attributed differences in relative precision of age estimates between male and female walleye to gender-related differences in growth and age at sexual maturity. Female walleye typically have greater asymptotic lengths than male walleye and continue to grow after reaching maturity. Slower somatic growth rates for male walleye likely result in more extreme crowding of annuli near the edge of the dorsal spine section, resulting in annuli that are more difficult to accurately identify (Kocovsky and Carline 2000).

Faster growing fish can be more reliably aged than slower growing fish, and many factors such as trophic status, level of exploitation, and population density can affect fish growth and in turn the accuracy and precision of age estimates (Belanger and Hogler 1982; Frie et al. 1989; Robillard and Marsden 1996; Kocovsky and Carline 2000). Erickson (1979, 1983) estimated similar ages from scales, sectioned dorsal spines, and sectioned otoliths for walleye in Lakes Winnipeg and Winnipegosis, Manitoba, where walleye are heavily exploited and exhibit fast somatic growth rates. In contrast, scales and dorsal spines underestimated the age of older fish relative to otoliths in Lakes Eardley and Obukowin, Manitoba, where walleye experience little to no exploitation and have slower growth rates (Erickson 1979, 1983). The Winnebago System is a eutrophic

water body with moderate to high levels of exploitation ( $\mu$ ) (mean  $\mu$  values of 22.6% for female walleye and 14.7% for male walleye spanning 1993-2010) (WI DNR, Oshkosh, unpublished data), which theoretically should contribute to above average growth rates of walleye and increased accuracy of age estimates from dorsal spines. Despite relatively fast growth, my results indicated that age estimates from dorsal spines consistently underestimated the age of walleye age-7 and older relative to otoliths. Given the longevity of walleye within the Winnebago System (20+ years) and the potential to live even longer in more oligotrophic waters in northern latitudes, it is imperative that the relationship between age estimates from otoliths and dorsal spines (or scales) is well understood. Age estimates from otoliths and other structures should periodically be compared to monitor changes in growth and growth increment formation that may result from changes in lake trophic status, exploitation, densities, forage, or other factors (Belanger and Hogler 1982; Marwitz and Hubert 1995).

I observed that age estimates from otoliths were more precise than those from dorsal spines, which complements past studies that reported precision of walleye age estimates (Marwitz and Hubert 1995; Kocovsky and Carline 2000; Isermann et al. 2003; Logsdon 2007), largemouth bass (Maceina and Sammons 2006), striped bass (Welch et al. 1993), and yellow perch (Vandergoot et al. 2008). More subjective interpretation of annuli is required when aging scales, fin rays, and spines, while annuli present on otoliths are typically more readily observable.

Reader experience can impact fish age estimation, but this appears to be dependent on the type of structure used. Vandergoot et al. (2008) observed that scale and

anal spine age estimates from a less-experienced reader underestimated age of Lake Erie yellow perch over age-4 relative to an experienced reader. In this study, the more experienced dorsal spine reader yielded older age estimates for larger walleye than the less experienced dorsal spine reader, while there was no difference in otolith age estimates between the two readers. These trends suggest that less training would be required to precisely and accurately estimate age with otoliths relative to dorsal spines and that other errors such as reader drift would be less of a factor when estimating age with otoliths.

Although extensive peer-reviewed literature has reported that scales and dorsal spines underestimate the age of older fish, this understanding has typically not been incorporated into fish aging strategies used by state and provincial agencies in the United States and Canada. Maceina et al. (2007) surveyed 45 state and 6 provincial agencies about fish aging practices and reported that agencies estimated age of percids using mostly scales (25 agencies, 8 exclusively) and otoliths (29 agencies, 10 exclusively), with 8 agencies reporting using spines and 1 using fin rays. Despite the wide use of scales, only 27% of the respondents felt that scale age estimates were accurate for estimating the age of older fish of any species. Most agencies felt that otoliths provided the most accurate age estimates (Maceina et al. 2007). I did not determine the accuracy or precision of age estimates from scales for walleye in the Winnebago System, but my results showed that age estimates from the structure of choice from 1989-2008, dorsal spines, underestimated the age of larger, older walleye. I recommend that accuracy of aging techniques be assessed whenever possible.

The strategy of following the progression of the length mode of the abundant 2008 year class worked well for sampling 1-3 year old known-age fish because the year class was clearly observable in length frequency plots. This technique can easily be applied to evaluate accuracy of age estimates from young fish in other populations. Independent age estimates of young fish also helps to identify the location of the first annulus, which is critically important but often problematic (Beamish 1973; Hubert et al. 1987; Isermann et al. 2003). Marking of young fish followed by recapture can also be a useful method for collection of known-age fish. The marking of young walleye with anchor tags was effective for sampling fish 1-7 years at large, but permanent marking of young, known-age fish by fin removal is the best marking technique. When marking fish with fin removal, the fin needs to be removed in a manner that ensures regeneration does not confound the ability to recognize marked fish in later years. Marking fish with tags exhibiting greater retention rates, such as PIT tags, also would be a superior method for marking young, known-age fish. By utilizing the combination of modal progression and mark-recapture surveys, managers can assess accuracy of age estimates from numerous age classes in a relatively short period of time, especially if methods for marking young fish are already in place. I was fortunate to have known-age fish from multiple age classes already marked in the Winnebago System walleye population before this study was initiated and was thus able to validate age estimates of walleye ages 1-10 in a period of three years.

Based on the results of this study, I recommend that otoliths be used to age walleye, as age estimates from otoliths are more accurate and precise than age estimates

from any other structure. Aging with otoliths does require euthanizing fish, which is viewed as an obstacle by many fisheries managers. However, in most exploited walleye populations the number of fish sacrificed in age-structured subsamples for otolith removal is relatively small compared to the total harvest by anglers (Isermann et al. 2003). In scenarios where fish cannot be justifiably euthanized during fisheries surveys, I recommend collecting paired aging structures from dead fish whenever possible (e.g. lethal testing and harvest by recreational anglers, Native American tribes, and commercial fisherman). By aging paired structures, managers can better understand the relationships that exist between age estimates from these structures and the impacts that aging error has on growth and mortality dynamics within their fish population, which can lead to more effective management of the fishery. Kocovsky and Carline (2000) compared walleye age estimates derived from scales, dorsal spines, and otoliths and developed a sampling protocol where non-lethal structures were used to estimate age of fish <500 mm and otoliths were used to accurately estimate age of fish >500 mm. Welch et al. (1993) developed a similar age sampling protocol, where anal spine and otolith age estimates were within 1 year of each other for striped bass <900 mm total length (10 years of age), but otoliths yielded older age estimates for fish >900 mm. Error in scale and spine age estimates can be corrected using an age-error matrix to adjust past age estimates to more accurately estimate rates of growth and mortality (Secor et al. 1995; Bruch et al. 2009).

Given the substantial impacts that aging error can have on estimates of fish growth and mortality and that different populations experience different environmental

factors and growth rates, it is important to investigate the accuracy of aging structures within each population whenever possible (Beamish and McFarlane 1983; Schram 1989; Robillard and Marsden 1996; Kocovsky and Carline 2000; Maceina and Sammons 2006; Vandergoot et al. 2008). Using inaccurate spine and scale age data underestimates fish age and overestimates mortality rates (Rien and Beamesderfer 1994; Robillard and Marsden 1996; Kocovsky and Carline 2000; Vandergoot et al. 2008), which negatively affect the ability of fisheries managers to make meaningful decisions about their fishery, particularly when setting harvest quotas.

## Chapter IV

### Impacts of Aging Error on Walleye Management in the Winnebago System

#### *Introduction*

Walleye are one of the most popular and actively-managed recreational and commercial freshwater gamefish species in North America, and extensive research has been conducted to determine the relationships between age estimates derived from various structures, including scales, spines, fin rays, vertebrae, cleithra, and otoliths. The majority of these studies have concluded that age estimates from otoliths are the most accurate and precise, and although age estimates from non-lethal structures (scales, spines, and fin rays) typically agree with otolith age estimates for fish up to a critical size, they underestimate the age of larger, older fish (Campbell and Babaluk 1979; Erickson 1979, 1983; Serns and Kempinger 1981; Heidinger and Clodfelter 1987; Kocovsky and Carline 2000; Logsdon 2007; Vandergoot et al. 2008; Bruch et al. 2009; Davis-Foust et al. 2009). If fisheries managers can identify this critical size for individual species, a sampling protocol can be developed where non-lethal structures can be used to accurately estimate age of smaller fish, and otoliths are used to accurately assign age to larger fish. Welch et al. (1993) observed that age estimates from anal spines and otoliths were within 1 year of each other for striped bass of total lengths <900 mm, while otoliths yielded older age estimates than scales for striped bass >900 mm. Scales were also used to estimate age of walleye <500 mm in Pymatuning Sanctuary, Pennsylvania, but otoliths

were required to accurately estimate age of walleye >500 mm (Kocovsky and Carline 2000).

Aging error reduces the accuracy of estimates of somatic growth, recruitment, and mortality, which are the three major factors that drive population dynamics (Ricker 1975; Beverton 1987; Colvin 1991; Maceina et al. 1998; Quist et al. 2004). Underestimating the age of older fish causes fish to be assigned to the wrong year classes, which reduces the accuracy of recruitment indices and causes inflated estimates of somatic growth and mortality (Beamish and McFarlane 1983; Rivard 1989; Bradford 1991; Rien and Beamesderfer 1994; Robillard and Marsden 1996; Kocovsky and Carline 2000; Maceina and Sammons 2006).

Using under-estimated age data when making harvest management decisions can lead to incorrect management decisions which may result in overexploitation of a fish stock. Systematic underestimates of age with scales, dorsal fin rays, and pectoral fin rays resulted in substantial bias in parameter estimates of mortality, somatic growth, and yield models for walleye pollock (*Theragra chalcogramma*) in the Bering Sea, and the population would be over-fished if the estimated optimal fishing mortality rate was utilized in the walleye pollock management program (Lai and Gunderson 1987). Age underestimation of red snappers (*Lutjanus erythropterus*, *L. malabaricus*, and *L. sebae*) of the Great Barrier Reef caused overestimates of natural mortality that would lead to serious over fishing if these natural mortality estimates were incorporated in the red snapper management program (Newman et al. 2000). Similarly, age estimation errors for cod (*Gadus morhua*) in the eastern Baltic Sea led to overly-optimistic Total Allowable Catch estimates (Reeves 2003).



The Winnebago System walleye fishery is nationally recognized, and accurate age data are required to estimate and track mortality rates for effective management of the fishery. Age estimates from known-age walleye collected from the Winnebago System showed that dorsal spines underestimated the age of walleye age-7 and older, while age estimates from otoliths were accurate for walleye up to at least age-10 with strong corroboratory evidence that age estimates were accurate for all ages of walleye (Koenigs et al., in prep). My objectives were: 1) to determine the impacts that aging error inherent with dorsal spine age assignments had on estimates of age distribution and mortality and somatic growth rates of walleye in the Winnebago System; and 2) to design a sampling protocol for collecting age structures that would provide accurate age estimates for walleye in the Winnebago System.

### *Methods*

*Fish collection.*—Adult walleye were collected during April spawning assessments (2009-2011) on the Upper Fox and Wolf Rivers via electro-fishing using a standard Wisconsin-style boom shocker with pulsed D/C current (25% duty cycle, 50 pulses per second, conductivities of 330-370  $\mu\text{mhos/cm}$ , typically producing an electrical field of 100 volts at 5 amps or less). In addition to electro-fishing, fyke nets (1 meter high, 19 mm bar mesh) were set in spawning marshes during 2011 spawning assessments. Sex and reproductive stage (ripe for males; green (hard), ripe, or spent for females) were determined for all captured fish based on extrusion of gametes. Total length of all fish was measured to the nearest 2.5 mm, and the first 50 fish at each

spawning location were weighed to the nearest 9 grams. Trumpeted random samples of adult male walleye were euthanized to obtain a representative aging sample for each 12.7 mm size class (8-16 fish per 12.7 mm length class, with increased sampling of larger size classes). Age assignments from otoliths and dorsal spines were independently used to estimate age, somatic growth, and mortality of adult male walleye, and estimates of these population characteristics were compared to assess the impacts that underestimating fish age with dorsal spines has on the Winnebago System walleye management program. All walleye that were not euthanized for sampling were marked with Floy anchor tags (FD-94) using a Floy Mark II tagging gun (Floy Tag and Manufacturing Inc.) equipped with a 33-mm needle. Tags were inserted at an acute angle into the base of the left posterior dorsal fin, similar to methods described by Guy et al. (1996). Special care was taken to ensure that tags were inserted behind pterygiophores and then properly seated by gently tugging on the tag. Each tag contained a unique number sequence and the address of the Wisconsin DNR in Oshkosh. Tag returns from angler-harvested walleye were used to estimate exploitation rates ( $u$ ) of adult walleye using the equation:

$$u = (N_C / 0.5) / (N_T) * 100$$

where ( $N_C$ ) represented the number of tagged fish reported by anglers as harvested and ( $N_T$ ) represented the total number of fish tagged during spawning assessments conducted that spring, and the 0.5 represented the 50% tag return rate by anglers, a standard value used as part of the Winnebago walleye management program that has been vetted over time, 1989-2011 (WI DNR, Oshkosh, unpublished data).

The Winnebago System hosts over 65 walleye tournaments annually, which provide an opportunity to collect aging structures from walleye mortalities  $>381$  mm (most Winnebago System walleye tournaments self impose a 381 mm size limit). Two tournaments were monitored in June 2009, while three tournaments were monitored in June 2010. After weigh-in, walleye were deemed releasable or un-releasable by WI DNR personnel, and all un-releasable fish were measured to the nearest 2.5 mm total length, weighed to the nearest 9 grams, and sex and maturity were classified based on color, shape, and development of the gonads. Dorsal spines and otoliths were removed from a trumpeted random sample of female walleye mortalities (8-16 fish per 12.7 mm length class, with increased sampling of larger size classes). As for male walleye, these age estimates were used to compare age, growth, and mortality of female walleye and to assess the impacts of aging error on walleye management in the Winnebago System.

*Fish age estimation from calcified structures.*—The second or third dorsal spine was removed as close to the skin interface as possible with surgical nail nippers, placed in a sample envelope, and allowed to air dry for a minimum of two weeks. Excess dry tissue was removed before cutting 0.30 – 0.50 mm sections with a Buehler Isomet low speed saw, using glycerol as a blade lubricant. Sections were aged, without knowledge of sex and size, using a Meiji microscope under 25-45x magnification and dark field transmitted light. To maintain consistency between past and present aging techniques and criteria for annuli enumeration, all age estimates were made by the same reader who has aged all walleye spines collected from the Winnebago System since 1989. This

consistency allowed me to accurately determine the impacts of current and past aging error on walleye management.

After removal, otoliths were placed in vials to minimize breakage and allow to air dry for a minimum of 30 days. Otoliths were then embedded in Epo-Quick two-part epoxy for a minimum of 24 hours before 0.30 – 0.40 mm sections were cut using a South Bay Technology low-speed diamond wheel saw, Model 650, using water as a blade lubricant. Cross sections were aged by a reader with 4 years of experience aging otoliths. Age was estimated without knowledge of sex and size, under 25-56x magnification with an Olympus SZX7 stereomicroscope and bright field transmitted light. Isopropyl alcohol (50%) was used to help clear sections, but no polishing was conducted.

*Data analysis.*—Due to sexual dimorphic growth, data from male and female walleye were analyzed independently. Male length and age data from April spawning assessments and female length and age data from June tournament monitoring were incorporated into sex-specific age-length keys to assign ages to all adult walleye that were sampled during April spawning assessments (Robson and Chapman 1961). Due to the active involvement of citizens in the Winnebago System walleye management program and the high-profile fishery of the Winnebago System, I was unable to euthanize adequate sample sizes of mature female walleye during April spawning assessments. Therefore, I used age structures removed from female walleye sampled within length classes during June tournament monitoring and incorporated these age data into age-length keys to assign ages to adult female walleye captured during April spawning assessments. Age assignments yielded from structure-and-sex-specific age-length keys

were used to estimate both age distributions of the spawning stock and mean length at age of fish within the sample, similar to methods described by Bettoli and Miranda (2001). Mean length at age data from individual spawning assessments (2009-2011) were averaged to establish a mean length at each age class for adult male and female walleye sampled during the three-year period. Mean lengths at age-1 and age-2 were derived from empirical data collected during night electro-fishing surveys conducted on Lake Winnebago in October 2008-2010. The von Bertalanffy growth model (von Bertalanffy 1938):

$$L_t = L_\infty * (1 - e^{-K*(t-t_0)}),$$

where:  $L_t$  = length at time  $t$ ;  $L_\infty$  = length infinity (model parameter);  $K$  = Brody's growth coefficient (model parameter); and  $t_0$  = time of zero length or fertilization (model parameter) was fit to mean length at age data to estimate model parameters  $L_\infty$ ,  $K$ , and  $t_0$  for male and female walleye (a total of four growth models were constructed, one based on age estimates from otolith age estimates and one from dorsal spine age estimates for each sex). Likelihood ratio tests were used to determine whether projected von Bertalanffy growth models from male and female walleye were significantly different from each other, and whether projected growth derived from otolith age estimates were significantly different from models derived from dorsal spine age estimates for male and female walleye ( $P \leq 0.05$ ).

Sex-specific catch curves were developed from both dorsal spine and otolith age assignments for all adult fish sampled during spring spawning assessments conducted in each year (2009-2011). The first ages represented in catch curves were age-4 for male

walleye and age-5 for female walleye (ages at which >85% of male walleye and >95% of female walleye are mature) (WI DNR, Oshkosh, unpublished data). Linear regression from each catch curve yielded the slope of the line of best fit through the descending limb of the catch curve, from which the rates of instantaneous total annual mortality,  $Z$ , were estimated as the negative of the slope of the line of best fit. Rates of conditional total annual mortality,  $A$ , were then calculated using the equation:

$$A = 1 - e^{-Z}$$

Mann-Whitney tests were used to determine whether mean estimates of total annual mortality (2009-2011, catch curve from each year is a replicate;  $n = 3$  for adult male walleye and  $n = 2$  for adult female walleye) derived from otolith-based catch curves were significantly different ( $\alpha \leq 0.05$ ) than mortality estimates derived from dorsal spine-based catch curves. Rates of instantaneous fishing mortality,  $F$ , were estimated from mean rates of conditional total annual mortality,  $A$ , and instantaneous annual mortality,  $Z$ , (2009-2011) using the Baranov catch equation (Ricker 1975):

$$F = \mu (Z / A)$$

where  $\mu$  represents the mean estimate of exploitation from angler tag returns.

Instantaneous natural mortality rates,  $M$ , were estimated by subtracting estimated rates of  $F$  from estimated rates of  $Z$ . Rates of conditional fishing mortality ( $m$ ) and conditional natural mortality ( $n$ ) were calculated using the equations:

$$m = 1 - e^{-F}$$

$$n = 1 - e^{-M}$$

Mean dorsal spine and otolith age estimates from 25.4 mm length classes were calculated from adult male age data collected during April spawning assessments (2009-2011) and female age data collected during June tournament monitoring (2009-2010) to determine lengths at which dorsal spines began to underestimate fish age relative to otoliths. Fisheries managers do not positively know the age of a fish when they handle them during surveys; therefore, it is important to determine the length at which age estimates from otoliths and non-lethal structures deviate. Dorsal spine age estimates were considered to underestimate fish age if the mean spine age estimates were not within the 95% confidence intervals around mean otolith age estimate for that length class.

### *Results*

Age was determined for 668 male walleye (ranging in size from 305 to 645 mm) and 537 female walleye (ranging in size from 381 to 716 mm). The adult stocks of male and female walleye were dominated by fish 10 years of age and less (>89% of the adult population in all years) (Figure 8). Walleye from older age classes were detected from otolith age estimates each year that were not detected with dorsal spine age estimates. The oldest adult male walleye were estimated with otoliths to be age-18 in 2009, age-19 in 2010, and age-20 in 2011, while when using spines the oldest male walleye were estimated to be age-14 in 2009, age-15 in 2010, and age-16 in 2011. Walleye age-10 and older were estimated to be more abundant within age distributions based on otolith age estimates than those from dorsal spine age estimates (Figure 8). Although relative age

distributions from otoliths for male and female walleye were similar, there was poor agreement when comparing age class strength estimated from otolith and dorsal spine developed age data (Figure 8). For example, the 2001 year class (represented as 8 year old fish in 2009 and 9 year old fish in 2010) was, based on otolith age assignments, estimated to compose >20% of the adult stock in both 2009 and 2010, while that same year class was estimated to be significantly smaller in both years based on dorsal spine age estimates (Figure 8).

Likelihood ratio tests detected a significant difference in otolith-based von Bertalanffy growth model parameters between male and female walleye ( $F = 30.5$ ;  $df = 3, 33$ ;  $P < 0.001$ ) (Figure 9). Based on growth models female walleye reached greater asymptotic total lengths than male walleye ( $L_{\infty} = 519.5$  mm for male walleye,  $L_{\infty} = 656.5$  for female walleye), while Brody growth coefficients were similar for both sexes ( $K = 0.28$  for both male and female walleye).

Growth model parameters estimated from otolith-based von Bertalanffy growth models were not significantly different from growth models derived from dorsal spine age estimates for male ( $F = 0.35$ ;  $df = 3, 33$ ;  $P = 0.79$ ) or female walleye ( $F = 0.93$ ;  $df = 3, 29$ ;  $P = 0.44$ ) (Table 5, Figure 10). Projected growth based on otolith and dorsal spine age estimates were nearly identical for both male and female walleye up to age-6 and remained very similar throughout all ages represented within growth models. Growth of walleye ages-1-5 was quite rapid, and asymptotic lengths were reached at circa age-9 for both male and female walleye (Figure 10). Based on parameters from growth models incorporating dorsal spine age estimates, walleye were projected to obtain greater



asymptotic lengths and to reach their asymptotic lengths in a shorter amount of time (larger  $K$  values) than when incorporating otolith age estimates into growth models (Table 5, Figure 10).

Mean estimates of conditional total annual mortality,  $A$ , derived from catch curves based on dorsal spine age estimates were higher than estimates of  $A$  derived from otolith-based catch curves for both male and female walleye (Appendix C). Mean estimates of  $A$  for adult male walleye were 39.9% (range = 32.2% - 47.2%, SD = 0.08) when utilizing dorsal spine age data and 29.3% (range = 22.0% - 33.7%, SD = 0.06) when using otolith age data, while mean estimates of  $A$  for adult female walleye were 38.8% (range = 34.8% - 42.7%, SD = 0.06) when utilizing dorsal spine age data and 32.6% (range = 29.3% - 36.0%, SD = 0.07) when using otolith age data (Appendix C). Although mean estimates of  $A$  from catch curves derived from dorsal spine age estimates were consistently higher than estimates of  $A$  derived from otolith-based catch curves, the mean estimates of  $A$  between the two structures were not significantly different for either male ( $P = 0.127$ ) or female walleye ( $P = 0.439$ ) due to small sample sizes ( $n=3$  for males;  $n=2$  for females).

Mean estimates of exploitation based on tag return data were 14.7% for adult male walleye and 22.6% for adult female walleye. Estimates of instantaneous fishing mortality,  $F$ , were very similar when incorporating dorsal spine age estimates (0.19 for male walleye and 0.29 for female walleye) compared to when incorporating otolith age estimates (0.17 for male walleye and 0.27 for female walleye), while estimates of instantaneous natural mortality,  $M$ , were higher when estimating age with dorsal spines (0.32 for male walleye and 0.20 for female walleye) relative to when estimating age with

otoliths (0.17 for male walleye and 0.12 for female walleye). Similar trends were observed when converting these rates to percentages of fish annually being removed from the population due to fishing mortality ( $m$ ) and natural mortality ( $n$ ); as estimates of  $m$  from dorsal spine age estimates (17.1% for male walleye and 24.9% for female walleye) and otolith age estimates (16.0% for male walleye and 23.9% for female walleye) were similar, but estimates of  $n$  were higher when estimating age with dorsal spines (27.6% for male walleye and 18.5% for female walleye) compared to when estimating age with otoliths (15.8% for male walleye and 11.4% for female walleye).

Mean dorsal spine and otolith age estimates were similar for male walleye <457 mm and female walleye <508 mm (Figure 11). However, mean dorsal spine age estimates were significantly lower than mean otolith age estimates for male and female walleye larger than these critical lengths, represented by 95% confidence intervals around mean otolith age estimates not overlapping with mean age estimates derived from dorsal spines (Figure 11).

### *Discussion*

Mean estimates of  $A$  calculated from catch curves incorporating dorsal spine age estimates were not significantly different than those derived from otolith age estimates (likely due to small sample size: male  $n = 3$ , female  $n = 2$ ). Although the differences in estimates of mean total annual mortality were not significantly different, mortality estimates derived from catch curves based on dorsal spines were higher than those based on otoliths for male and female walleye sampled in every year (2009-2011). These

results are expected, as underestimating the age of older fish leads to overestimates of mortality. Future sampling would increase the statistical power inherent with our data set, allowing for detection of a significant difference, if indeed one existed.

Mortality estimates can be quite variable due to a number of factors including variable recruitment, exploitation, forage abundance, and thermal regimes from year to year (Kocovsky and Carline 2001). In addition to variability from environmental factors, estimates of mortality can be heavily influenced by aging error, as underestimated ages of older fish leads to inflated estimates of mortality (Serns and Kempinger 1981; Beamish and McFarlane 1983; Rien and Beamesderfer 1994; Robillard and Marsden 1996; Kocovsky and Carline 2000; Maceina and Sammons 2006). The combination of varying mortality rates caused by environmental conditions and inaccurate mortality estimates from aging error make it difficult to compare estimated rates of mortality across walleye populations. Quist et al. (2004) estimated total annual mortality rates of age-2 and older walleye ranging from 40.7% to 59.5% and attributed high estimates of total annual mortality to high summer water temperatures and high levels of exploitation. Kocovsky and Carline (2001) estimated total annual mortality rates of 32-34% for male walleye and 36-41% for female walleye in Pymatuning Sanctuary, and because the sanctuary is closed to angling, all mortality was due to natural causes. Both of these studies estimated age and mortality rates with scales but collected a stratified random sample of otoliths to verify scale age estimates. Estimates of mortality derived from dorsal spine based-catch curves for walleye in Lake Superior were 47.5% for adult male walleye and 34.9% for adult female walleye (Schram et al. 1992). My estimates of total annual mortality based

on age estimates from dorsal spines (39.9% for male walleye and 38.8% for female walleye) were comparable to the mortality estimates reported above, while my estimates of total annual mortality based on otolith age estimates (29.3% for male walleye and 32.6% for female walleye) were lower than all of the mortality estimates reported above. Due to the high variability in estimated rates of mortality across populations combined with the variation within populations from variable recruitment, it is imperative to collect accurate age data for an extended period of time to fully understand the mortality dynamics of a fish population (Koonce et al. 1977; Kocovsky and Carline 2001).

The estimates of annual conditional fishing mortality,  $m$ , for walleye in the Winnebago System were very similar when assigning age with dorsal spines relative to otoliths. However, aging error involved with dorsal spine age estimates lead to conditional natural mortality,  $n$ , estimates that were higher than those base on otolith age estimates. Fishing mortality and natural mortality are typically believed to be compensatory, therefore by overestimating natural mortality rates managers may incorrectly believe that harvest can be increased, which could potentially lead to the over-harvest of the fishery (Lai and Gunderson 1987; Rien and Beamesderfer 1994; Reeves 2003). Leaman and Nagtegaal (1987) estimated the instantaneous natural mortality rate to be 0.07 for yellowtail rockfish *Sebastes flavidus* when using age estimates from sectioned otoliths, a rate that was substantially lower than the previous estimate of 0.25 based on otolith surface readings. This reduction in estimated natural mortality rates lead to substantial reductions in total allowable catches. Similarly, underestimating the age of red snappers caused overestimates of natural mortality rates, and the population would

have been over-fished if the inflated estimates of natural mortality were applied to the red snapper management program (Newman et al. 2000). The greater the degree of aging error, the more severe the reduction in accuracy of mortality estimates, underscoring the importance of using accurate age data to estimate mortality rates used to make management decisions.

The results reported in this study demonstrate that age distributions derived from otolith age estimates accurately portray variable recruitment of walleye in the Winnebago System, with each generation of fish containing multiple strong year classes that collectively comprise the majority of the adult stock. Due to relatively high fishing mortality rates exerted on the Winnebago System walleye fishery, especially on female walleye, the robustness of the population is dependent on these regular strong year classes. By underestimating age with dorsal spines, fish from abundant year classes were mistakenly assigned to adjacent weaker and younger year classes, which in turn reduced estimated interannual variability in recruitment. Bradford (1991) further described this process and stated that underestimating fish age through the use of unvalidated aging techniques can affect recruitment estimates and severely hinder studies to assess environmental influences on recruitment.

Year classes of walleye were also observed from otolith age estimates that, due to aging error, were not represented from dorsal spine age estimates. Colby and Nepszy (1981) reported that average life expectancy for walleye varies from 12-15 years near the northern limits of the geographic range of walleye and 5-7 years near the southern limits, while Scott and Crossman (1973) reported that the maximum age for walleye was 20

years. With otoliths, I estimated age of walleye in the Winnebago System up to age-20, whereas 16 years was the maximum age estimated from dorsal spines. Observing these older year classes provides a better understanding of the longevity and age structure of our walleye population, in addition to providing insight into the long-term impacts of the recreational fishery on the walleye population.

Underestimating the age of larger walleye with dorsal spines had little impact on predicted growth parameters from von Bertalanffy growth models for male and female walleye. The majority of somatic growth of walleye inhabiting the Winnebago System has already occurred by age-7, the age at which age assignments from dorsal spines begin to underestimate walleye age relative to otolith age estimates (Chapter III). Similar results were reported by Kocovsky and Carline (2001) for walleye in Pymatuning Sanctuary, where walleye attained approximately 67% of their terminal length before reaching maturity and grew very slowly following maturity. Thus, underestimating the age of older fish with dorsal spines has little impact on estimated growth rates of walleye because the majority of somatic growth has already occurred by the ages at which age underestimation occurs.

Growth parameters reported in this study from von Bertalanffy growth models for Winnebago System walleye were considerably different than those previously reported from scale age estimates dating back to the 1960s (Priegel 1969). Length infinity estimates for walleye in Lake Winnebago were previously reported at 469 mm for male walleye and 616 mm for female walleye, values below our current estimates of 519 mm for male walleye and 657 mm for female walleye (Quist et al. 2003). Past estimates of

the Brody growth coefficients (0.37 for male walleye and 0.25 for female walleye) (Quist et al. 2003) were also different from current estimates (0.28 for both male and female walleye). The maximum age of walleye in the population historically was believed to be 8 years of age (Priegel 1969), whereas otolith age estimates now show that walleye are able to live up to at least age-20. Growth of walleye in the Winnebago System may have changed over the past 50 years, due in part to the sustained relative abundance of gizzard shad since the late 1980s (WI DNR, Oshkosh, unpublished data), but historical ages derived from scales were undoubtedly underestimating fish age, thereby affecting the accuracy of the parameters estimated within the growth model.

Mean age estimates from dorsal spines and otoliths were very similar for adult male walleye <457 mm and adult female walleye <508 mm, but dorsal spines yielded significantly lower age estimates than otoliths for walleye larger than these critical lengths. These data could be used to develop an age sampling protocol where dorsal spines would be used to estimate the age of smaller walleye (female walleye <508 mm and male walleye < 457 mm) with relative accuracy, but otoliths would be required to accurately estimate age of larger walleye. Kocovsky and Carline (2000) observed similar results in Pymatuning Sanctuary, where scales yielded relatively accurate age estimates for walleye <500 mm, but otoliths were required to accurately estimate age of walleye >500 mm.

The Winnebago System walleye population is dominated by younger fish (>89% of the adult population being age-10 or less), which is likely the result of moderate to high levels of exploitation, particularly of adult female walleye. Growth of walleye in the

Winnebago System is generally considered to be rapid because of abundant forage and moderate to high levels of exploitation, both of which contribute to increased growth rates (Knight et al. 1984; Johnson et al. 1988; Hartman and Margraf 1992; Santucci and Wahl 1993; Quist et al. 2003). Young, fast growing fish are usually aged more accurately because annuli are easier to identify (Erickson 1979, 1983; Belanger and Hogler 1982; Frie et al. 1989). Therefore, dorsal spines should yield relatively accurate age estimates for most of the fish within the Winnebago System walleye population. However, aging error still occurred when dorsal spines were used to age larger fish, which led to inflated estimates of mortality. If a higher percentage of older fish were present in the population, aging error could even more severely confound the understanding of mortality dynamics and potentially further negatively impact the management program.

The application of age data should be taken into account when determining which aging structure should be used to estimate fish age. Although age estimates derived from scales or dorsal spines are likely inaccurate to varying degrees, age estimates from these structures may be acceptable for observing general trends in age and growth data for young, fast growing fish populations. However, otoliths should be used to estimate fish age when populations contain a large percentage of older fish or when age data are used to estimate mortality and growth rates that are used to set harvest regulations. Otoliths yield the most accurate and precise age estimates of any structure, and aging error inherent with scale and dorsal spine age estimates reduce the accuracy of estimated rates of growth, mortality, and recruitment (Bradford 1991; Mertz and Meyers 1997). These



three rates have the greatest impact on the dynamics of a fish stock and are used extensively in population dynamics models including catch-at-age models and cohort analyses, which are becoming more common in fisheries management and research (Ricker 1975; Beverton 1987; Colvin 1991; Maceina et al 1998; Quist et al. 2004). Model results are only as accurate as the data that are input into them, underlining the critical importance of collecting accurate age data for producing reliable and meaningful results (Mertz and Meyers 1997). In scenarios where adequate numbers of fish from all sizes cannot be euthanized, I recommend collection of paired aging structures to determine the relationship between age estimates from non-lethal structures and otoliths. Doing this will allow managers to assess the impacts that any potential aging error may have on estimates of somatic growth, mortality, and ultimately on population management decision making. These data may also allow fisheries managers to design a sampling protocol where smaller, younger fish are aged from non-lethal structures with relative accuracy while otoliths are collected to estimate the age of larger fish. Such protocols would reduce the number of fish sampled for age estimation.

## Chapter V

### Conclusions

The results observed in this study indicate that the Wisconsin DNR has been incorporating inaccurate data into their walleye management program on the Winnebago System. Estimated population abundances and exploitation rates were not accounting for tag loss, and inaccurate age assignments from dorsal spines were incorporated into estimated age distributions and rates of somatic growth and mortality. The Wisconsin DNR has incorporated the results of this study into their Winnebago walleye management plan and now account for tag loss and utilize more accurate and precise age estimates derived from sectioned otoliths.

I estimated that instantaneous tag loss rates of Floy anchor tags in walleye from the Winnebago System were negligible ( $<0.3\%$ ), likely attributable to the extensive experience that Wisconsin DNR staff have with walleye tagging procedures. Tag loss rates increased with longer time intervals following tagging, with 4.7% mean tag loss observed within the first 90 days following tagging and 21.9% mean tag loss observed after one year post tagging. The majority of the walleye harvest from the Winnebago System occurs within the first 90 days post tagging, and walleye catches during June tournaments are utilized as the recapture sample for estimating population abundances. Thus, the 4.7% mean tag loss rate observed within the first 90 days post tagging must be accounted for to accurately estimate densities following initial spring tagging and collection of recapture data during early summer tournaments.

Exploitation estimates increased by roughly 5% and population abundances decreased by roughly 5.5% after accounting for tag loss. These results suggest that Floy anchor tags are adequate for marking walleye to estimate population abundances and exploitation rates on the Winnebago System. However, if recapture samples occurred more than 90 days post tagging, or if a higher portion of the overall harvest occurred later in the calendar year, higher percentages of tag loss would be experienced, and fisheries managers may be well served to use marks with greater retention (PIT tags, fin removal, etc.).

Using known-age walleye, I validated the accuracy of age estimates from otoliths for walleye up to age-10. I also provided additional corroboratory evidence from catch curve analyses demonstrating that otolith age estimates are accurate for all ages of walleye in the Winnebago System. These results expand on the previous literature reporting that age estimates from otoliths were accurate for walleye 0-4 years of age (Erickson 1983; Heidinger and Clodfelter 1987). I also demonstrated that age estimates from dorsal spines underestimated the age of older, known-age walleye. Mean dorsal spine age estimates from known-age fish were within 1 year of true age for walleye 0-9 years of age but were significantly younger for walleye age-10 and older. Estimated age distributions from dorsal spines did not correlate well with empirical year class strength from fall trawling data, supporting the conclusion that dorsal spines were underestimating the age of older walleye.

Extensive sampling of paired walleye aging structures demonstrated that age estimates from otoliths and dorsal spines exhibit a clear deviation at age-7 for both sexes.

Age estimates from the two structures are in close agreement for walleye ages-0-6, while dorsal spines underestimate the age of walleye 7 years of age and older relative to otoliths. Differences between age estimates from the two structures increased with fish age and were more pronounced for male walleye than female walleye. Walleye were also estimated to reach older maximum ages when estimating age with otoliths (up to age-20) relative to dorsal spines (up to age-16).

Estimates of age distribution and mortality rates were most affected by aging error from dorsal spines, while effects on estimated growth models were minimal. A wider age range of walleye was observed, and older fish were estimated to be more abundant when estimating walleye age with otoliths compared to dorsal spines. Estimates of conditional total annual mortality were higher when incorporating age estimates from dorsal spines relative to otoliths (10.6% higher for male walleye and 6.2% higher for female walleye). Although these differences were not significantly different, due to small sample sizes, they may affect the interpretation of the mortality dynamics within the walleye population. Aging error from dorsal spines had little effect on estimates of conditional fishing mortality, while estimates of conditional natural mortality were much higher when incorporating dorsal spine age estimates into mortality estimates compared to otolith age estimates. By overestimating natural mortality, fisheries managers may believe that harvest quotas can be increased, which could potentially lead to overfishing of a population. Growth models were, for the most part, unaffected by aging error because walleye have attained most of their asymptotic length by age-7, the age at which dorsal spines begin to underestimate walleye age. Mean dorsal spine and otolith age

estimates were not significantly different for male walleye <457 mm and female walleye <508 mm, but otoliths did yield significantly older age estimates than dorsal spines for walleye of greater sizes.

To my knowledge, this study is the most comprehensive investigation of walleye aging procedures and the impacts of aging error on walleye management. Over the course of the three-year study, I was able to collect paired aging structures from 298 known-age walleye (ages-1-10, 16) and over 2,000 total walleye (known and unknown age fish). With this extensive data set, I was able to gain a comprehensive understanding of the dynamics of walleye age estimation and the use of age data in the Winnebago System walleye management program. Due to the conclusiveness of these results, the Wisconsin DNR has modified their walleye management program to include recommendations outlined in this thesis. Current management practices now incorporate estimated tag loss rates in estimates of population abundance and exploitation rates, and otoliths are now used to accurately estimate walleye age and dynamics of age structure, somatic growth, and mortality. The use of more accurate data will yield estimates of population parameters for walleye that better represent the population and allow for more effective management decision making for the walleye fishery. The walleye fishery on the Winnebago System is world renowned and annually contributes \$234 million to the local economy, and through the collection of more accurate data, fisheries managers will be better suited to maintain the fishery for future generations.

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Table 1. Number of walleye observed, number of caudal clipped walleye observed, number of anchor tag (Floy FD-94) sheds observed, and rate of tag loss for each individual tournament (Master Walleye Circuit (MWC), Mercury Marine National Walleye Tournament (Mercury), and Otter Street Walleye Tournament (Otter Street)) monitored on the Winnebago System, WI in June, 2010.

	MWC	Mercury	Otter Street	Total	
Number of fish observed	1,345	1,257	1,294	3,896	
Number of clips observed	26	19	20	65	
Number of tag sheds observed	1	1	1	3	
Rate of tag loss	3.8%	5.3%	5.0%	4.6%	(Mean=4.7%, SD=0.008)

Table 2. Total number of recaptured caudal clipped walleye, number of anchor tag (FD-94) sheds observed, and percent tag loss observed from walleye captured by electro-fishing and fyke net surveys conducted on the Wolf River, WI in April 2011 (fish initially tagged and clipped during 2010 spawning assessments).

Gear	Total number of caudal clips	Number of sheds	Rate of tag loss
Electro-fishing	161	38	23.6%
Fyke Net	154	31	20.1%
Combined	315	69	21.9% (Mean=21.9%, SD=0.02)

Table 3. Age, sample size (n), and mean otolith and dorsal spine age estimates for known-age walleye collected on the Winnebago System, WI (2009-2011). Known-age walleye ages-0-3 were assigned true ages by following modal length of the abundant 2008 year class, while known-age walleye ages-4-10 and age-16 were assigned true ages by adding the number of years at large since tagging to the assigned age at tagging based on length ( $\pm 1$  year).

Age (years)	n	Mean age estimate	
		Otolith	Dorsal spine
1	40	1.00	0.95
2	86	2.02	2.31
3	16	3.00	3.31
4	13	4.23	4.46
5	76	4.63	4.79
6	38	5.66	5.63
7	14	6.50	6.29
8	5	8.00	7.20
9	3	8.67	8.67
10	6	9.67	7.67
16	1	16	12

Table 4. Pearson product moment correlation coefficient values between standardized values of age-1 trawl CPUE (August-October assessment trawling) and residuals from catch curves constructed from otolith and dorsal spine age estimates derived from adult male and female walleye sampled during April spawning assessments conducted on the Winnebago System, WI (2009-2011).

	Male		Female	
	Otolith	Dorsal spine	Otolith	Dorsal spine
2009	0.54	0.13	0.62	0.40
2010	0.62	0.17	0.70	-0.17
2011	0.62	-0.29		

Table 5. Parameters from von Bertalanffy growth models ( $L_{\infty}$  = length infinity (mm);  $K$  = Brody's growth coefficient; and  $t_0$  = time of zero length or fertilization) based on otolith age estimates and dorsal spine age estimates for male and female walleye sampled during April spawning assessments conducted on the Winnebago System, WI (2009-2011).

	Male		Female	
	Dorsal spine	Otolith	Dorsal spine	Otolith
$L_{\infty}$	533	519	672	657
$K$	0.26	0.28	0.27	0.28
$t_0$	-0.85	-0.75	-0.01	-0.06



## Figure Captions

Figure 1. Photos of the caudal fin of two walleye that were clipped in April 2010 and then recaptured in April 2011 on the Wolf River, WI, representing range of fin regeneration observed after 1 year post clipping. Note distinct line between original and regenerated fin tissue at site of initial cutting of fin.

Figure 2. Year class strength of walleye indicated by catch per unit effort (CPUE) of age-1 walleye during August-October bottom trawling assessments on Lake Winnebago, WI (1986-2010).

Figure 3. Age bias plots comparing known-age to mean age estimates from (A) dorsal spines and (B) otoliths for known-age walleye sampled in the Winnebago System, WI (2009-2011) (solid line represents 1:1 agreement line and error bars represent 95% confidence intervals around the mean,  $n = 298$ ). Known-age walleye ages-0-3 were assigned true ages by following modal length of the strong 2008 year class, while known-age walleye ages-4-10 and age-16 were assigned true ages through mark-recapture methods where the years at large since tagging was added to the assigned age at tagging based on length ( $\pm 1$  year).

### Figure Captions (Continued)

Figure 4. Growth increments observed on an (A) otolith and a (B) dorsal spine removed from a 554 mm male walleye sampled in April 2010 on the Winnebago System, WI.

Black circles indicate approximate locations of interpreted annuli (18 years from otolith and 14 years from dorsal spine). The edge was counted as an annulus because the fish was sampled in April, and therefore the annulus had not yet formed.

Figure 5. Age bias plots comparing otolith age estimates to mean dorsal spine age estimates for (A) male ( $n = 1161$ ) and (B) female walleye ( $n = 1020$ ) sampled from the Winnebago System, WI (2009-2011). Solid lines represent 1:1 agreement, and error bars represent 95% confidence intervals around the mean dorsal spine age estimates.

Figure 6. Precision of (a) dorsal spine age estimates from male walleye, (b) dorsal spine age estimates from female walleye, (c) otolith age estimates from male walleye, and (d) otolith age estimates from female walleye. Walleye were collected during fisheries surveys conducted on the Winnebago System, WI (2009-2011).

### Figure Captions (Continued)

Figure 7. Age bias plots comparing: (A) dorsal spine age estimates from male walleye, (B) dorsal spine age estimates from female walleye, (C) otolith age estimates from male walleye, and (D) otolith age estimates from female walleye sampled during fisheries assessments conducted on the Winnebago System, WI (2009-2011). Solid lines represent 1:1 agreement line and error bars represent 95% confidence intervals around mean dorsal spine age estimates (male  $n = 1161$ , female  $n = 1020$ ).

Figure 8. Age distributions of mature male walleye in (A) 2009, (B) 2010, and (C) 2011 and mature female walleye in (D) 2009 and (E) 2010. Age distributions were based on estimated age (dorsal spines = black bars, otoliths = white bars) of walleye sampled during April spawning assessments conducted on the Winnebago System, WI.

Figure 9. Empirical length at age data derived from otolith age estimates and predicted growth from otolith based von Bertalanffy growth models fit to empirical length at age data for male and female walleye sampled during April spawning assessments conducted on the Winnebago System, WI (2009-2011).

Figure Captions (Continued)

Figure 10. Comparison of empirical length at age and predicted growth from von Bertalanffy growth models constructed from dorsal spine age estimates and otolith age estimates for (A) male walleye and (B) female walleye sampled during April spawning assessments conducted on the Winnebago System, WI (2009-2011).

Figure 11. Mean age estimates derived from dorsal spines (dashed line) and otoliths (solid line) for 25.4 mm length classes of (A) male walleye sampled during April spawning assessments and (B) female walleye sampled during June tournament monitoring conducted on the Winnebago System, WI (2009-2011). Error bars represent 95% confidence intervals around mean otolith age estimates.



Figure 1.

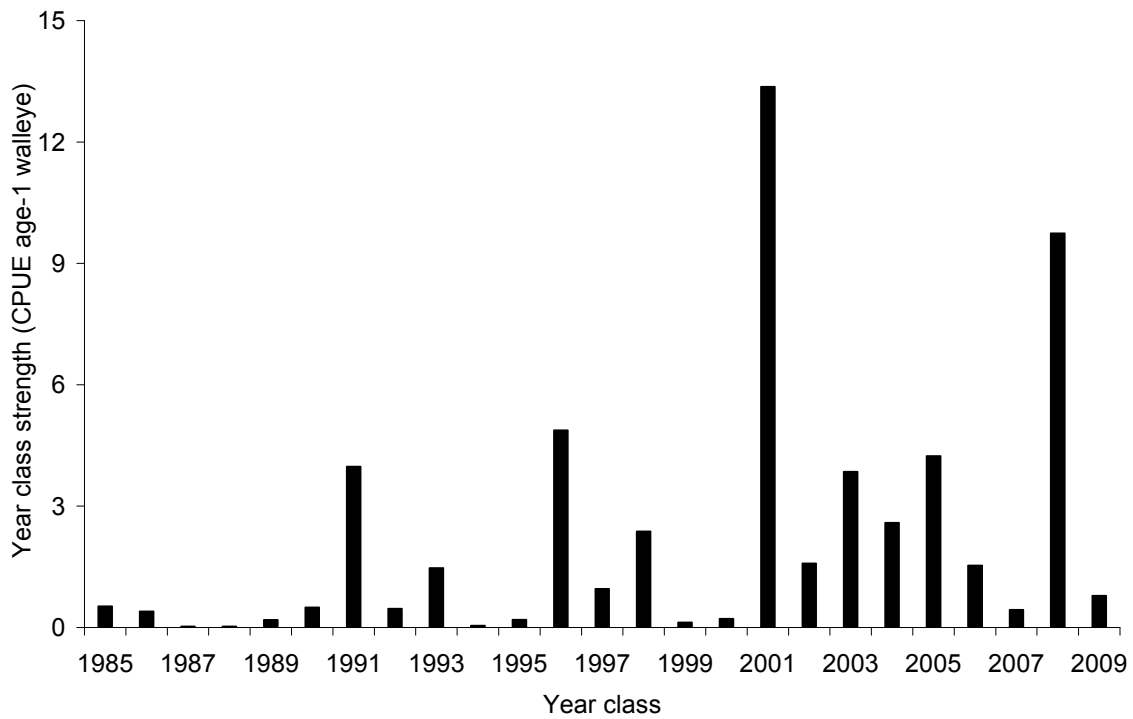


Figure 2.

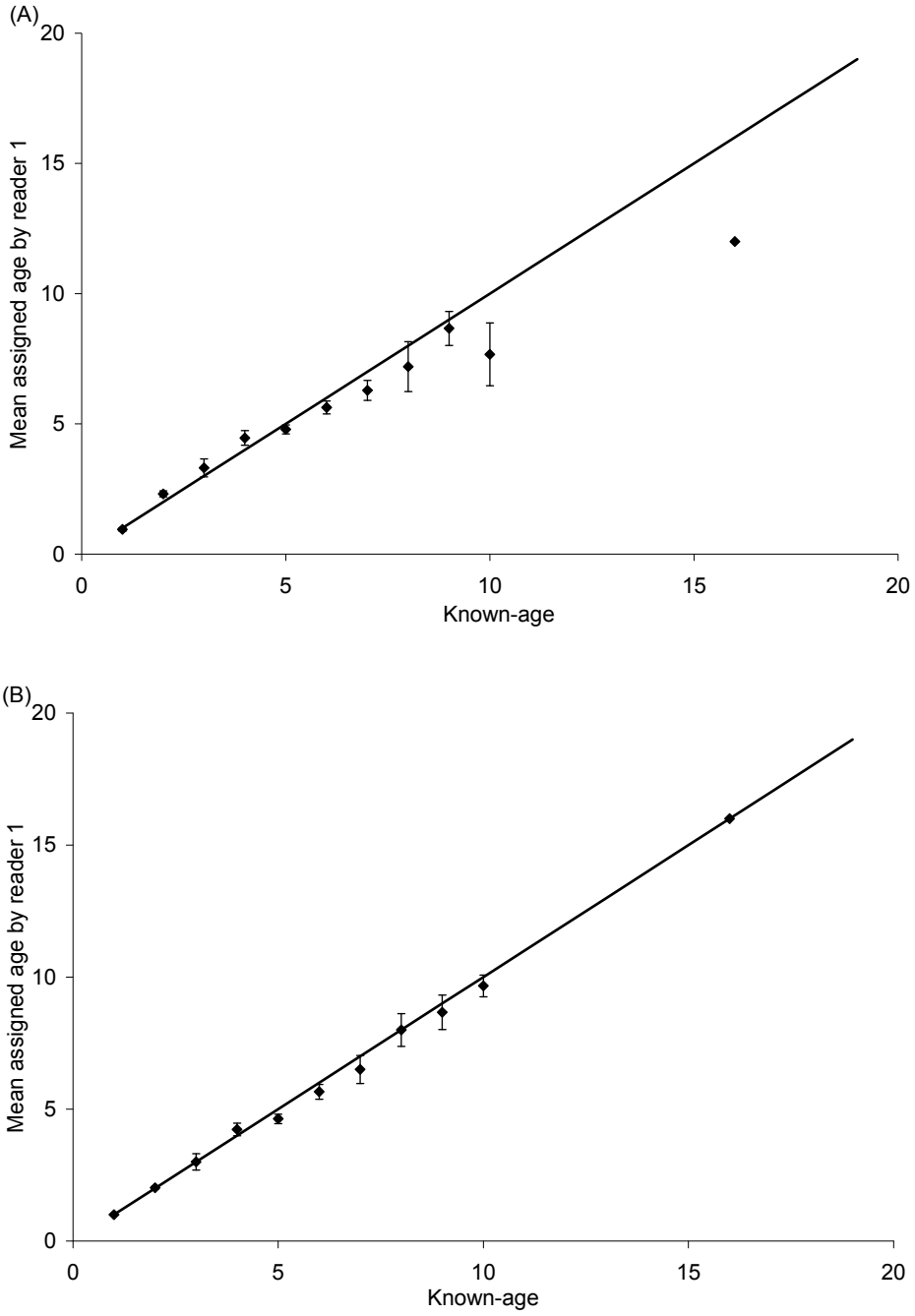


Figure 3.

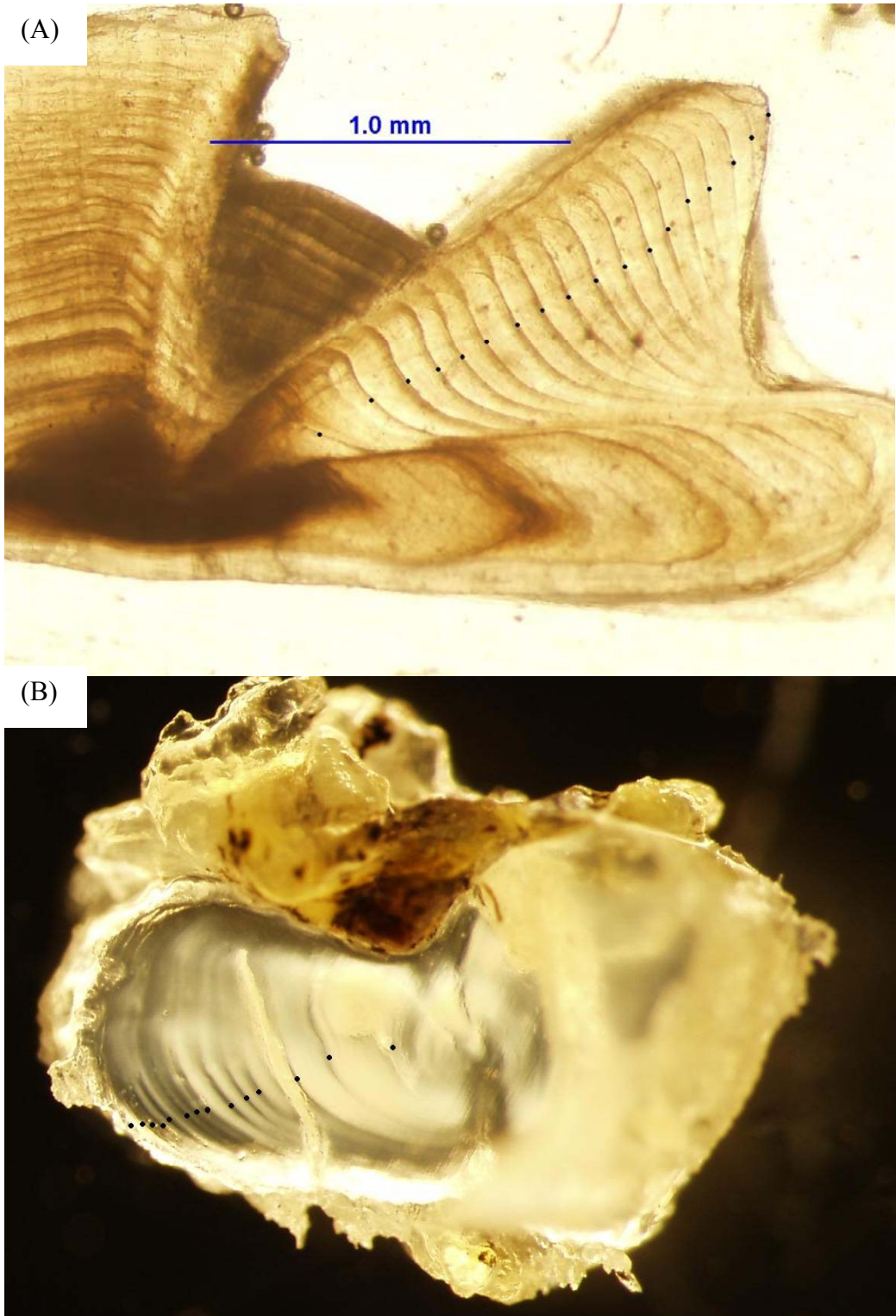


Figure 4.



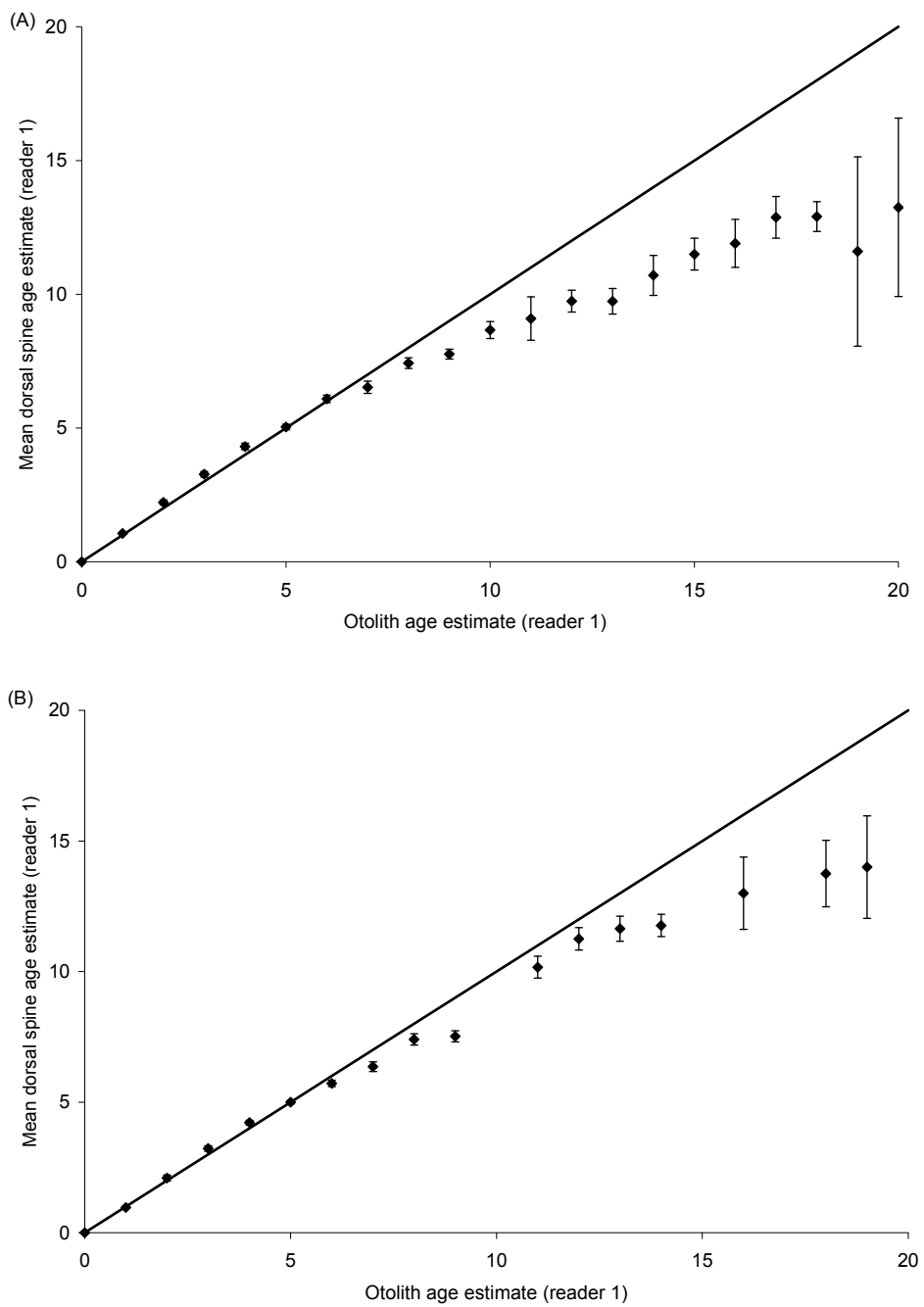


Figure 5.

Male Walleye

Female Walleye

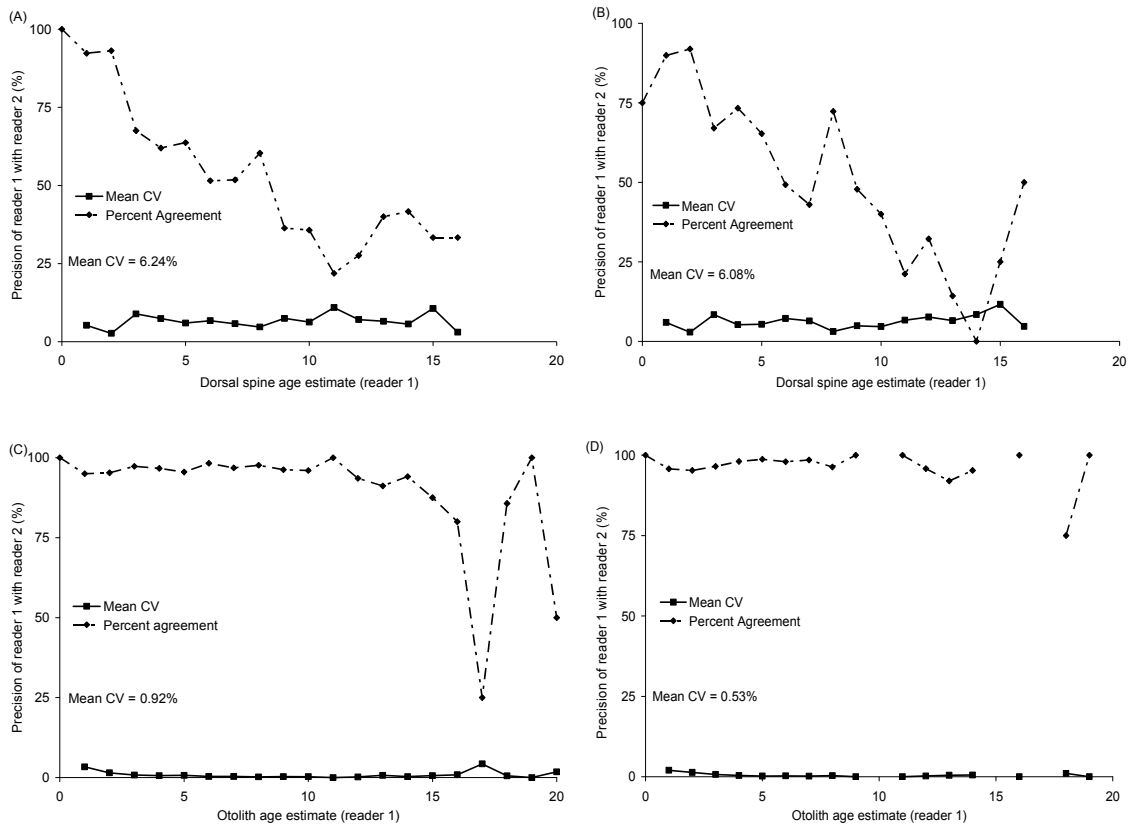


Figure 6.

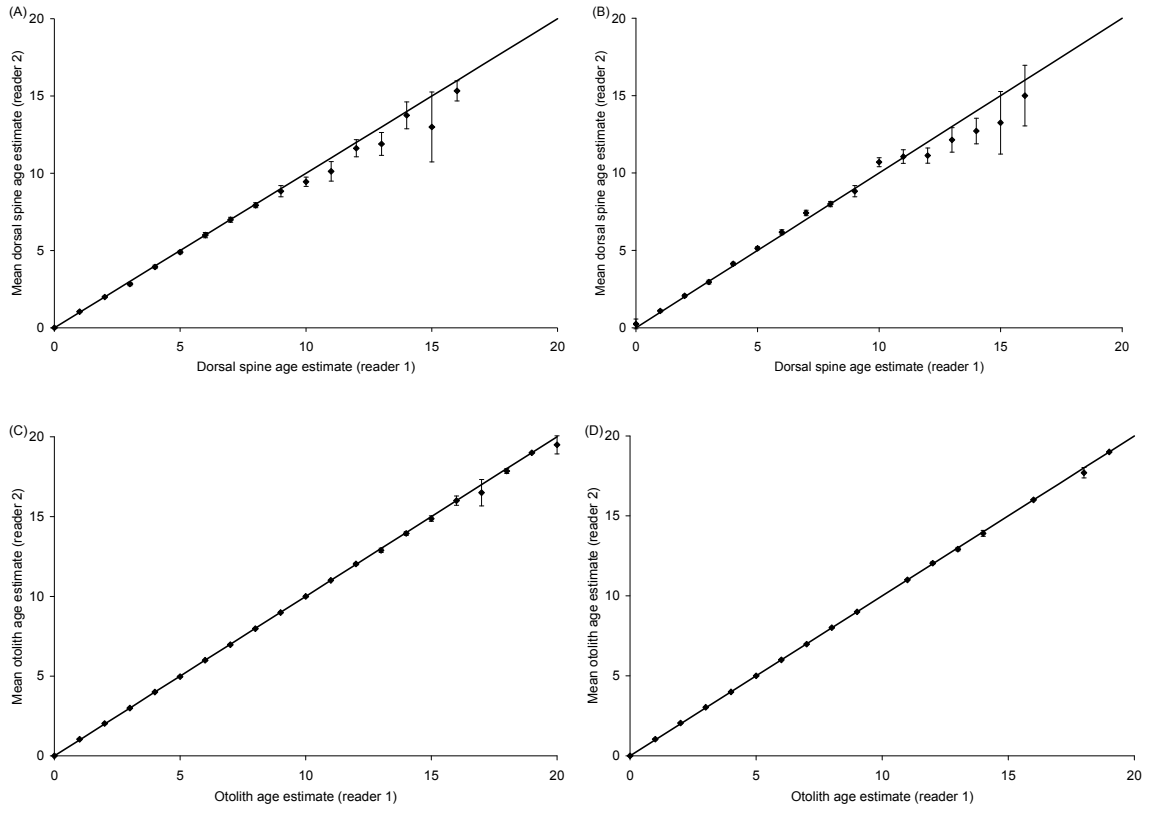


Figure 7.

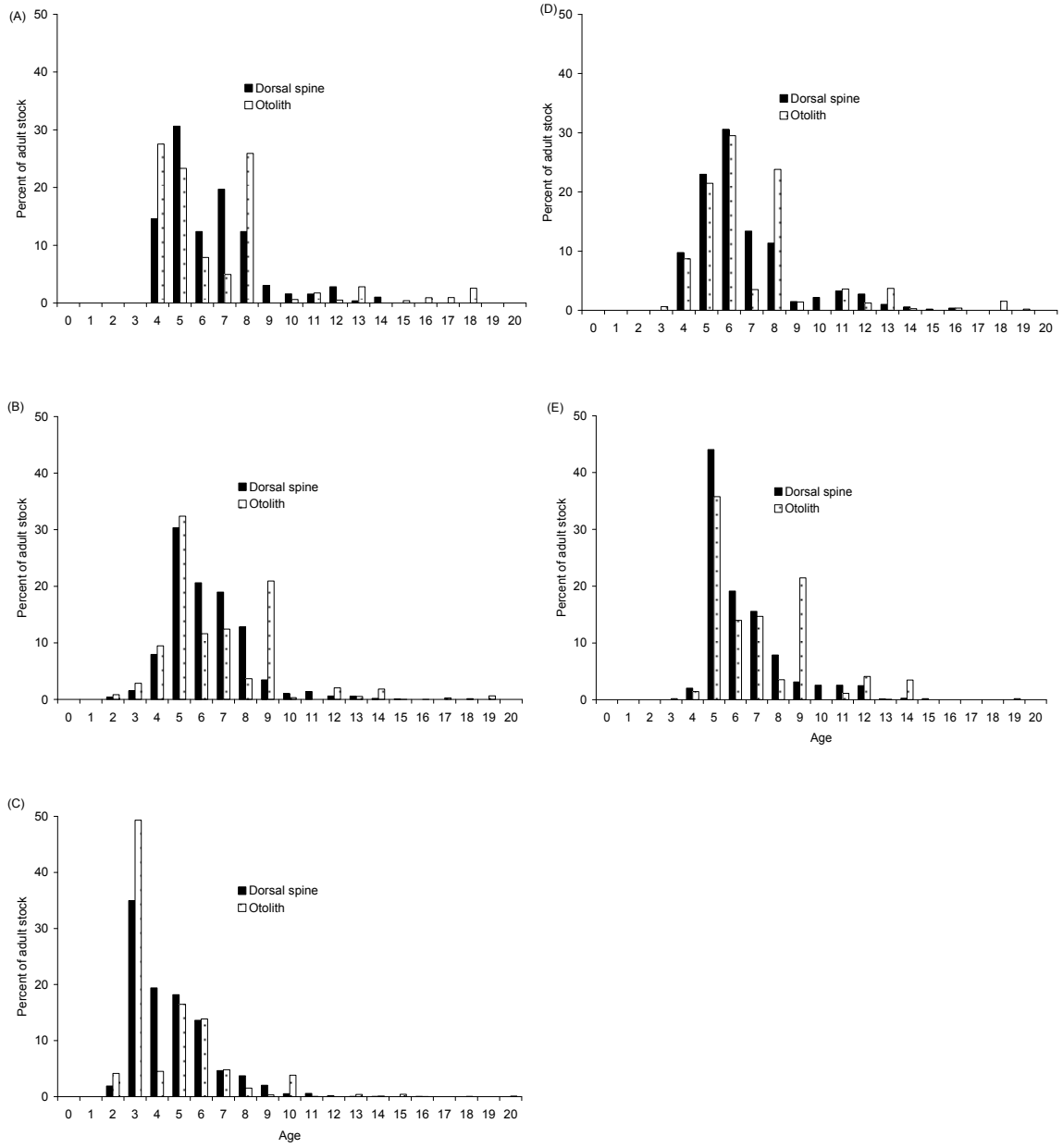


Figure 8.

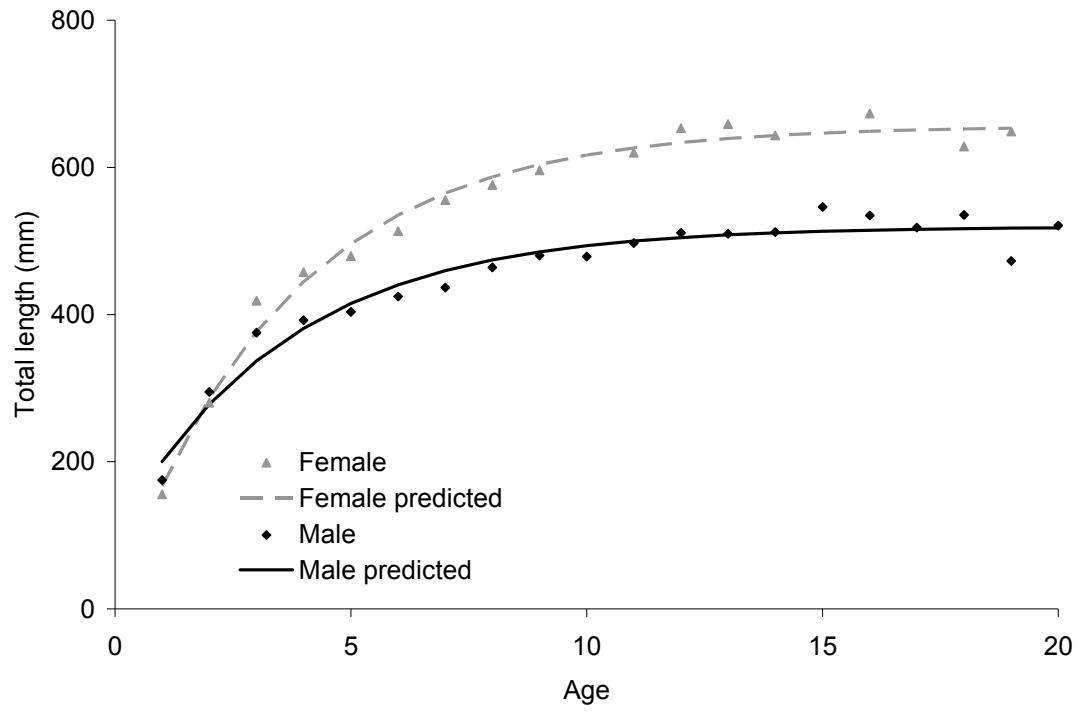


Figure 9.

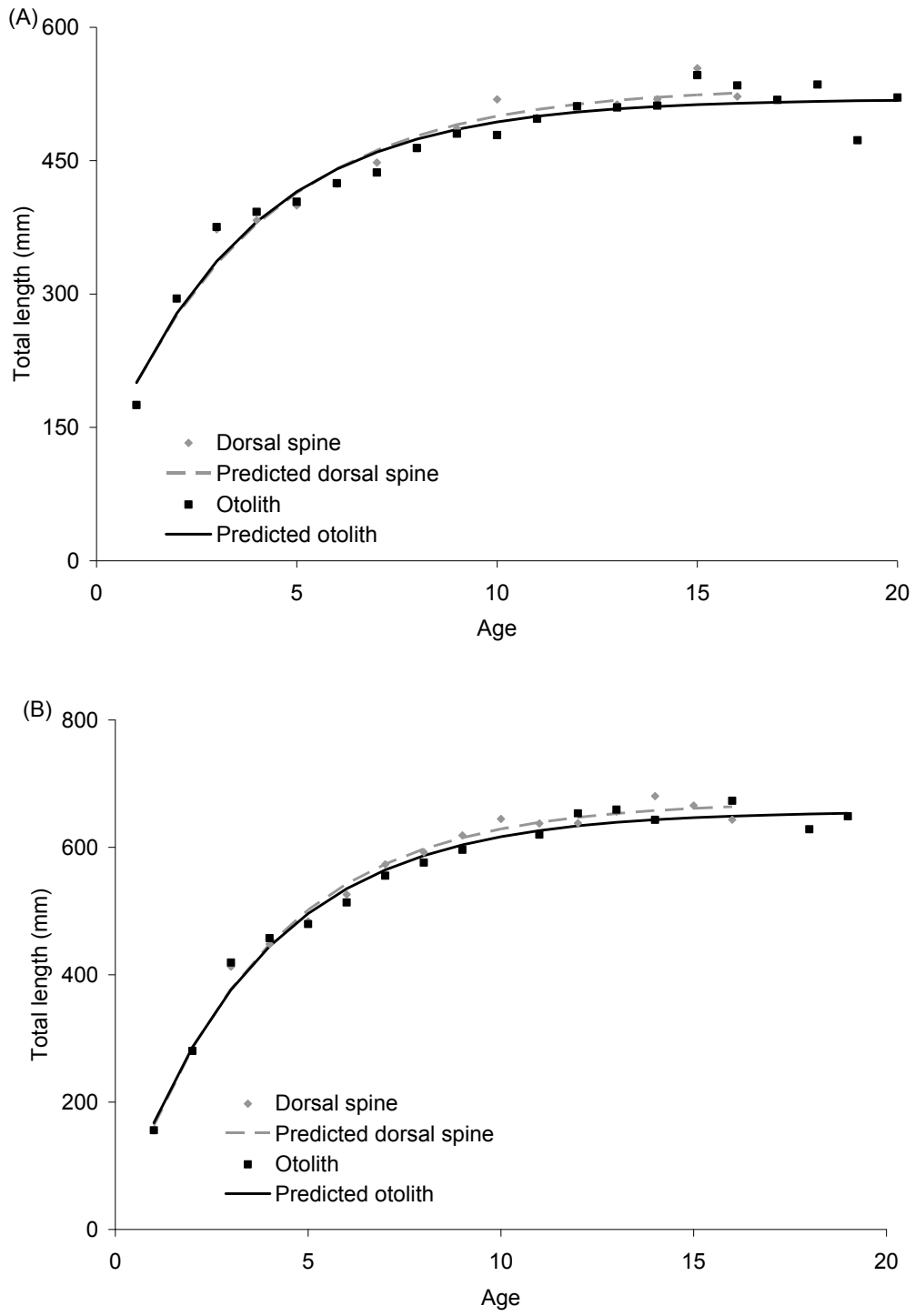


Figure 10.

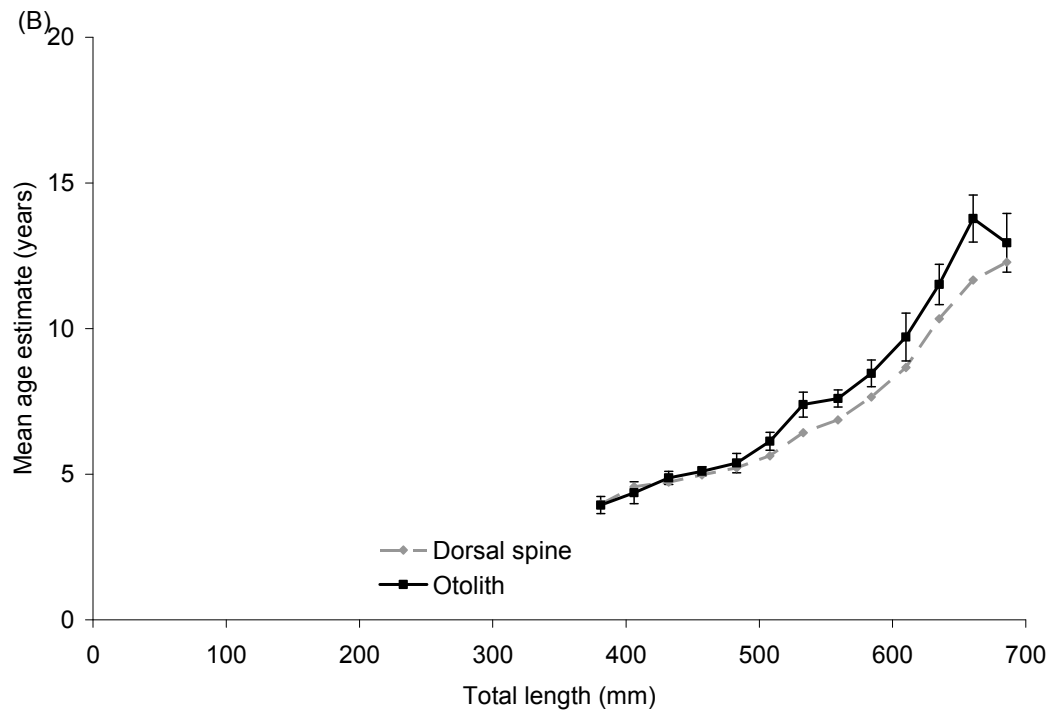
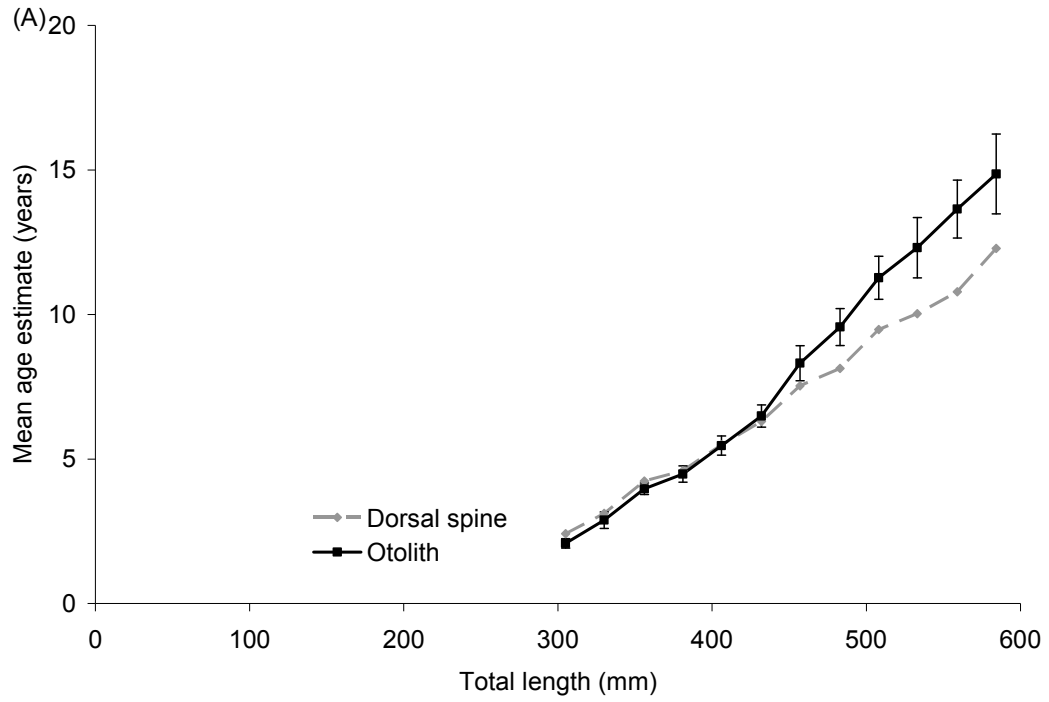


Figure 11.

APPENDIX A

Length frequencies from monthly progression of length mode data collection



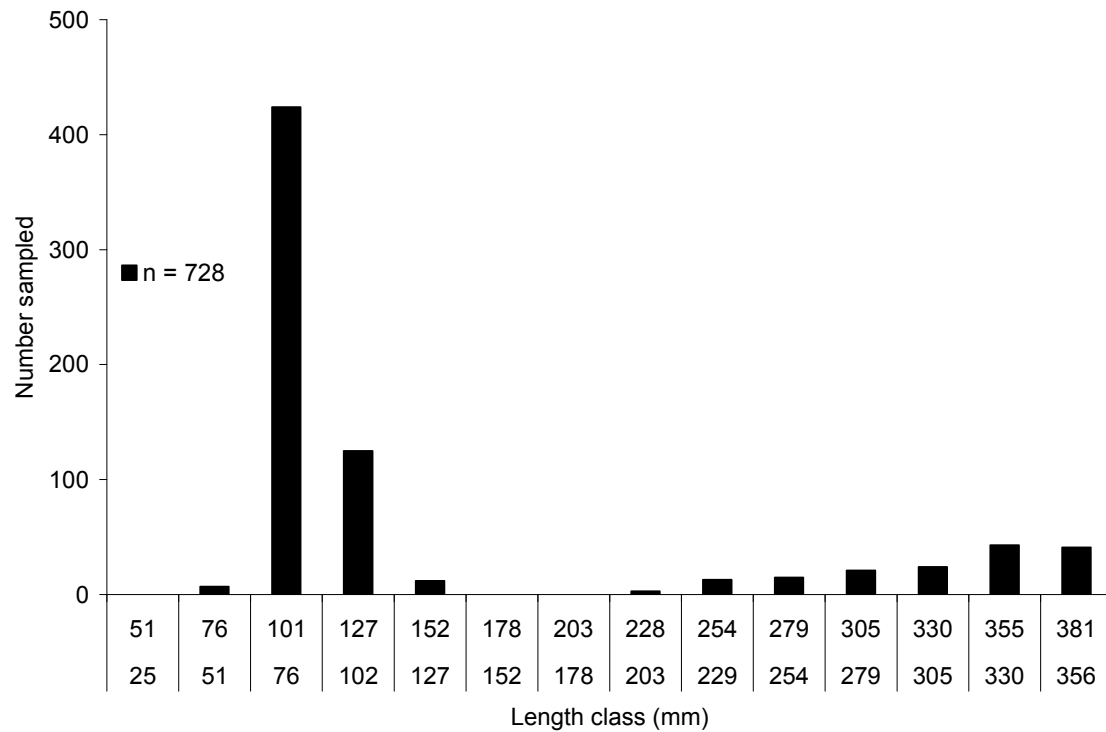


Figure A-1. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 5 days of bottom trawling assessments conducted on Lake Winnebago, WI in August 2008. Abundant 76-127 mm walleye represent the strong 2008 year class (age-0).

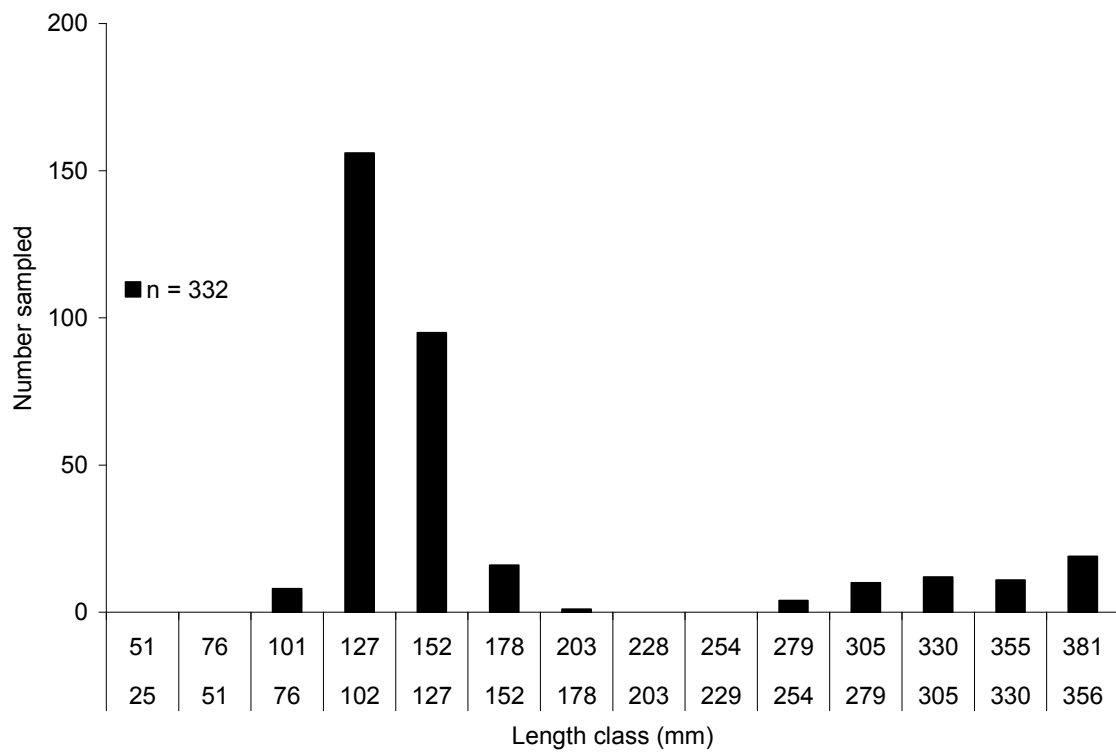


Figure A-2. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 5 days of bottom trawling assessments conducted on Lake Winnebago, WI in September 2008. Abundant 102-152 mm walleye represent the strong 2008 year class (age-0).

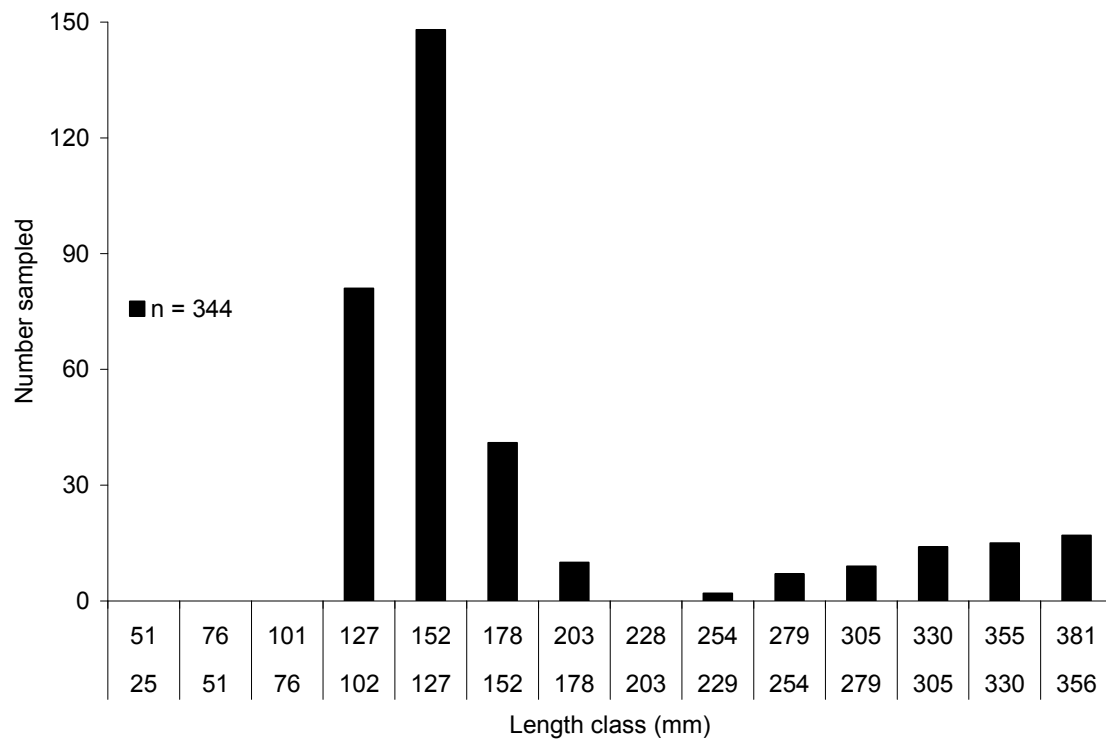


Figure A-3. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 5 days of bottom trawling assessments conducted on Lake Winnebago, WI in October 2008. Abundant 102-178 mm walleye represent the strong 2008 year class (age-0).

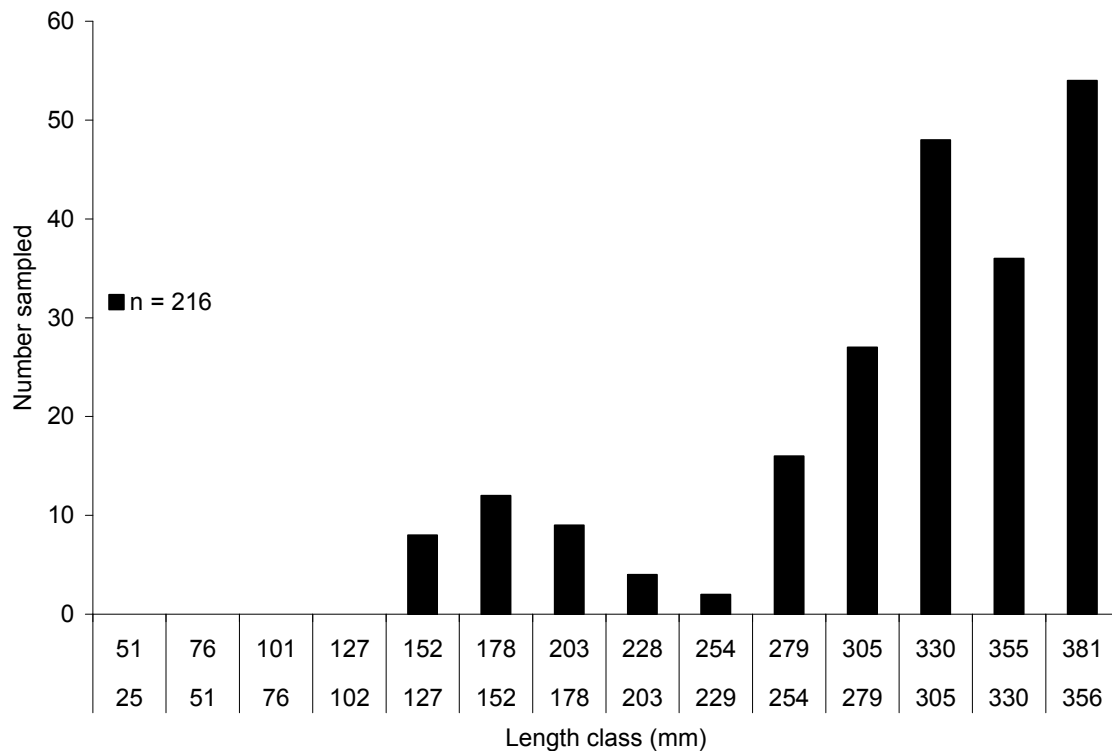


Figure A-4. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 2 evenings of electro-fishing assessments conducted on Lake Winnebago, WI in May 2009. Walleye in size ranges 127-203 mm represent the strong 2008 year class (age-1). Abundant walleye  $\geq 254$  mm were present on shorelines due to abundant forage corresponding with trout-perch spawning.

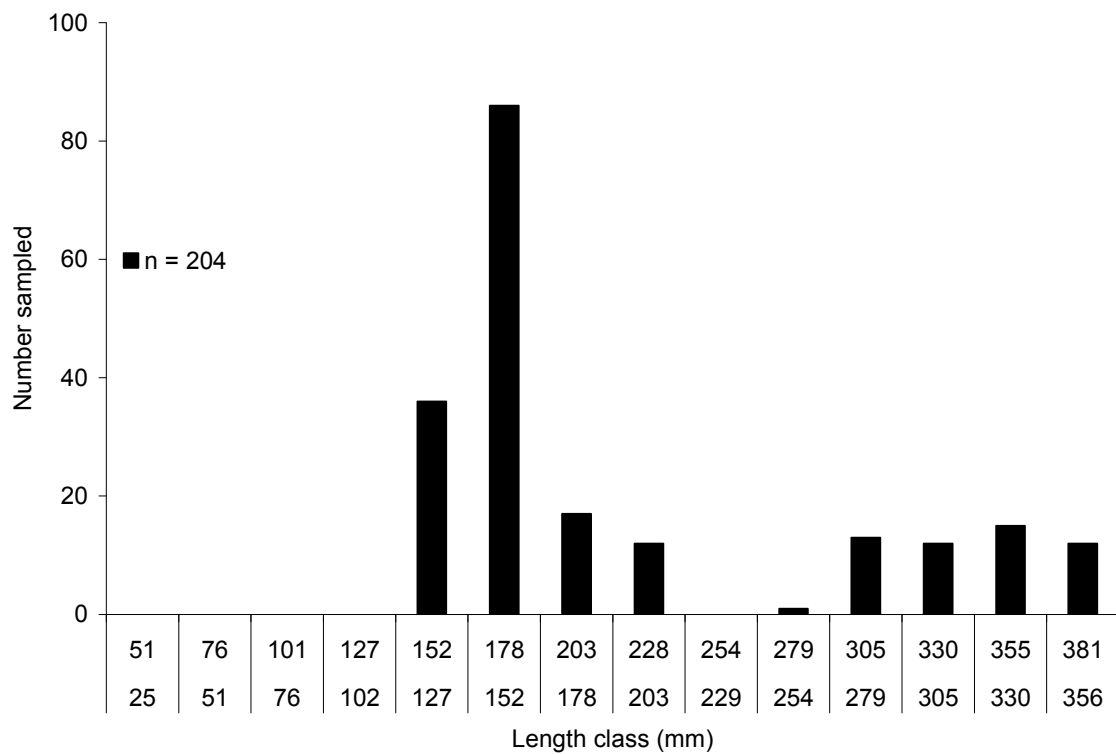


Figure A-5. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 2 evenings of electro-fishing assessments conducted on Lake Winnebago, WI in June 2009. Abundant 127-203 mm walleye represent the strong 2008 year class (age-1).

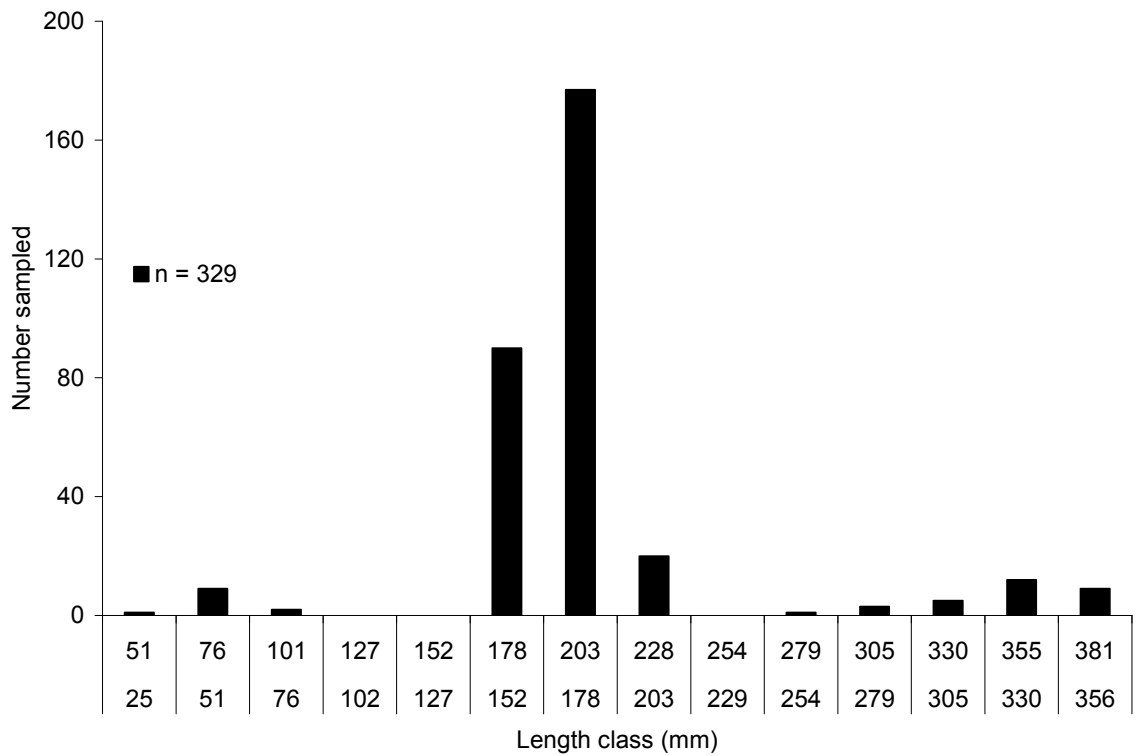


Figure A-6. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 2 days of bottom trawling assessments conducted on Lake Winnebago, WI in July 2009. Abundant 152-203 mm walleye represent the strong 2008 year class (age-1).

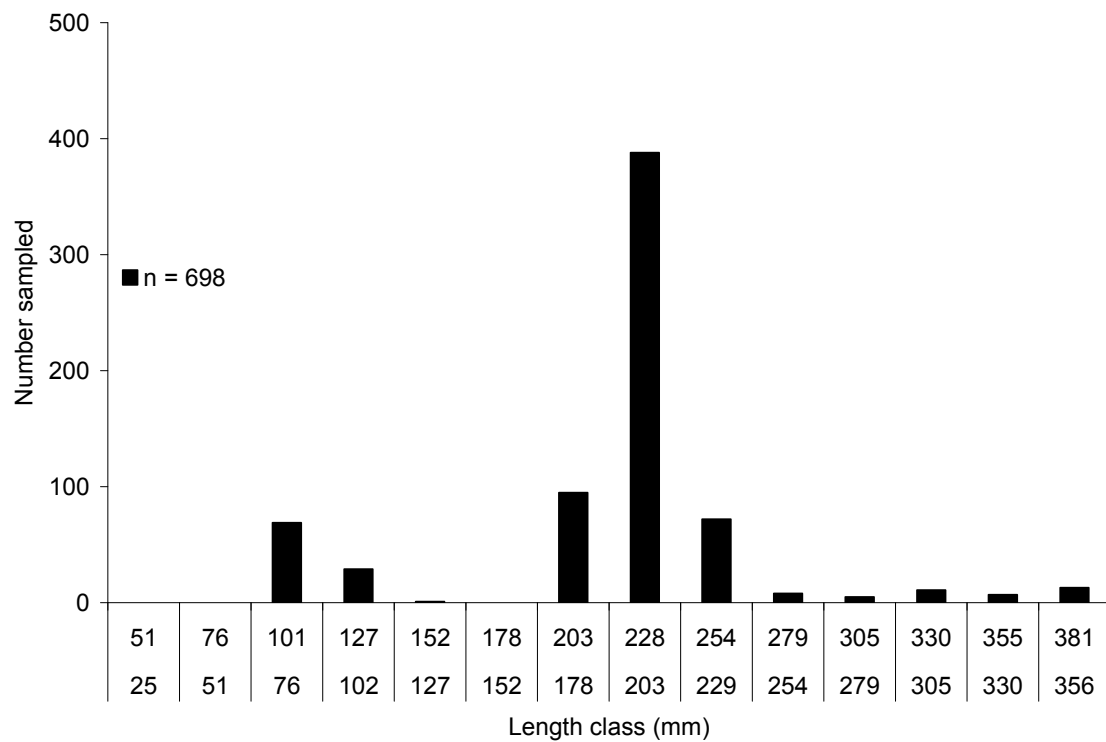


Figure A-7. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 5 days of bottom trawling assessments conducted on Lake Winnebago, WI in August 2009. Abundant 178-254 mm walleye represent the strong 2008 year class (age-1).

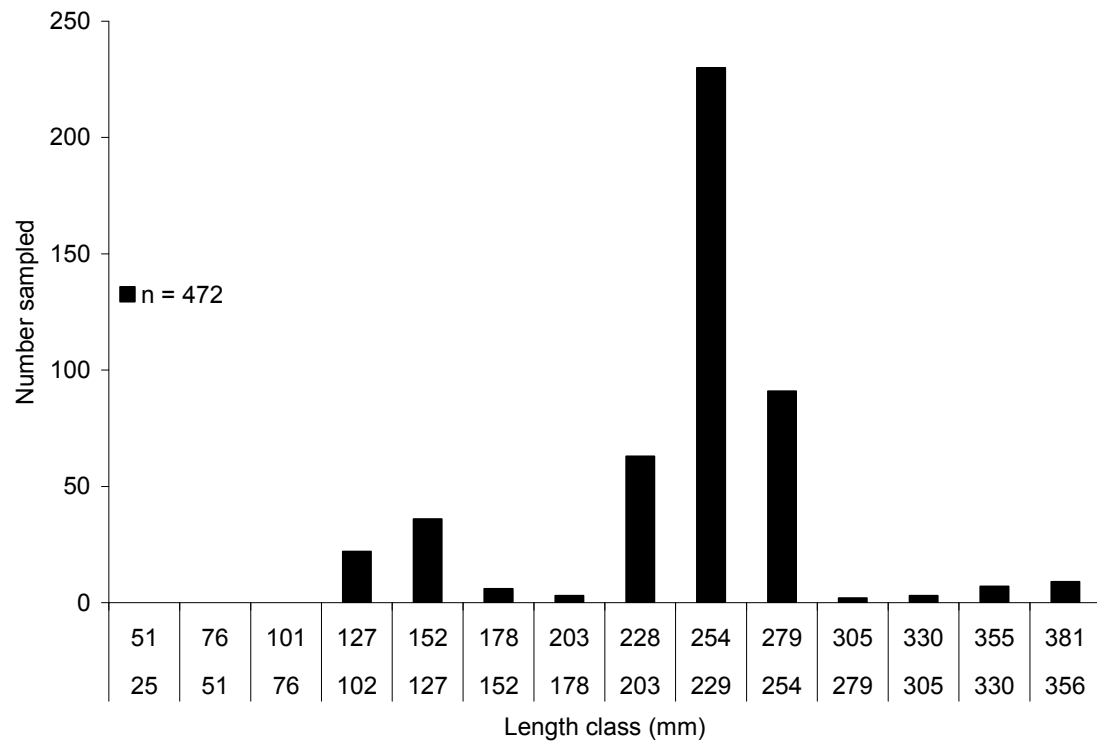


Figure A-8. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 5 days of bottom trawling assessments conducted on Lake Winnebago, WI in September 2009. Abundant 203-279 mm walleye represent the strong 2008 year class (age-1).



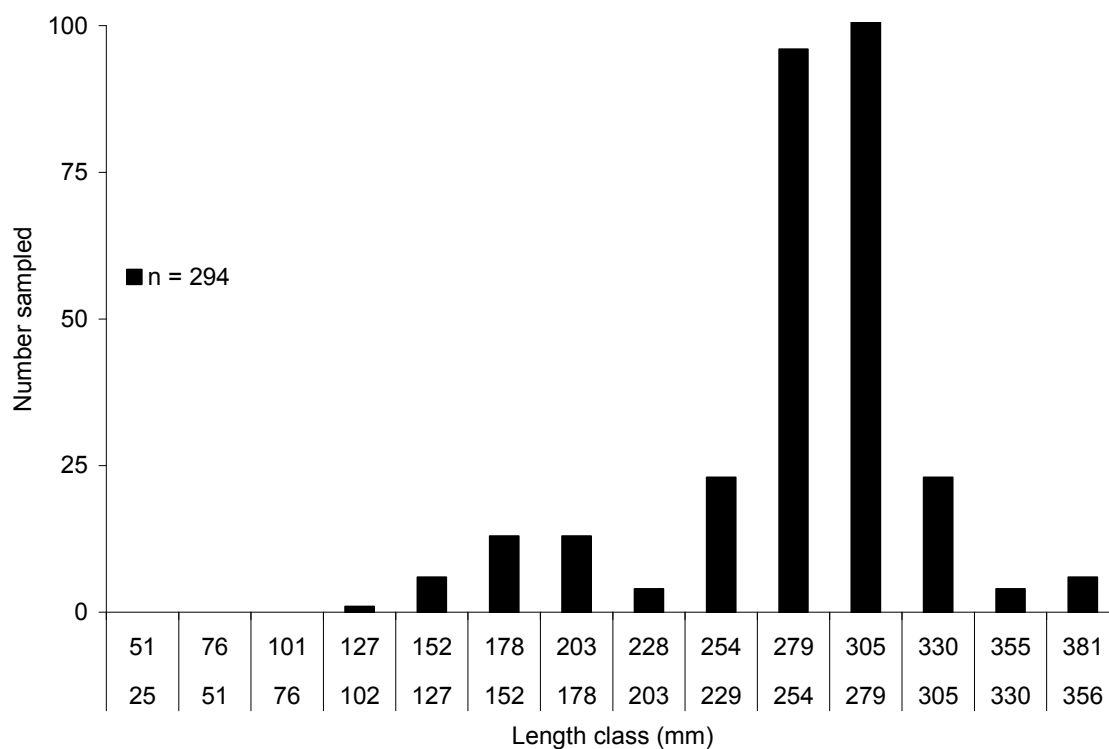


Figure A-9. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 5 days of bottom trawling assessments conducted on Lake Winnebago, WI in October 2009. Abundant 254-305 mm walleye represent the strong 2008 year class (age-1).

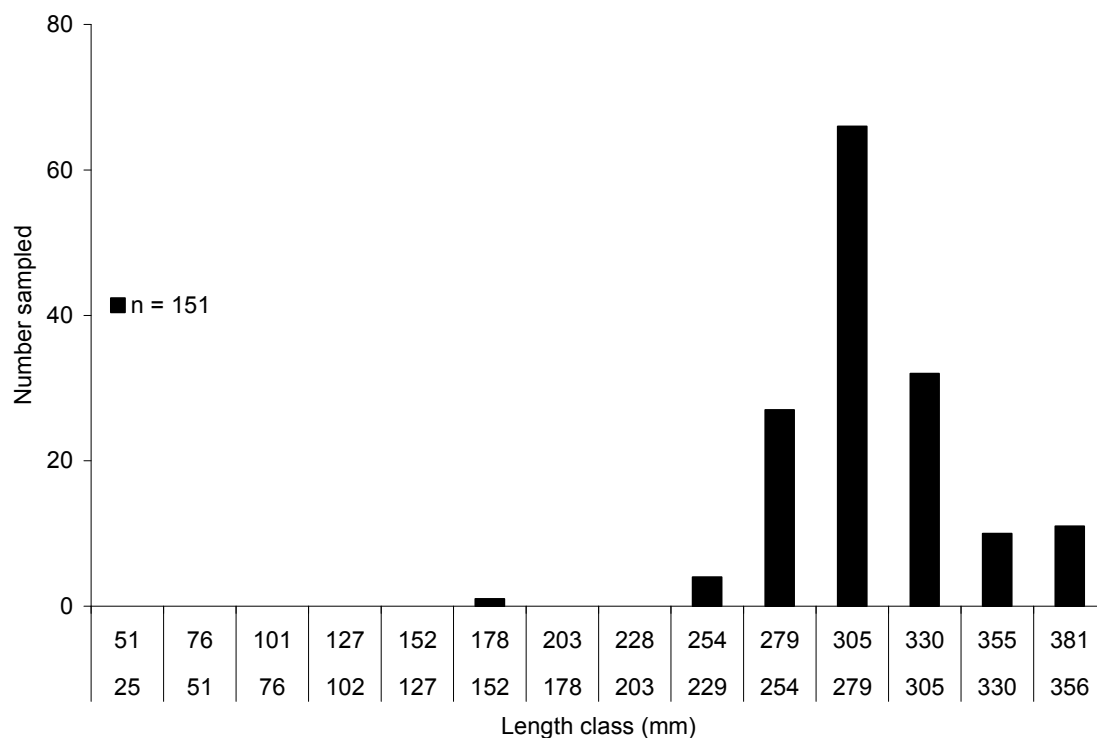


Figure A-10. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during a night electro-fishing assessment conducted on Lake Winnebago, WI in April 2010. Abundant 254-330 mm walleye represent the strong 2008 year class (age-2). All walleye contained in this length frequency were euthanized for VHS testing, otoliths and dorsal spines were removed from the majority of these fish for age estimation.

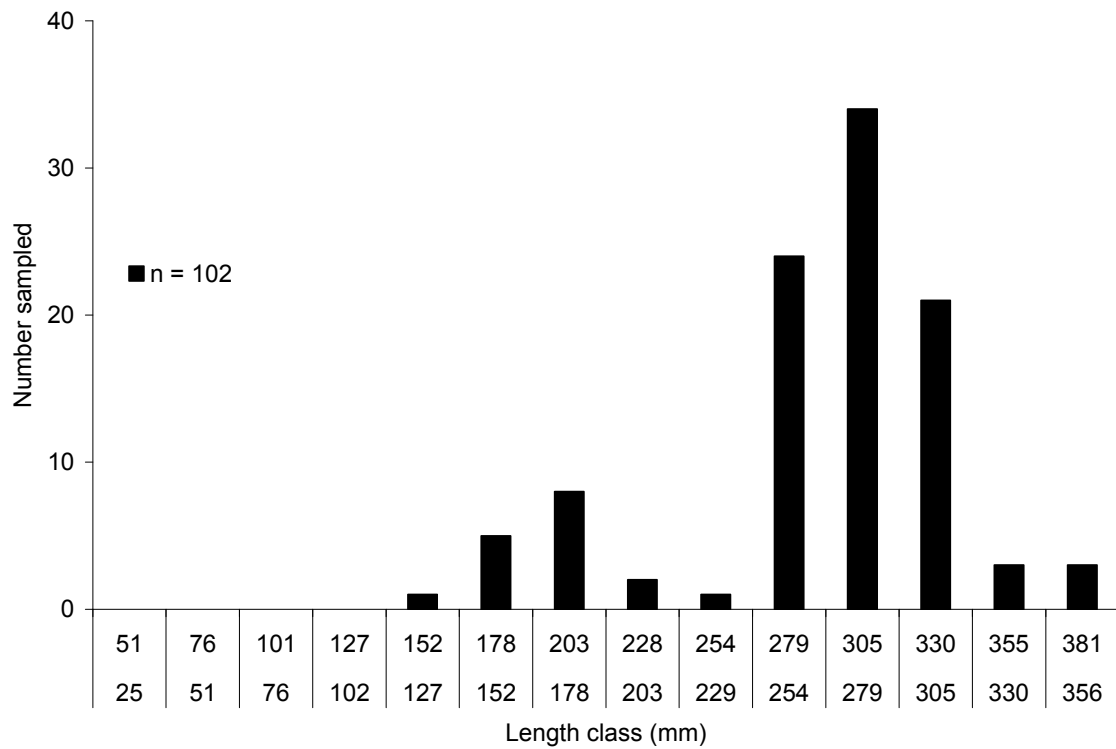


Figure A-11. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 2 evenings of electro-fishing assessments conducted on Lake Winnebago, WI in May 2010. Abundant 254-330 mm walleye represent the strong 2008 year class (age-2).

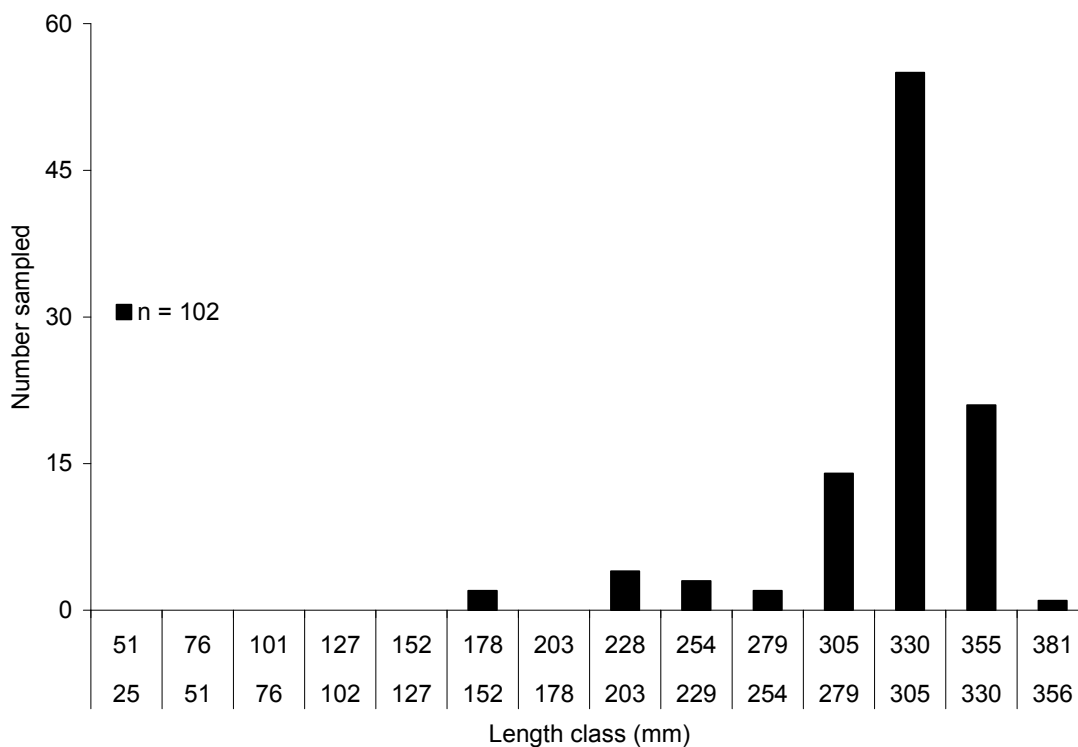


Figure A-12. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 2 evenings of electro-fishing assessments conducted on Lake Winnebago, WI in June 2010. Abundant 279-355 mm walleye represent the strong 2008 year class (age-2).

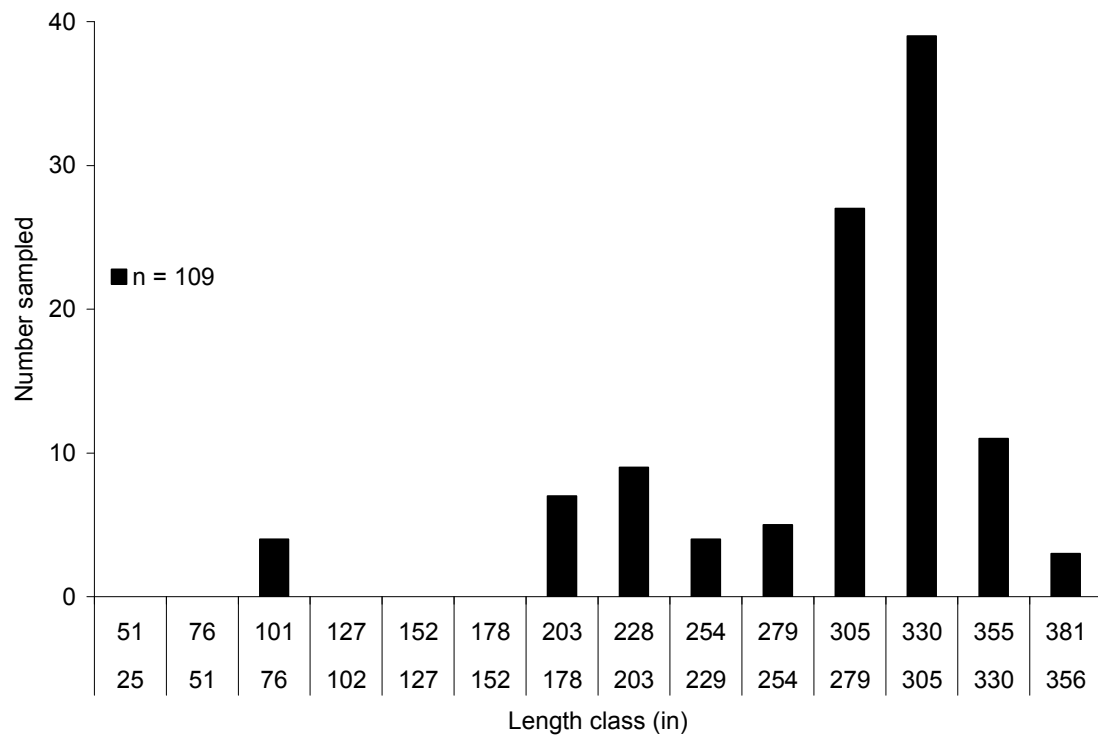


Figure A-13. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 2 days of bottom trawling assessments conducted on Lake Winnebago, WI in July 2010. Abundant 279-330 mm walleye represent the strong 2008 year class (age-2).

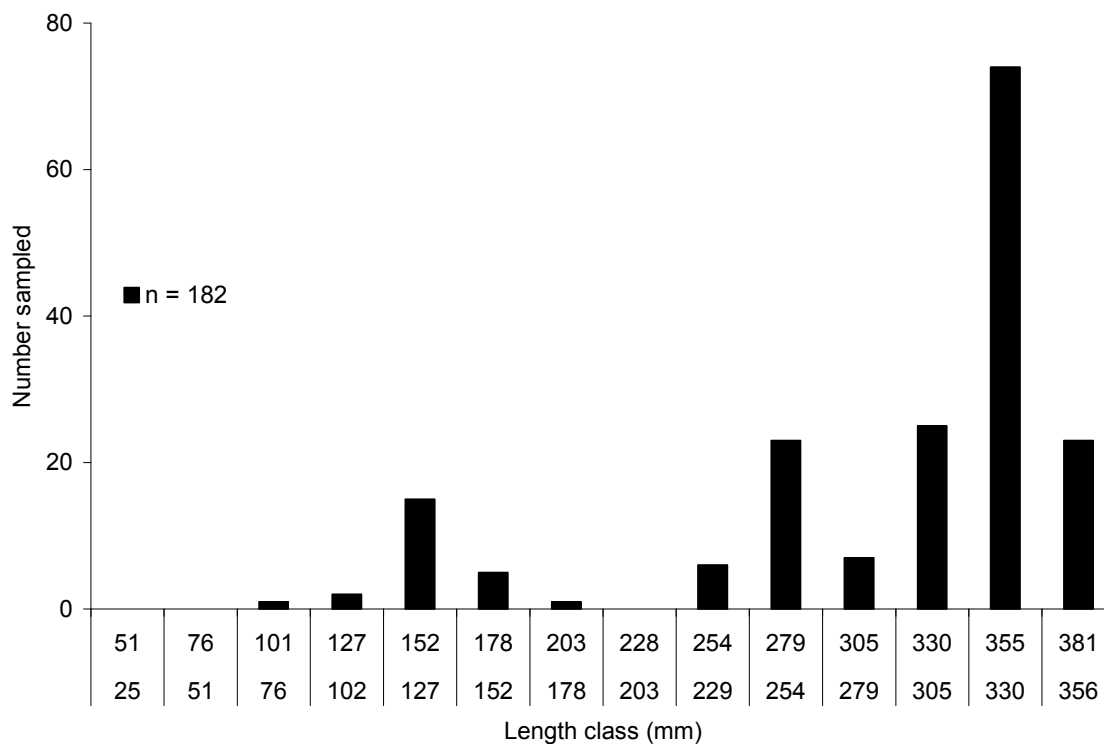


Figure A-14. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 5 days of bottom trawling assessments conducted on Lake Winnebago, WI in August 2010. Abundant 330-355 mm walleye represent the strong 2008 year class (age-2).

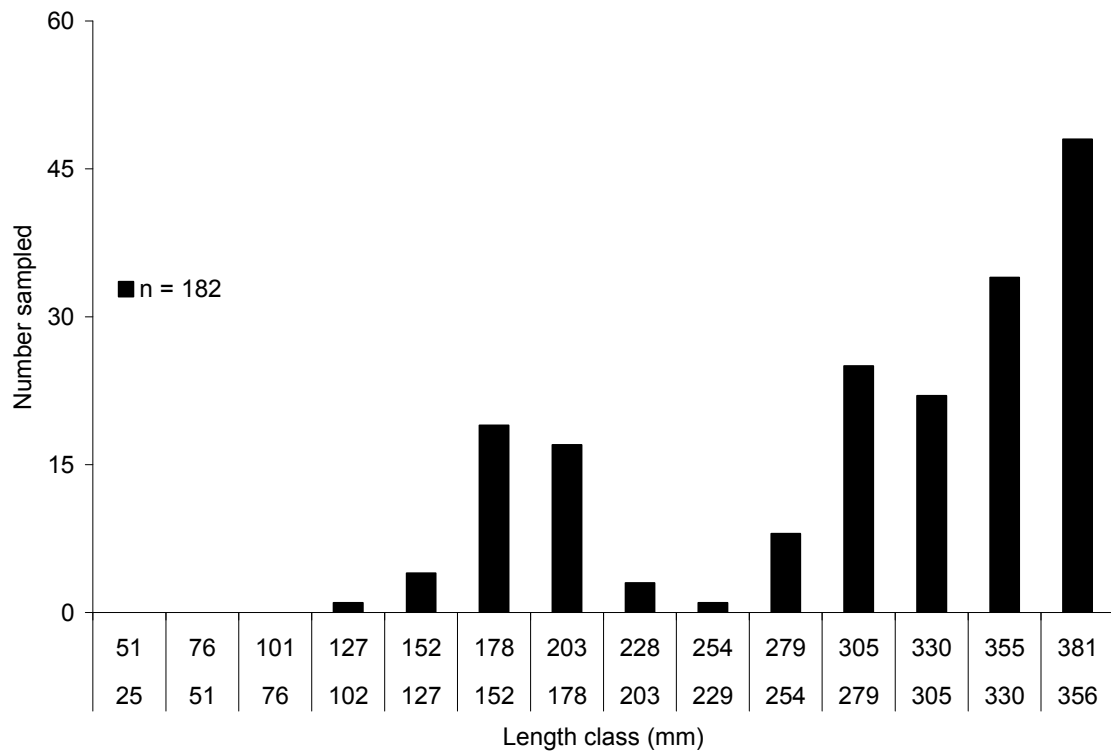


Figure A-15. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 5 days of bottom trawling assessments conducted on Lake Winnebago, WI in September 2010. Abundant 330-381 mm walleye represent the strong 2008 year class (age-2).

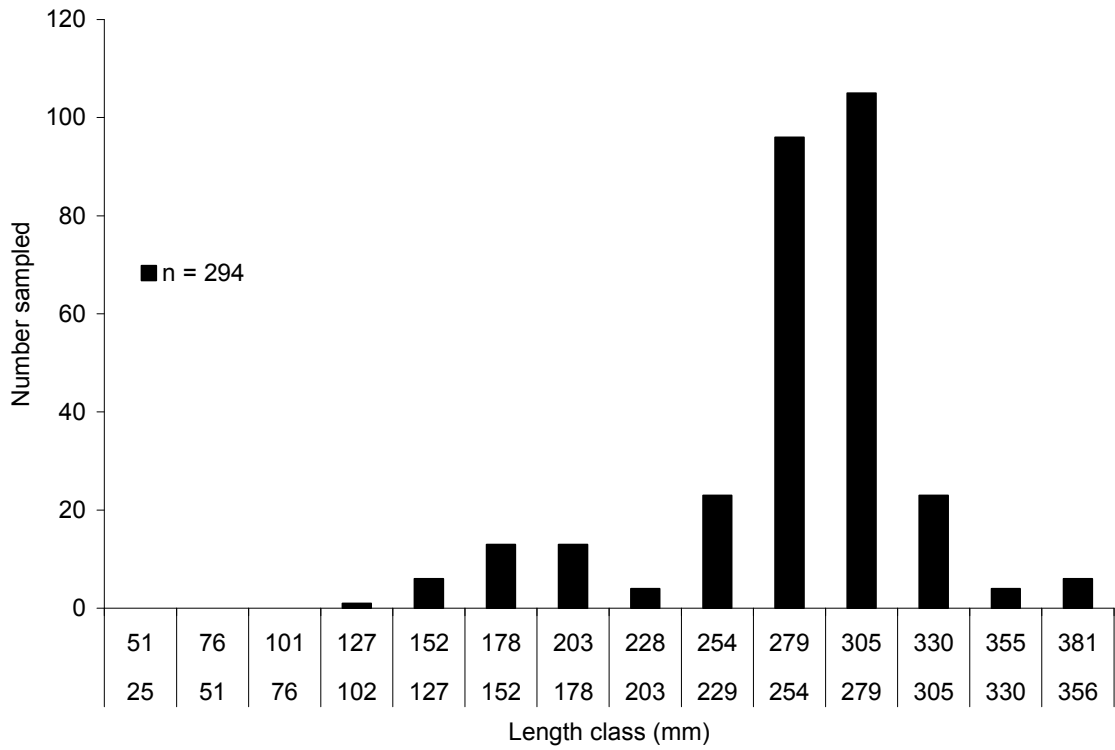


Figure A-16. Length frequency plot showing the size distribution of walleye  $\leq 381$  mm collected during 5 days of bottom trawling assessments conducted on Lake Winnebago, WI in October (2010).



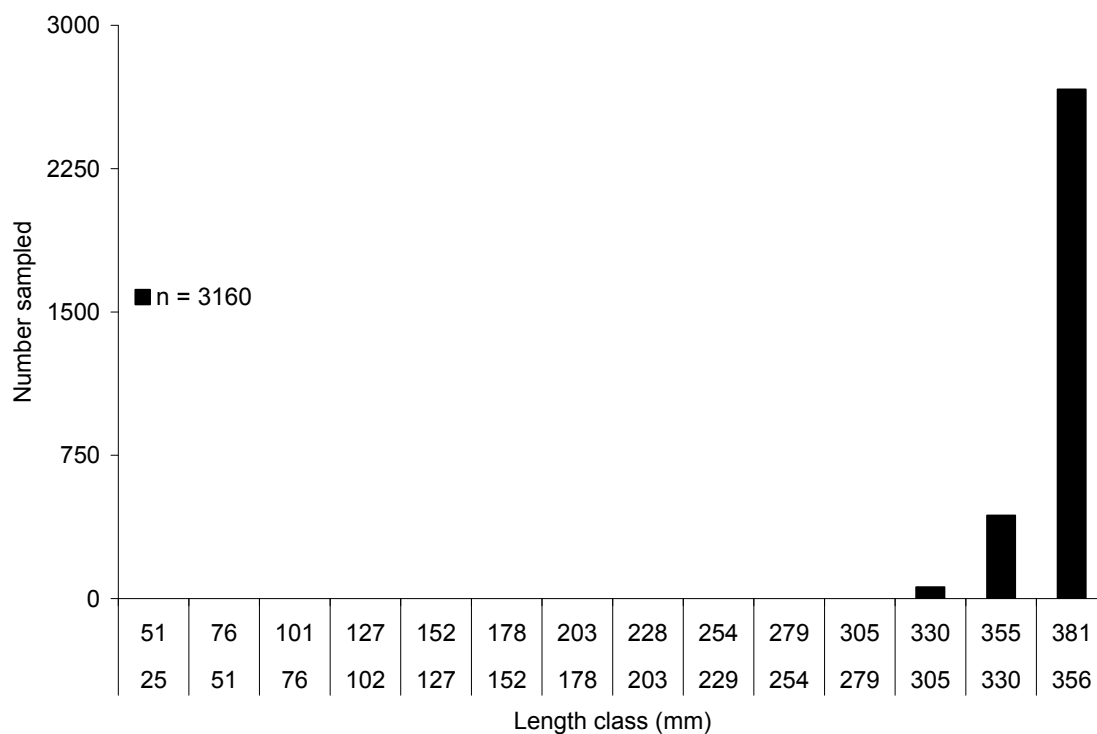


Figure A-17. Length Frequency plot showing the size distribution of adult male walleye  $\leq 381$  mm collected during April (2011) spawning assessments on the Wolf River, WI. Walleye were captured through the combined effort of 10 days of electro-fishing surveys and 10 days of fyke netting surveys. Abundant 356-381 mm walleye represent adult male walleye from the 2008 year class that were likely making their first spawning migration at age-3.

## APPENDIX B

Age corroboration: standardized age class residuals from catch curve analyses vs. standardized year class strength from fall trawling data (CPUE age-1 walleye)

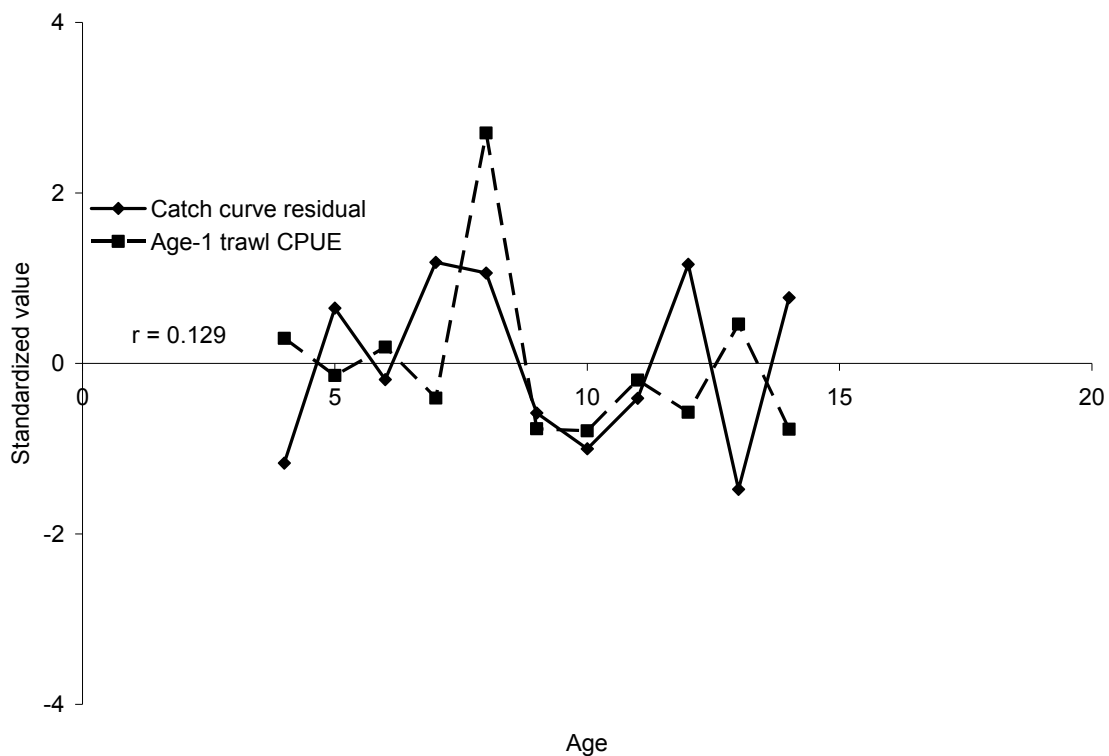


Figure B-1. Plot comparing standardized values of trawl CPUE of age-1 walleye (dashed line) and standardized residual values from a catch curve (solid line) constructed from dorsal spine age estimates, showing the relative age distribution of adult male walleye sampled during April spawning assessments conducted on the Winnebago System, WI in 2009.

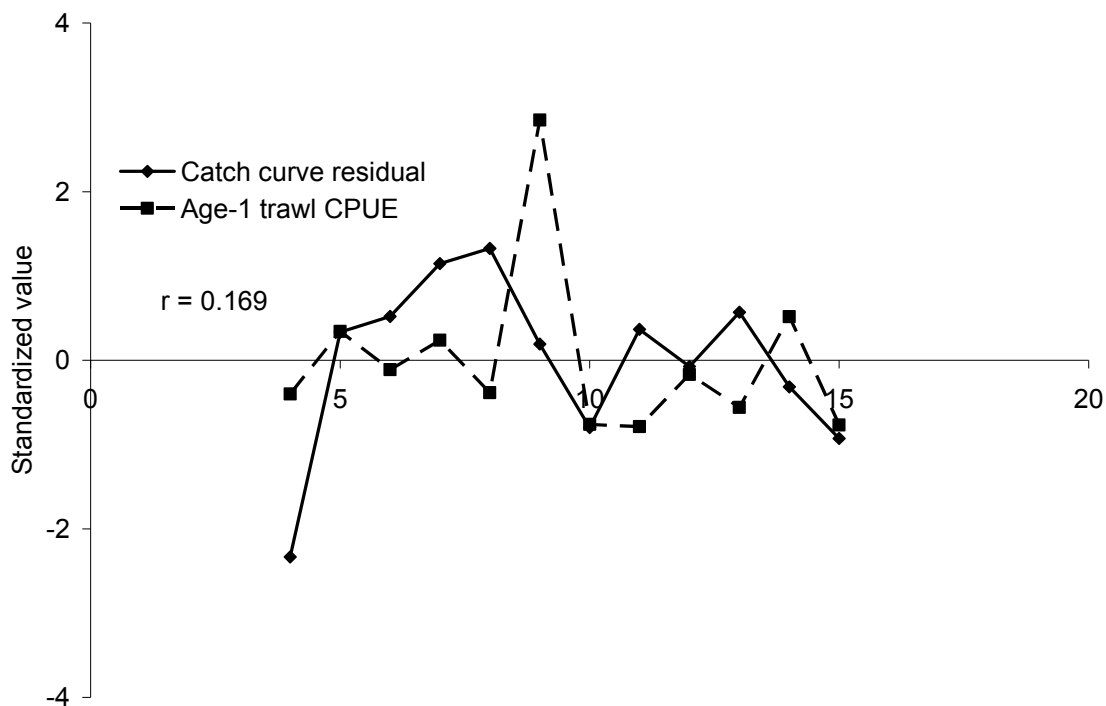


Figure B-2. Plot comparing standardized values of trawl CPUE of age-1 walleye (dashed line) and standardized residual values from a catch curve (solid line) constructed from dorsal spine age estimates, showing the relative age distribution of adult male walleye sampled during April spawning assessments conducted on the Winnebago System, WI in 2010.

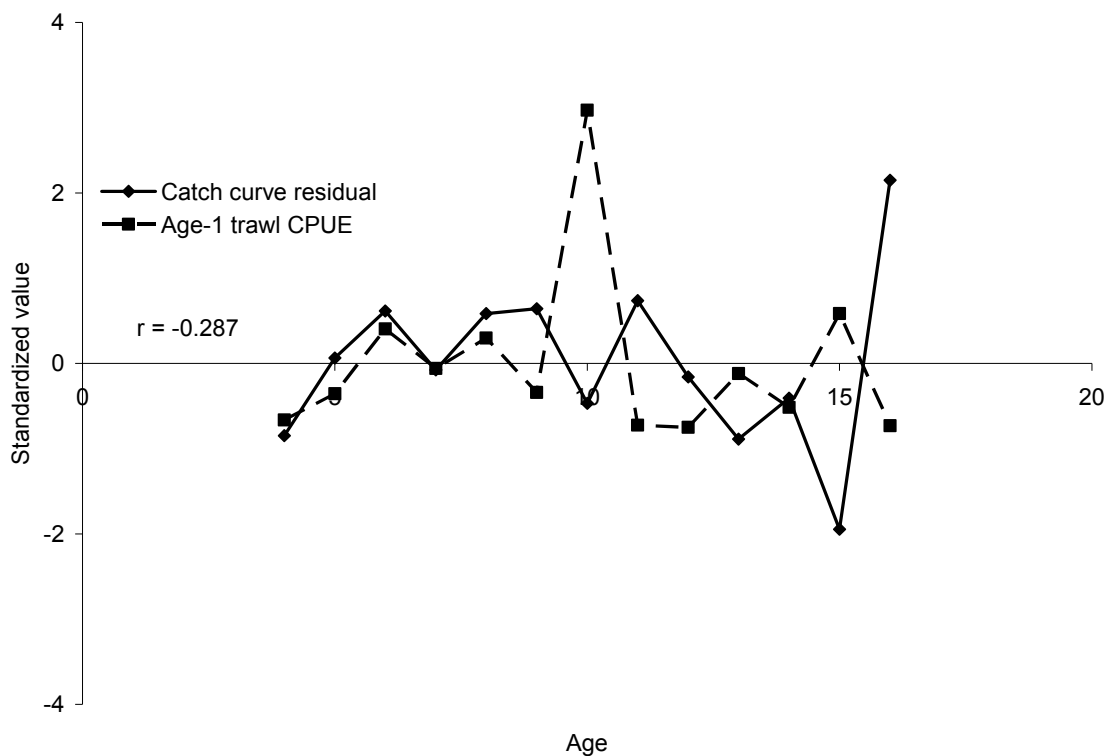


Figure B-3. Plot comparing standardized values of trawl CPUE of age-1 walleye (dashed line) and standardized residual values from a catch curve (solid line) constructed from dorsal spine age estimates, showing the relative age distribution of adult male walleye sampled during April spawning assessments conducted on the Winnebago System, WI in 2011.

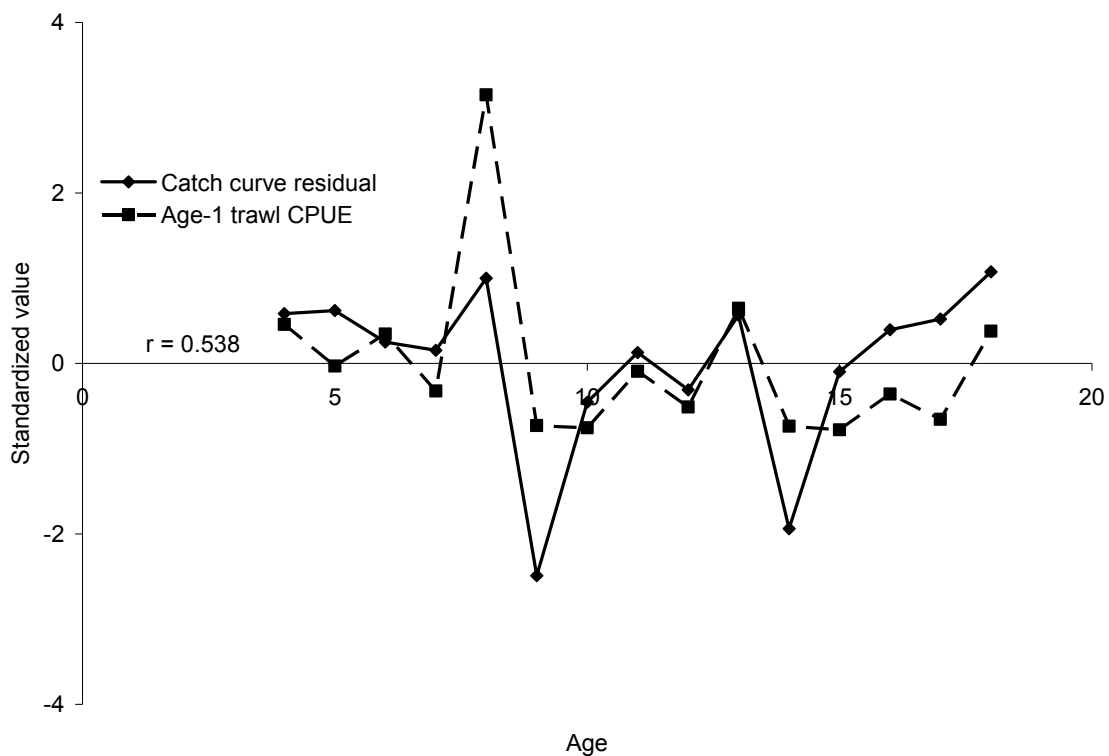


Figure B-4. Plot comparing standardized values of trawl CPUE of age-1 walleye (dashed line) and standardized residual values from a catch curve (solid line) constructed from otolith age estimates, showing the relative age distribution of adult male walleye sampled during April spawning assessments conducted on the Winnebago System, WI in 2009.

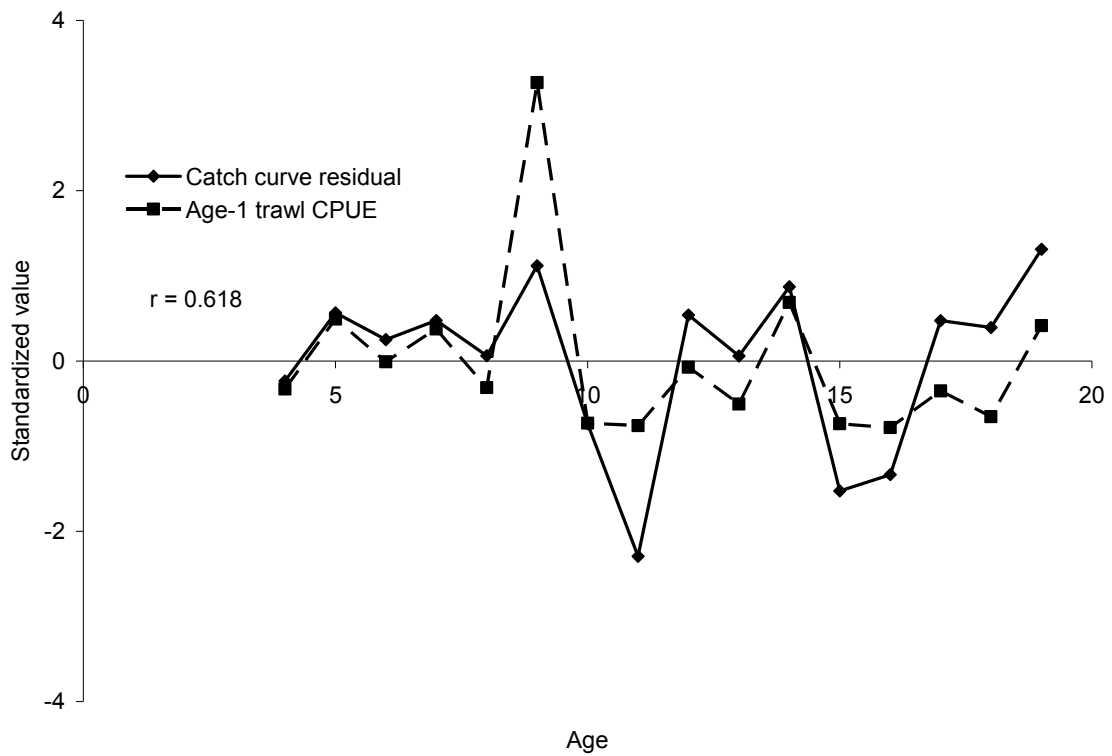


Figure B-5. Plot comparing standardized values of trawl CPUE of age-1 walleye (dashed line) and standardized residual values from a catch curve (solid line) constructed from otolith age estimates, showing the relative age distribution of adult male walleye sampled during April spawning assessments conducted on the Winnebago System, WI in 2010.

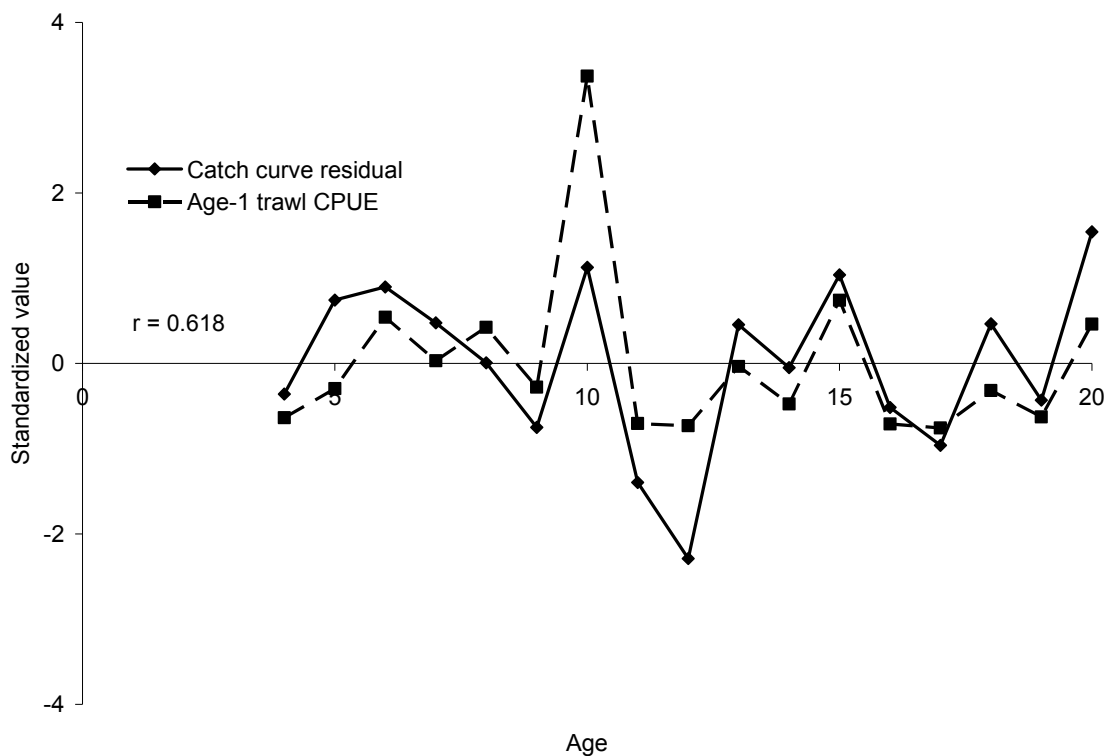


Figure B-6. Plot comparing standardized values of trawl CPUE of age-1 walleye (dashed line) and standardized residual values from a catch curve (solid line) constructed from otolith age estimates, showing the relative age distribution of adult male walleye sampled during April spawning assessments conducted on the Winnebago System, WI in 2011.



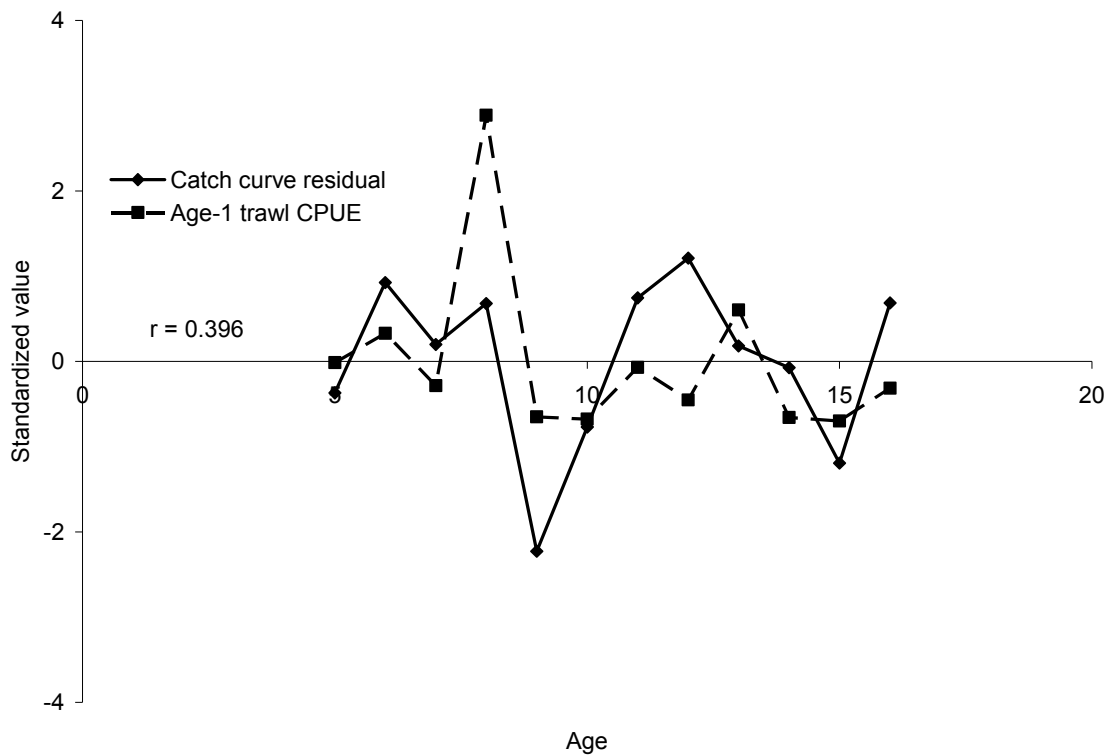


Figure B-7. Plot comparing standardized values of trawl CPUE of age-1 walleye (dashed line) and standardized residual values from a catch curve (solid line) constructed from dorsal spine age estimates, showing the relative age distribution of adult female walleye sampled during April spawning assessments conducted on the Winnebago System, WI in 2009.

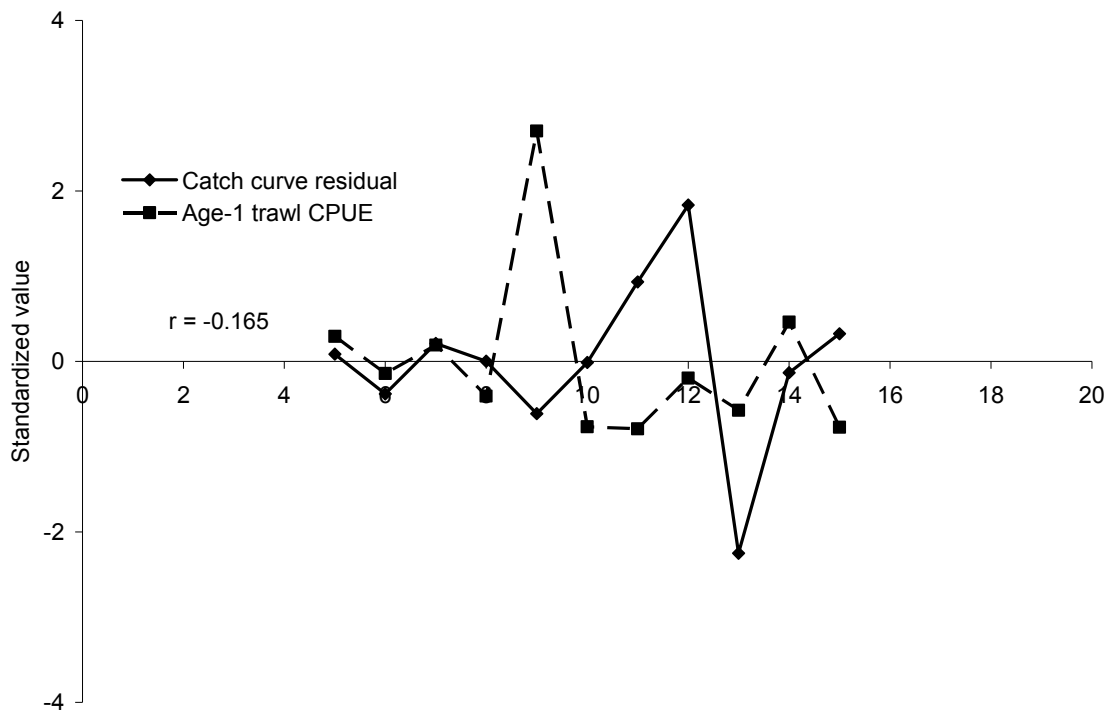


Figure B-8. Plot comparing standardized values of trawl CPUE of age-1 walleye (dashed line) and standardized residual values from a catch curve (solid line) constructed from dorsal spine age estimates, showing the relative age distribution of adult female walleye sampled during April spawning assessments conducted on the Winnebago System, WI in 2010.

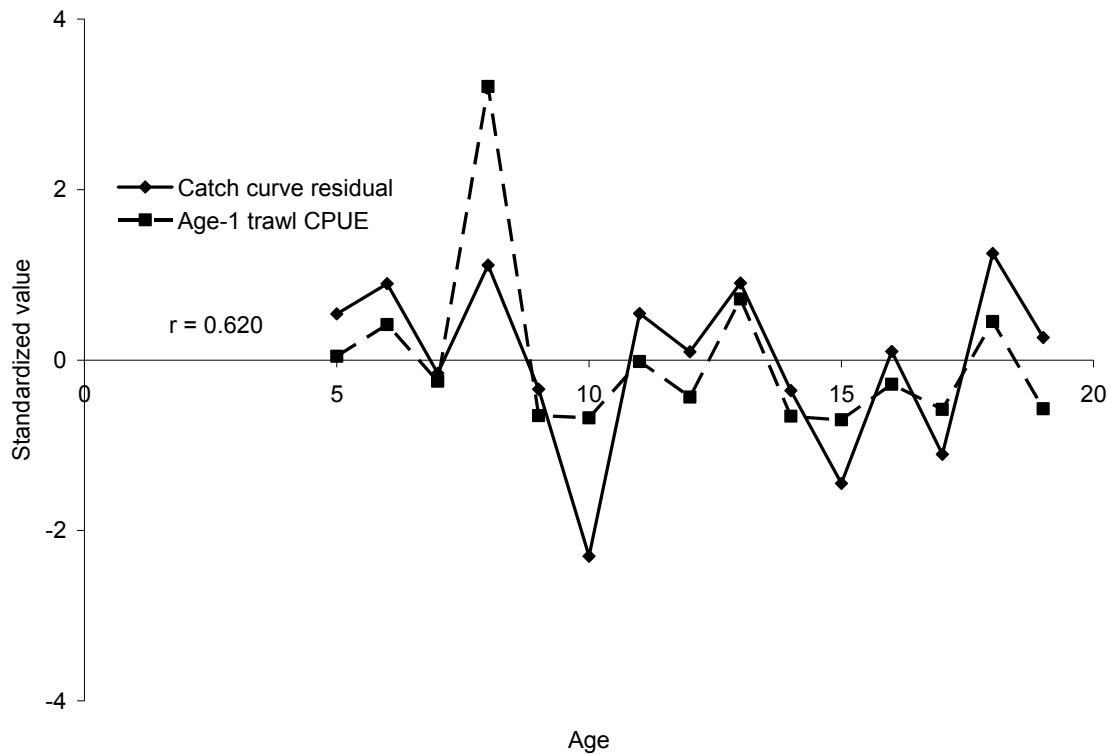


Figure B-9. Plot comparing standardized values of trawl CPUE of age-1 walleye (dashed line) and standardized residual values from a catch curve (solid line) constructed from otolith age estimates, showing the relative age distribution of adult female walleye sampled during April spawning assessments conducted on the Winnebago System, WI in 2009.

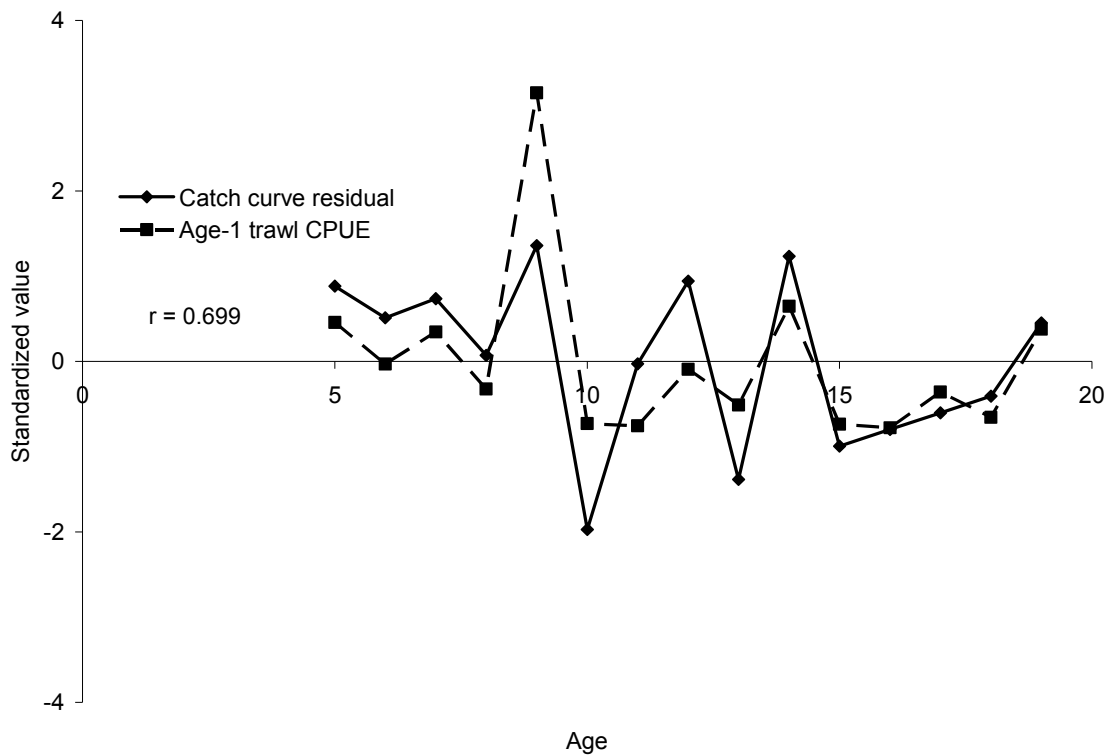


Figure B-10. Plot comparing standardized values of trawl CPUE of age-1 walleye (dashed line) and standardized residual values from a catch curve (solid line) constructed from otolith age estimates, showing the relative age distribution of adult female walleye sampled during April spawning assessments conducted on the Winnebago System, WI, during April spawning assessments in 2010.

## APPENDIX C

Catch curves and estimated rates of conditional total annual mortality

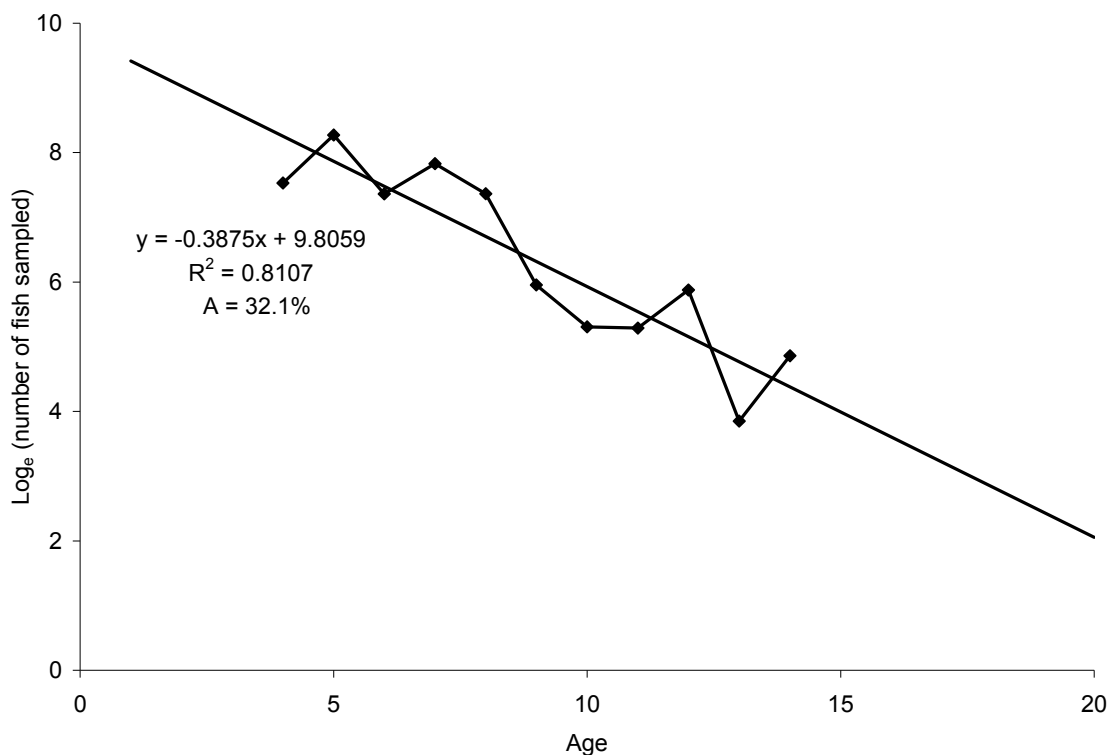


Figure C-1. Catch curve, based on dorsal spine age estimates, displaying relative age distribution of adult male walleye collected during April spawning assessments conducted on the Winnebago System, WI in 2009. Estimate of conditional annual mortality,  $A$ , calculated using the equation:  $A = 1 - e^{(\text{slope of line of best fit})}$ , where the slope of the line of best fit is calculated from a linear regression analysis of the  $\log_e$ (number of fish in each age class) on the age class of walleye.

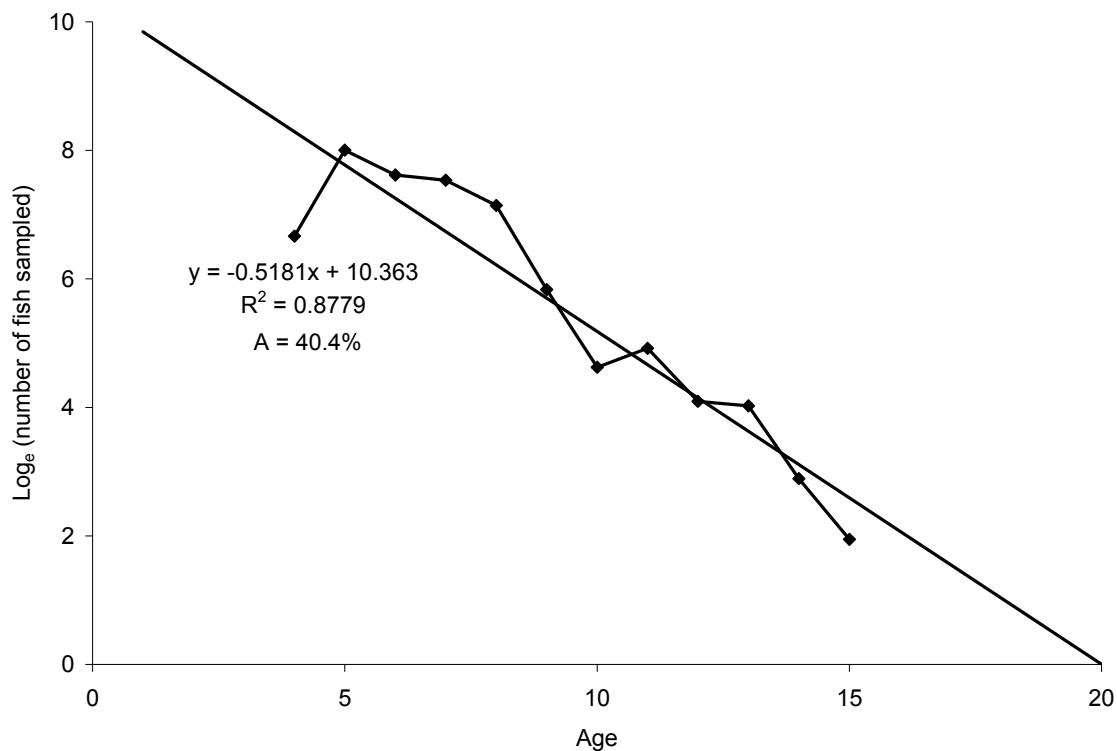


Figure C-2. Catch curve, based on dorsal spine age estimates, displaying relative age distribution of adult male walleye collected during April spawning assessments conducted on the Winnebago System, WI in 2010. Estimate of conditional annual mortality,  $A$ , calculated using the equation:  $A = 1 - e^{(\text{slope of line of best fit})}$ , where the slope of the line of best fit is calculated from a linear regression analysis of the  $\log_e$ (number of fish in each age class) on the age class of walleye.

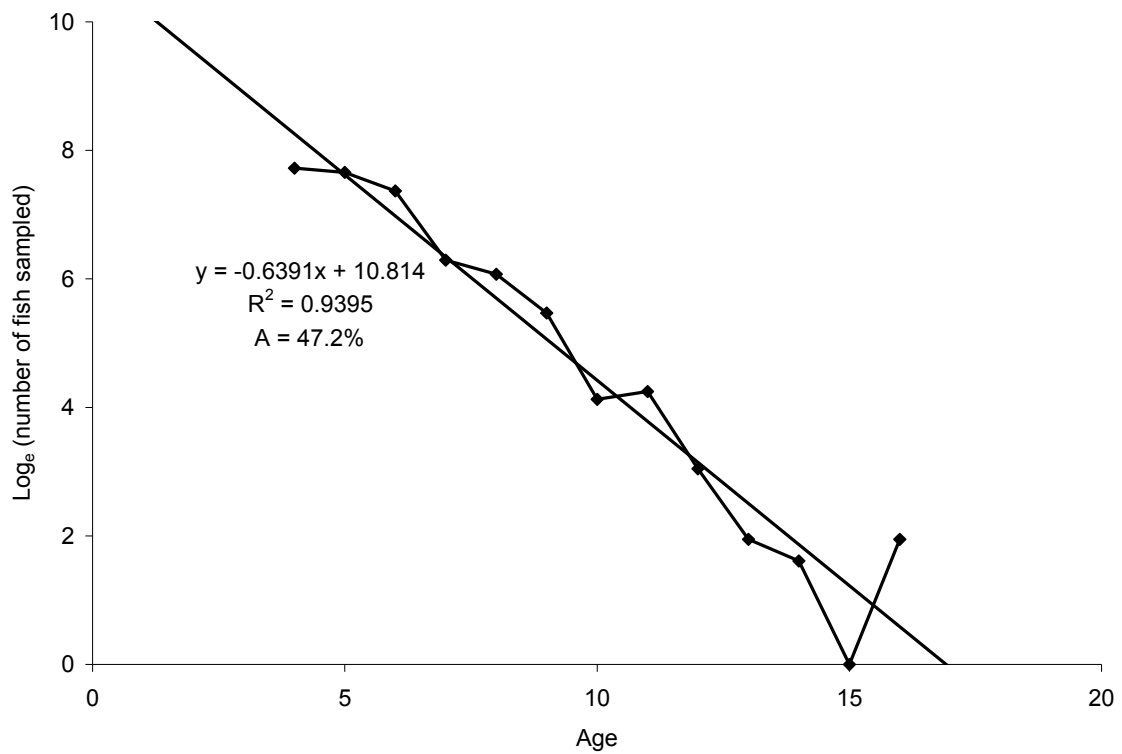


Figure C-3. Catch curve, based on dorsal spine age estimates, displaying relative age distribution of adult male walleye collected during April spawning assessments conducted on the Winnebago System, WI in 2011. Estimate of conditional annual mortality,  $A$ , calculated using the equation:  $A = 1 - e^{(\text{slope of line of best fit})}$ , where the slope of the line of best fit is calculated from a linear regression analysis of the  $\log_e$ (number of fish in each age class) on the age class of walleye.



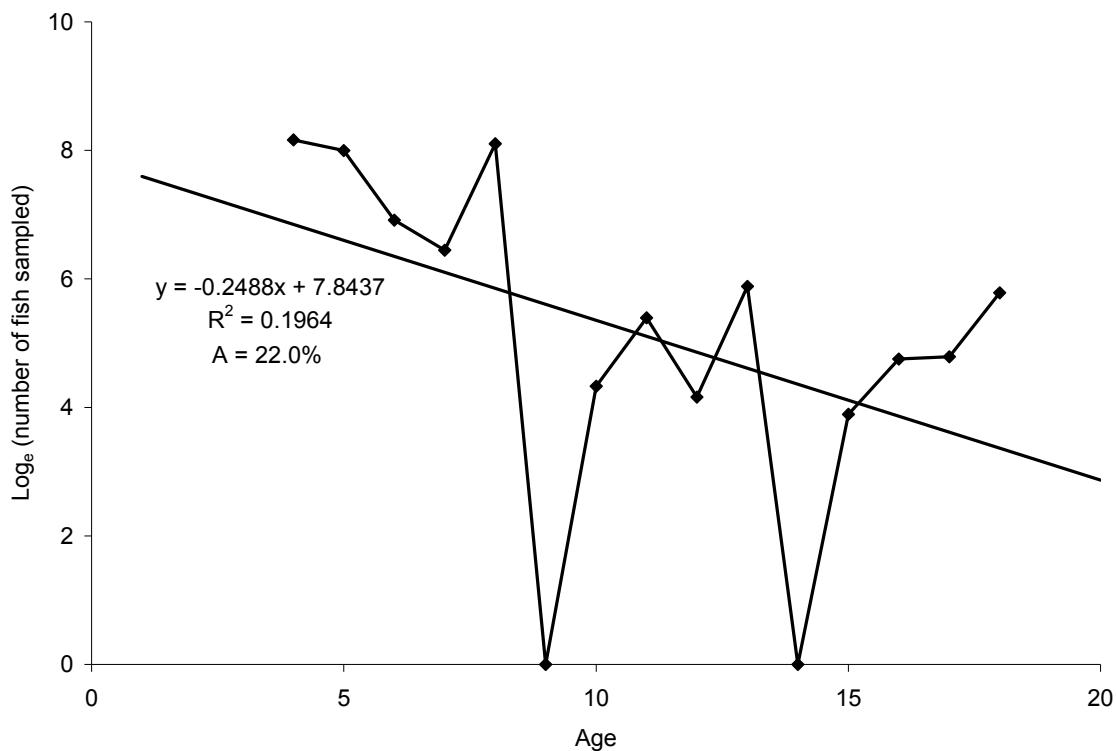


Figure C-4. Catch curve, based on otolith age estimates, displaying relative age distribution of adult male walleye collected during April spawning assessments conducted on the Winnebago System, WI in 2009. Estimate of conditional annual mortality,  $A$ , calculated using the equation:  $A = 1 - e^{(\text{slope of line of best fit})}$ , where the slope of the line of best fit is calculated from a linear regression analysis of the  $\log_e$ (number of fish in each age class) on the age class of walleye.

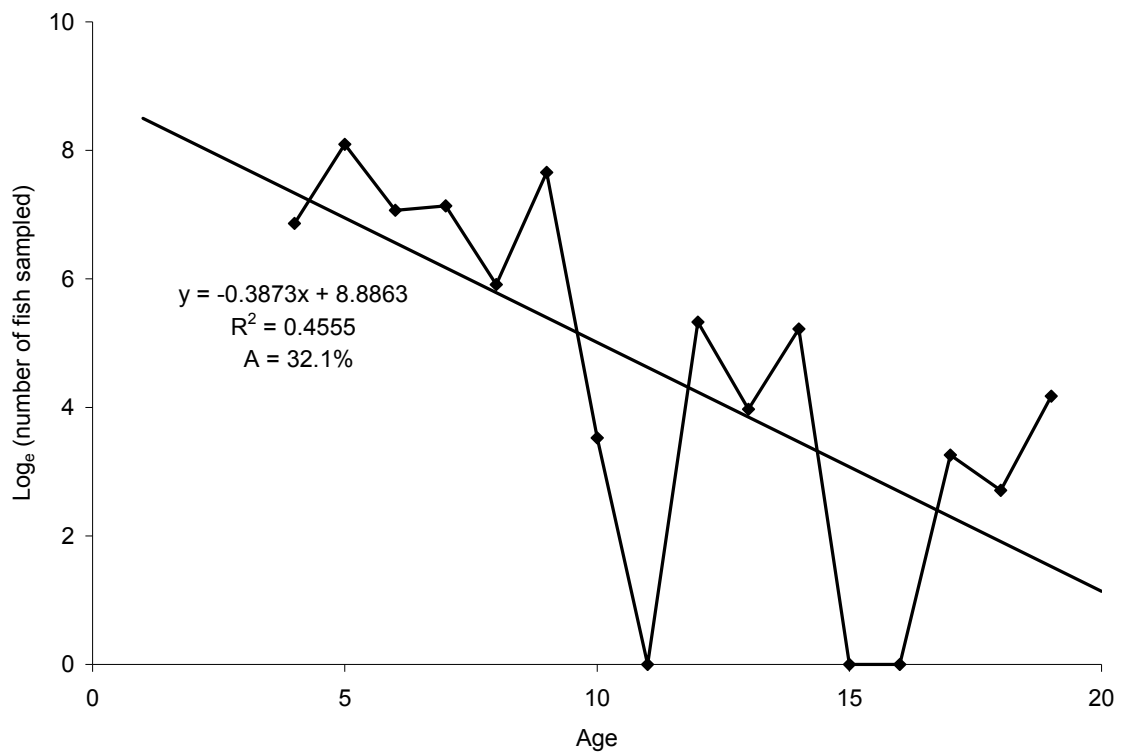


Figure C-5. Catch curve, based on otolith age estimates, displaying relative age distribution of adult male walleye collected during April spawning assessments conducted on the Winnebago System, WI in 2010. Estimate of conditional annual mortality,  $A$ , calculated using the equation:  $A = 1 - e^{(\text{slope of line of best fit})}$ , where the slope of the line of best fit is calculated from a linear regression analysis of the  $\log_e(\text{number of fish in each age class})$  on the age class of walleye.

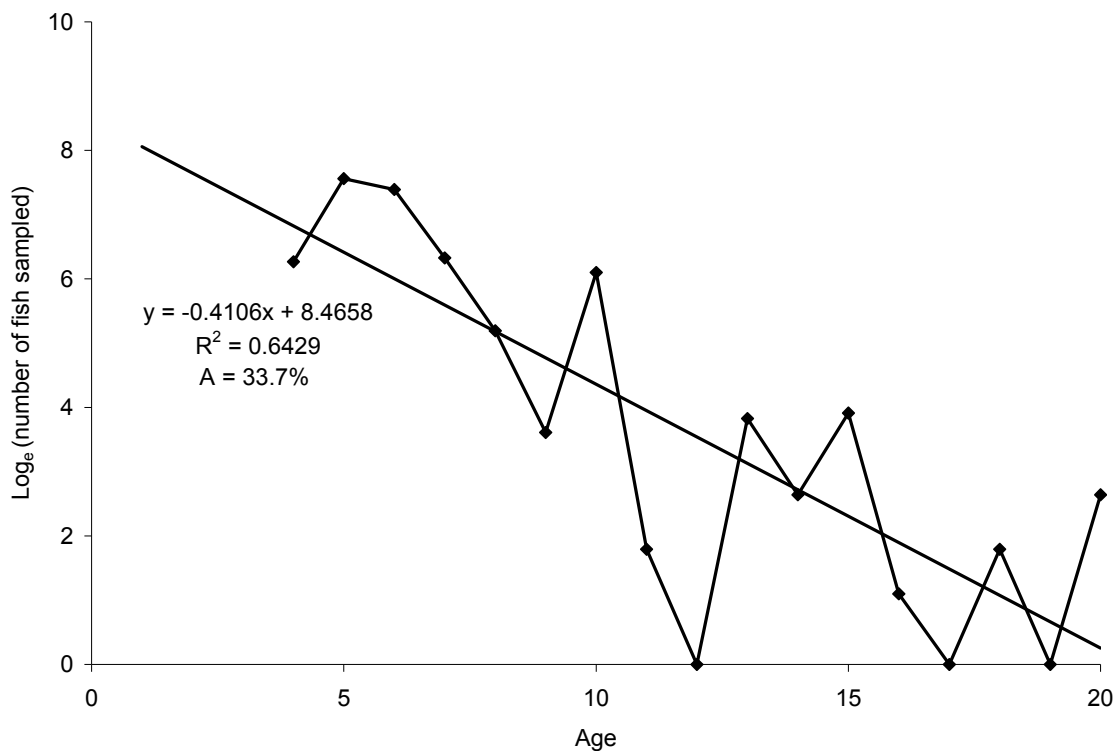


Figure C-6. Catch curve, based on otolith age estimates, displaying relative age distribution of adult male walleye collected during April spawning assessments conducted on the Winnebago System, WI in 2011. Estimate of conditional annual mortality,  $A$ , calculated using the equation:  $A = 1 - e^{(\text{slope of line of best fit})}$ , where the slope of the line of best fit is calculated from a linear regression analysis of the  $\log_e(\text{number of fish in each age class})$  on the age class of walleye.

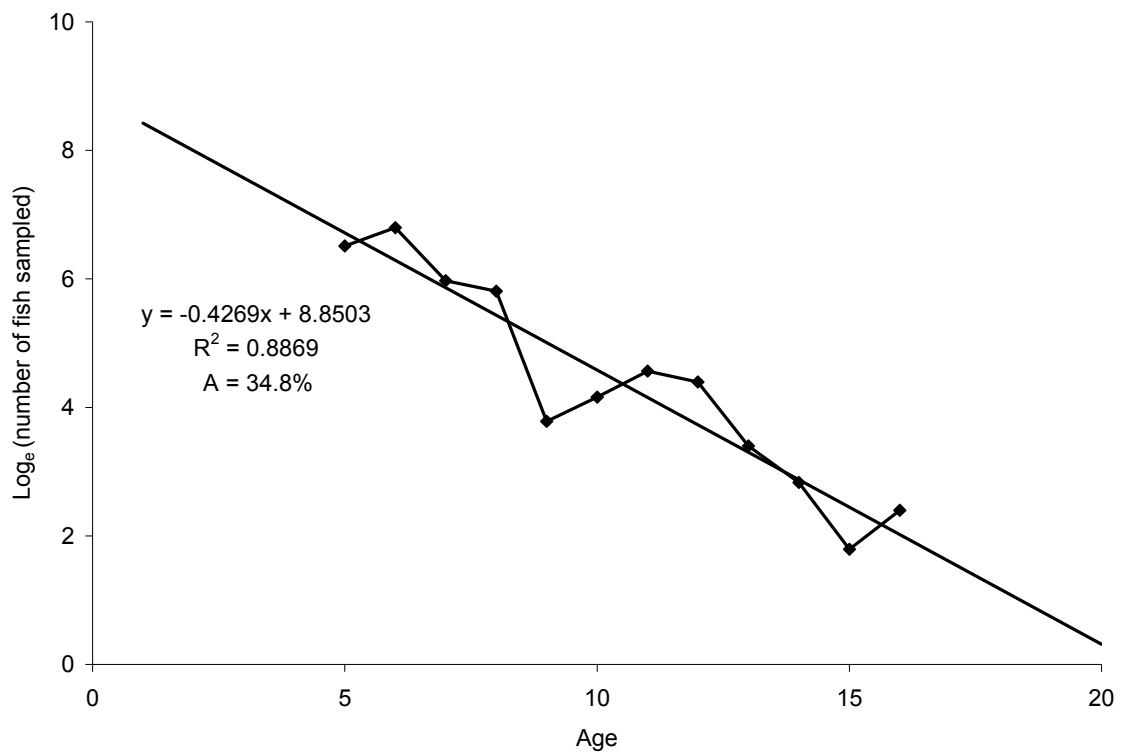


Figure C-7. Catch curve, based on dorsal age estimates, displaying relative age distribution of adult female walleye collected during April spawning assessments conducted on the Winnebago System, WI in 2009. Estimate of conditional annual mortality,  $A$ , calculated using the equation:  $A = 1 - e^{(\text{slope of line of best fit})}$ , where the slope of the line of best fit is calculated from a linear regression analysis of the  $\log_e$ (number of fish in each age class) on the age class of walleye.

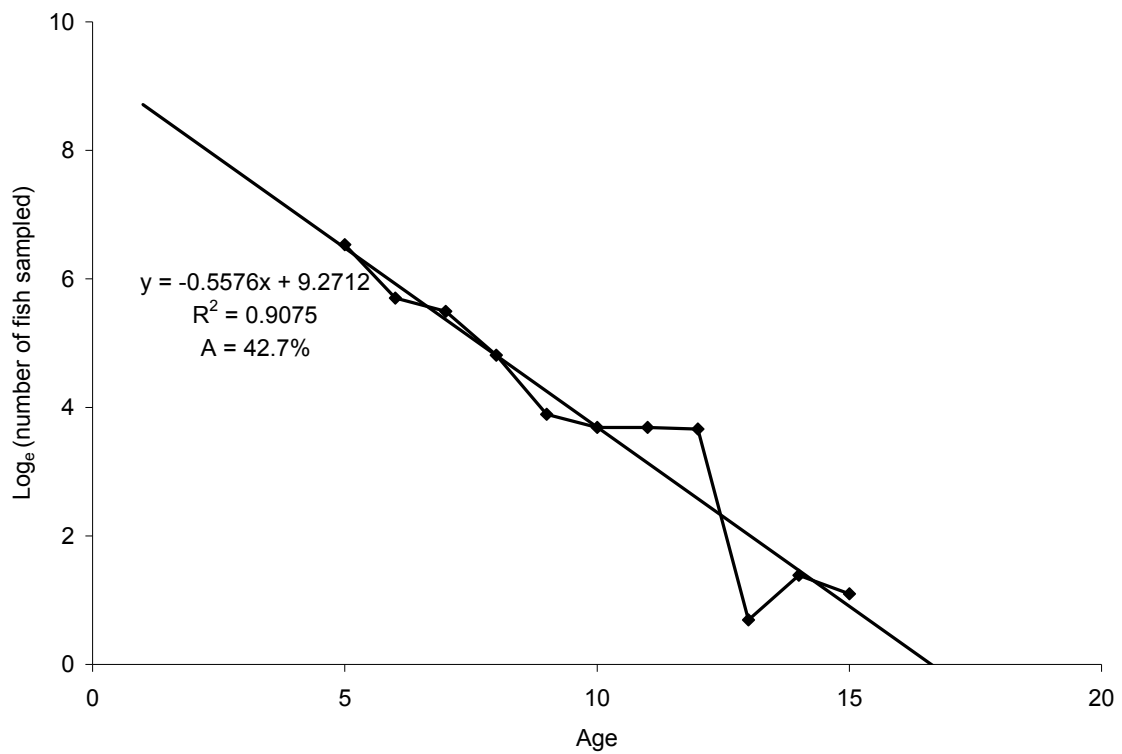


Figure C-8 Catch curve, based on dorsal age estimates, displaying relative age distribution of adult female walleye collected during April spawning assessments conducted on the Winnebago System, WI in 2010. Estimate of conditional annual mortality,  $A$ , calculated using the equation:  $A = 1 - e^{(\text{slope of line of best fit})}$ , where the slope of the line of best fit is calculated from a linear regression analysis of the  $\log_e$ (number of fish in each age class) on the age class of walleye.

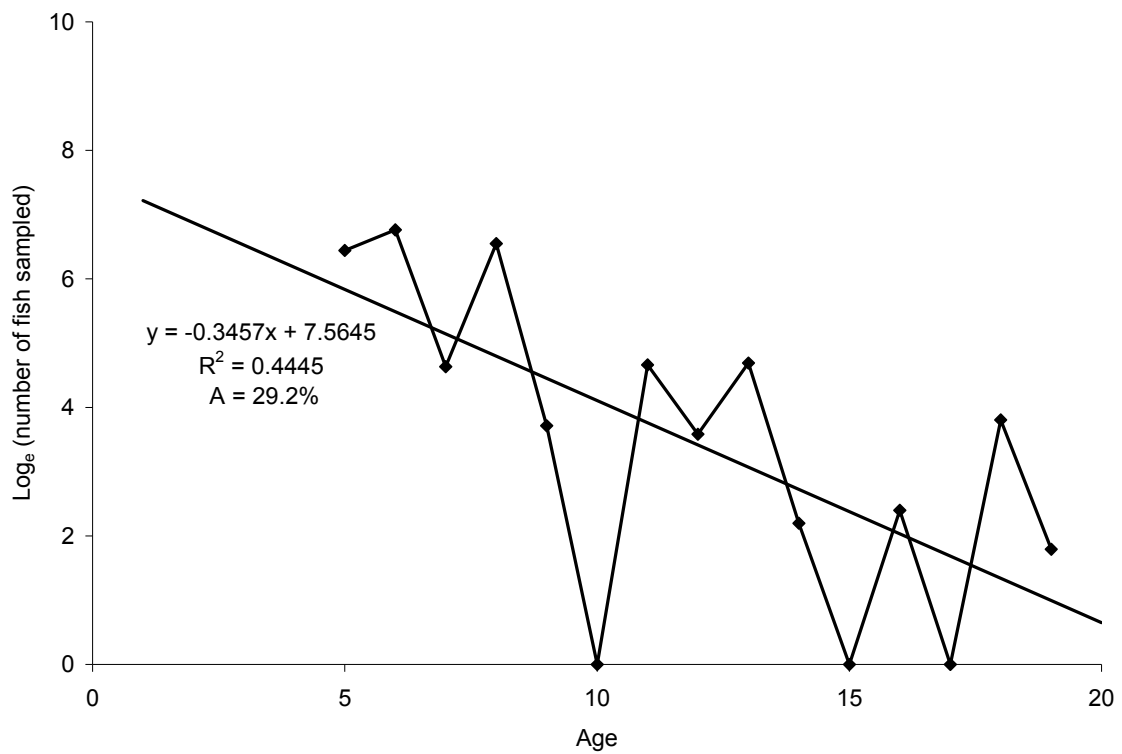


Figure C-9. Catch curve, based on otolith age estimates, displaying relative age distribution of adult female walleye collected during April spawning assessments conducted on the Winnebago System, WI in 2009. Estimate of conditional annual mortality,  $A$ , calculated using the equation:  $A = 1 - e^{(\text{slope of line of best fit})}$ , where the slope of the line of best fit is calculated from a linear regression analysis of the  $\log_e(\text{number of fish in each age class})$  on the age class of walleye.

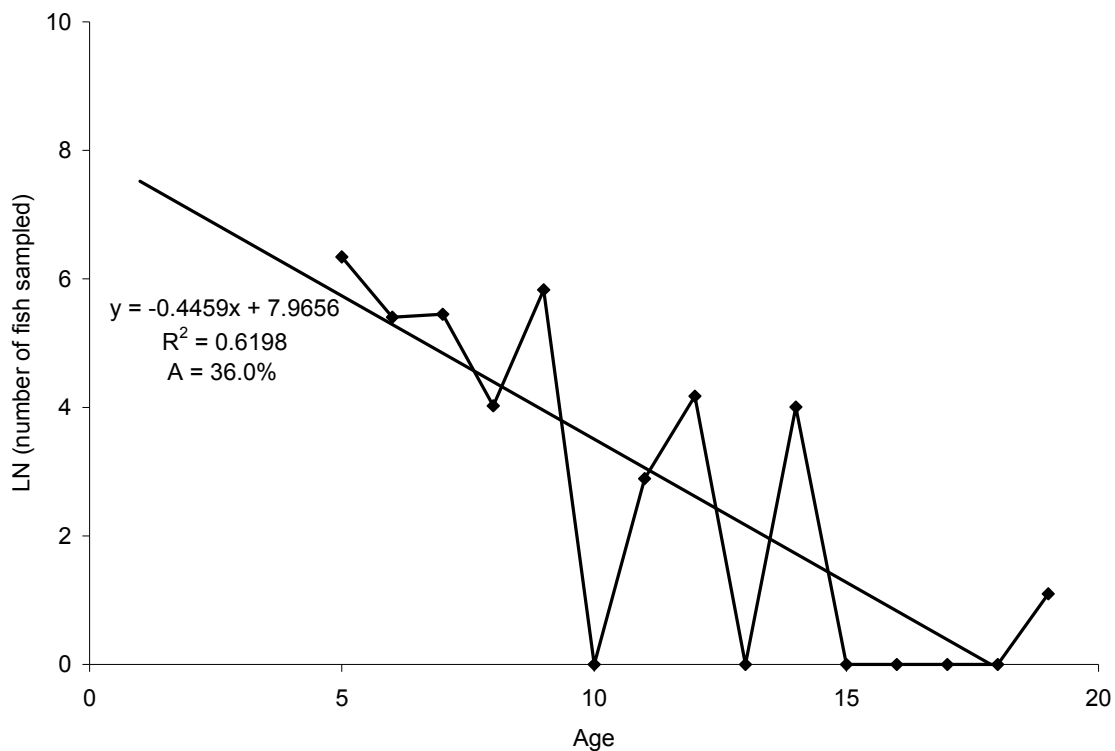


Figure C-10. Catch curve, based on otolith age estimates, displaying relative age distribution of adult female walleye collected during April spawning assessments conducted on the Winnebago System, WI in 2010. Estimate of conditional annual mortality,  $A$ , calculated using the equation:  $A = 1 - e^{(\text{slope of line of best fit})}$ , where the slope of the line of best fit is calculated from a linear regression analysis of the  $\log_e$ (number of fish in each age class) on the age class of walleye.