12-2015

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Notes

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Abstract

The popularity of walleye *Sander vitreus* fishing has resulted in the development of specialized regulations that are designed to protect these fisheries. In the case of Sherman Reservoir, Sherman County, Nebraska, the walleye population provides a sportfishing opportunity and serves as broodstock for the state. In 2009, for the primary purpose of protecting female broodstock, the regulation changed from a harvest limit of four walleye with 457-mm minimum length to allowing a reduced harvest limit of two walleye within a harvest slot (381–508 mm) and one walleye more than 711 mm. This study examined existing data sets to assess the percentage of spawning walleye protected with each regulation, sex-specific differences in relative abundance and size structure during broodstock collection and angler effort, total catch, and harvest of walleye. The new regulation has increased protection of female walleye by more than 90%, but decreased protection of male walleye by more than 60%. The relative abundance of female walleye caught per net during broodstock collection has more than doubled since the regulation was changed, but the size structure of female walleye collected during broodstock operations was similar. Correspondingly, the relative abundance of male walleye has declined since changing the regulation, but size structure remained similar. Effort and total catch of walleye by anglers were similar before and after the regulation was enacted, but harvest has increased by 130%. This regulation appears to protect female broodstock walleye, but it makes male walleye more vulnerable to angler harvest.

Keywords: broodstock; female; male; regulation; *Sander vitreus*; sex-specific, walleye

Received: October 13, 2014; Accepted: June 11, 2015; Published Online Early: June 2015; Published: December 2015

Citation: Koupal KD, Katt JD, Schoenebeck CW, Eifert BE. 2015. Sex-specific changes in walleye abundance, size structure and harvest following implementation of regulation to protect broodstock. *Journal of Fish and Wildlife Management* 6(2):448–455; e1944-687X. doi: 10.3996/102014-JFWM-074

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Introduction

Walleye *Sander vitreus* is a popular sportfish that often requires restrictive management to maintain fishable populations (Isermann 2007) as anglers that target walleye tend to be harvest oriented (Fayram 2003). Walleye exploitation has been reported to vary between 3 and 55% (Baccante and Colby 1996). In populations on the southern edge of walleye distribution, higher levels of exploitation have been reported and sustained (Quist et al. 2010; Schmalz et al. 2011). Harvest of walleye has been reported to decrease relative abundance, production, and biomass, despite improvements in body condition and fecundity (Colby and Baccante 1996). Managers struggle to find an appropriate balance between sociological, ecological, and harvest-oriented goals while trying to avoid undesirable consequences, such as low abundance and size structure.

Three common techniques used to manage for high exploitation rates are stocking, daily harvest limits, and length based regulations. Walleye broodstock are used to produce and stock more than 1 billion walleye annually in the United States (Halverson 2008). The need to protect these broodstock for the continued establishment and maintenance of populations has complicated the balance of managing walleye angling and harvest opportunities (Kerr 2011). Traditionally, reduction in creel limits has demonstrated limited success in protecting walleye populations because most walleye harvest occurs from anglers who harvest fewer walleye than allowed in daily creel limits (Munger and Kraai 1997; Cook et al. 2001). Length-based regulations have been associated with variable changes in walleye populations. For example, minimum length limits (MLLs) reduced walleye harvest (Fayram et al. 2001; Sullivan 2003) and improved abundance and size structure (Stone and Lott 2002), whereas a reduction in abundance and growth was reported in other waters with this regulation (Serns 1978; Isermann 2007).

Reporting of walleye length limit regulation case studies is necessary to understand population-level responses and angler dynamics. Traditionally, length-based regulations have been categorized as minimum, maximum, protected slot, or harvest slot (Noble and Jones 1999). Isermann and Parsons (2011) allude to combining these traditional length-limit approaches for walleye, with a “one over” opportunity allowing anglers to harvest one fish greater than a designated size. Hypothetical modeling of various life-history strategies found that harvest slot regulations produced a more favorable compromise between harvest and conservation objectives than minimum length limits, but case study evaluations are needed to substantiate the response of walleye populations (Gwinn et al. 2013). The development of hybrid length regulation approaches that combine traditional categories of length protection is becoming more common. Sharing experiences of specific regulations, especially case studies that assess sex-specific, population-level responses on species that demonstrate variable male and female growth rates (Henderson et al. 2003), is important to the understanding and use of these management tools.

Data surrounding walleye broodstock operations conducted at Sherman Reservoir, Sherman County, Nebraska, offer an opportunity to evaluate several walleye population metrics from a reservoir that has a history of a MLL and a combined regulation that incorporated a harvest slot and a one over component (HSO). The data provide sex-specific responses after the implementation of this regulation that can be useful to fishery managers. Our objectives were to describe changes in 1) the sex-specific protection afforded to walleye broodstock available to be harvested under MLL and HSO regulations; 2) mature, sex-specific walleye abundance and size structure; and 3) angler effort and harvest following the implementation of the HSO.

Study Site

Sherman Reservoir is located near Loup City, Nebraska, and is an off-stream irrigation reservoir of the Middle Loup River. At conservation pool, the reservoir covers 1,151 ha, with a maximum depth of 20 m. Primary species in the Sherman Reservoir fish community include walleye, crappie *Pomoxis* spp., white bass *Morone chrysops*, channel catfish *Ictalurus punctatus*, gizzard shad *Dorosoma cepedianum*, and common carp *Cyprinus carpio*. From 1992 to 2008 walleye at Sherman Reservoir were regulated, with a 457-mm MLL and a four-walleye daily harvest limit. On January 1, 2009, the Nebraska Game and Parks Commission changed the walleye harvest regulation to allow the daily harvest of two walleye between 381 and 508 mm and one walleye greater than 711 mm (HSO). The new regulation was intended to protect female walleye broodstock within the reservoir.

Methods

Female relative abundance and size structure

Female walleye were collected with monofilament gill nets that measured 1.8 m in depth, 7.6-cm mesh (bar measure) and were 61.0 m in length. Nets were set in March and April (2000–2014) along the dam and on mud flats adjacent to the dam as these areas have been found to have the highest egg deposition and catch rates of mature female walleye (Katt et al. 2010, 2011). Gill nets were set at sunset and allowed to fish for 1–2 h, which was considered a net set, with multiple sets run during each night (CPUE = number of mature females per net set). All mature female walleye collected for egg propagation were measured for total length (centimeters).

Annual length frequency histograms were used to calculate the percentage of measured mature female walleye collected during broodstock operations that were protected by the MLL (2000–2008) and HSO (2009–2014) regulations. Mean percentage of mature females protected was reported with the associated standard error for the MLL ($n = 9$) and HSO ($n = 6$) regulations. The mean CPUEs of mature female walleye captured under the MLL (2000–2008) and the HSO (2009–2014) were compared with a Mann–Whitney *U* test because data were not normally distributed. Size structure was compared using a Kolmogorov–Smirnov test by pooling the lengths of measured mature female walleye collected under the MLL (2000–2008) and the HSO (2009–2014) into 1-cm length bins and standardizing by the total number sampled.

Male relative abundance and size structure

Electrofishing in March and April (2000–2014) was used to collect mature male walleye because of sex-specific gear biases (Koupal et al. 1997). We used a Smith–Root GPP model 5 boat electrofisher unit to

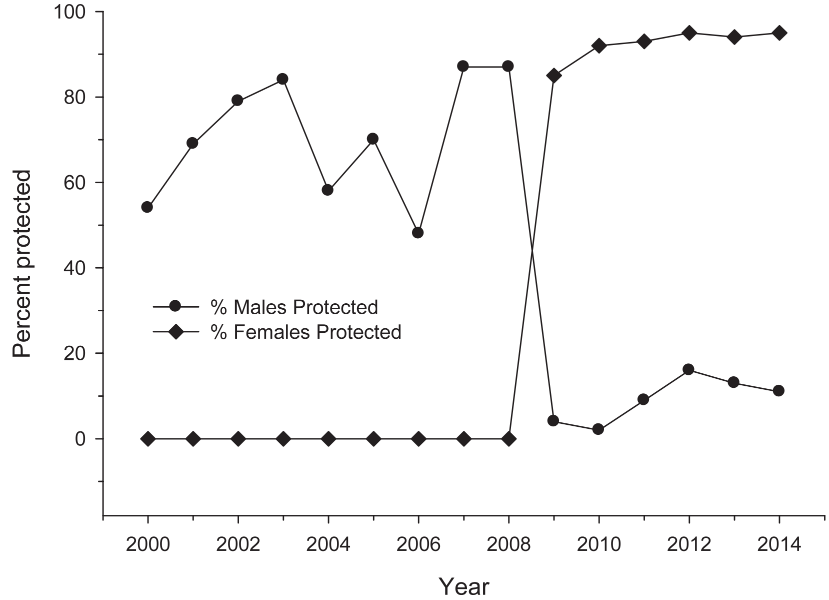

Figure 1. Percentage of female and male walleye *Sander vitreus* sampled during broodstock collections with gill nets and electrofishing, respectively, that were protected from harvest by the minimum length limit (2000–2008) and harvest slot one over regulation (2009–2014) at Sherman Reservoir, Nebraska.

achieve a target output of 5–8 amps of pulsed direct current. Electrofishing began approximately 30 min after sunset and was concentrated along the dam where the highest densities of male walleye have been found (Katt et al. 2011). Initially, male walleye were collected without recording effort (2000–2006) or from only a portion of the dam (2000–2009) and continued until enough individuals were collected for propagation purposes. During 2010–2014, a standardized approach was established that electrofished 12 defined stations (entire length of the dam) each sampling night and recorded total effort (seconds) and number of male walleye captured per site. All male walleye were measured for total length (centimeters) in 2000–2014. Therefore, male relative abundance was assessed with data from 2010 to 2014, and size structure analysis used data from 2000 to 2014 for comparison of MLL and HSO male walleye broodstock populations.

Annual length frequency histograms were used to calculate the percentage of measured mature male walleye collected during broodstock operations that were protected by the MLL (2000–2008) and HSO (2009–2014) regulations. Mean percentage of mature males protected was reported with the associated standard error for the MLL ($n = 9$) and HSO ($n = 6$) regulations. Relative abundance of mature male walleye (2010–2014) was compared with Kruskal–Wallis (KW) test. Size structure of mature male walleye during the MLL (2000–2008) and HSO (2009–2014) were pooled by regulation into 1-cm length bins, standardized, and compared using a Kolmogorov–Smirnov test.

Angler effort and harvest

Creel surveys were conducted on Sherman Reservoir annually from 1996 to 2001, in odd years from 2003 to 2007, and annually from 2009 to 2013 during April 1–September 30. A roving creel design was used, with 10 randomly selected days per month (four weekend days, six weekdays). A randomly selected time period (sunrise-azimuth or azimuth-sunset) was surveyed on each selected date. Anglers were surveyed during and following their trips, and annual estimates for total angler effort (hours), angler effort seeking walleye (hours), total angler catch of walleye (number), and total angler harvest of walleye (number) were calculated. The mean estimate (±SE) of each angler parameter was calculated under the MLL (1996–2007) and HSO (2009–2013) regulations and compared using the Mann–Whitney U test as data were not normally distributed. SYSTAT version 11 software (SPSS Inc., Chicago, IL) was used for all analyses, with $\alpha = 0.10$.

Results

The HSO regulation protected a higher proportion (92 ± 2%) of mature female walleye compared to the MLL (0 ± 0%; Figure 1; Data S1). Mature female walleye relative abundance has more than doubled ($U = 8.50$, $P = 0.07$) from 2.6 ± 0.3 fish per net set under the MLL regulation to 5.3 ± 1.1 fish per net set under the HSO regulation (Table 1). The length frequency distributions of mature female walleye did not differ under the two harvest regulations ($D = 0.12$, $P = 0.89$; Figure 2; Data S1).

The HSO regulation protected a lower percentage (9 ± 2%) of mature male walleye compared to the MLL (71 ± 5% annually; Figure 1; Data S2). Following the implementation of the HSO, the relative abundance of mature male walleye remained similar through 2012, but it has significantly decreased in both 2013 and 2014 ($KW = 71.64$, $P < 0.0001$; Table 2; Data S3). The size structure of mature male walleye has remained similar ($D = 0.16$, $P = 0.78$) under both regulations (Figure 2; Data S2).

Table 1. Mean number of mature female walleye *Sander vitreus* per net set (CPUE) collected with gill nets during broodstock collections at Sherman Reservoir, Nebraska, during the minimum length limit regulation (2000–2008) and the harvest slot one over regulation (2009–2014). Letters indicates that means are significantly different at the $P \leq 0.10$ level.

Year	MLL CPUE	No. nets run	HSO CPUE	No. nets run
2000	3	106		
2001	3	58		
2002	3	105		
2003	2	141		
2004	1	140		
2005	3	40		
2006	2	135		
2007	4	56		
2008	2	44		
2009			1	83
2010			4	47
2011			8	42
2012			8	51
2013			5	72
2014			6	75
Mean (SE)	2.6 (0.3) A	92	5.3 (1.1) B	62

No changes in total angler effort ($U = 10.00$, $P = 0.11$) and angler effort seeking walleye ($U = 16.00$, $P = 0.44$) were seen following the implementation of the HSO. The number of walleye caught by anglers did not change ($U = 18.00$, $P = 0.61$). However, the number of walleye harvested by anglers increased by 130% ($U = 8.00$, $P = 0.06$) under the HSO (Table 3; Data S4).

Discussion

Implementation of the HSO regulation resulted in greater protection and relative abundance of mature female walleye, but no difference in size structure. The protected length range included at least 85% of all mature females collected on an annual basis since 2009, which has resulted in collecting more female broodstock per the netting effort from Sherman Reservoir. In addition, increased relative abundance of female broodstock walleye allows for the potential of increasing egg production in the future. Although the size structure is similar, the length range of female walleye has become wider and includes more individuals of shorter total length. The presence of smaller mature female walleye during the HSO regulation could be a response to higher exploitation of male and immature female walleye, leading to earlier maturation of females as was observed in a Kansas reservoir (Quist et al. 2010). The increase in relative abundance of female walleye, along with a greater percentage of spawning female walleye being protected by the HSO than were traditionally seen under the MLL, would suggest that the HSO regulation has initially been successful at protecting female walleye.

Male walleye were less protected from harvest with the HSO compared with the MLL, which may be associated with the observed decrease in relative abundance, but the size structure did not change. Although there is a lack of relative abundance data for male walleye under the MLL, the current downward trend in relative abundance under the HSO indicates there are fewer male walleye in Sherman Reservoir. Whether this is directly linked to the HSO is unknown, but slower growth rates for male walleye (Halverson 2008) would expose them to harvest for a longer time and may result in greater angler harvest. In addition, walleye of shorter lengths and younger ages are reported as more vulnerable to angling (Serns and Kempinger 1981; Jacobson 1994; Myers et al. 2014), which would suggest an increase in male harvest may have been responsible for the increase in total walleye harvest and the declining male abundance observed under the HSO. Exploitation of walleye has been reported as similar between males and females (Serns and Kempinger 1981; Jacobson 1994), but these studies were conducted on more northern waters that typically have lower exploitation rates than Great Plains reservoirs (Quist et al. 2010). Similar male size structure with the MLL and HSO regulations is not surprising as a relationship between density and growth was not observed in Wisconsin (Sass et al. 2004) or seen in age-4 males following the implementation of the regulation allowing harvest of one walleye greater than 356 mm (Fayram and Schmalz 2006). A concern is that male walleye abundance does not become reduced to the point that artificial extension of male gametes would be needed to complete broodstock collection operations, as was reported in Colorado reservoirs (Satterfield and Flickinger 1995). Abundance of male walleye and subsequent genetic implications should be monitored in the future to ensure adequate numbers for broodstock operations.

Angler effort and total catch have been consistent, but harvest of walleye has increased since the HSO was established despite the lower harvest limits. In Wisconsin lakes, Beard et al. (2003) predicted that a reduction in walleye harvest limits would lead to reduced angler effort and greater catch rates. Traditionally, harvest limits have not been as effective at protecting walleye populations from exploitation (Munger and Kraai 1997; Fayram et al. 2001). The impact of this combined harvest and length limit change may be a restriction on individual angler harvest, but not overall harvest because this regulation did not restrict individual angler effort, mortality associated with catch and release (Post et al. 2003), or vulnerability of specific walleye lengths to angler capture. A modeling effort by Myers et al. (2014) found increased vulnerability to harvest for the 381–456-mm lengths of walleye that were opened up to harvest. Our data support that the reduction in minimum harvest length from 457 to 381 mm had more of an impact on angler harvest than the reduced creel limit.

Length-based regulations are often used to restrict the harvest of certain size classes of fish regardless of sex. However, sexes are not likely to respond in a similar manner to length-based regulations when populations exhibit sexual size dimorphism. A MLL could result in female-biased harvest in populations that exhibit female-biased sexual size dimorphism, as females exhibit faster growth

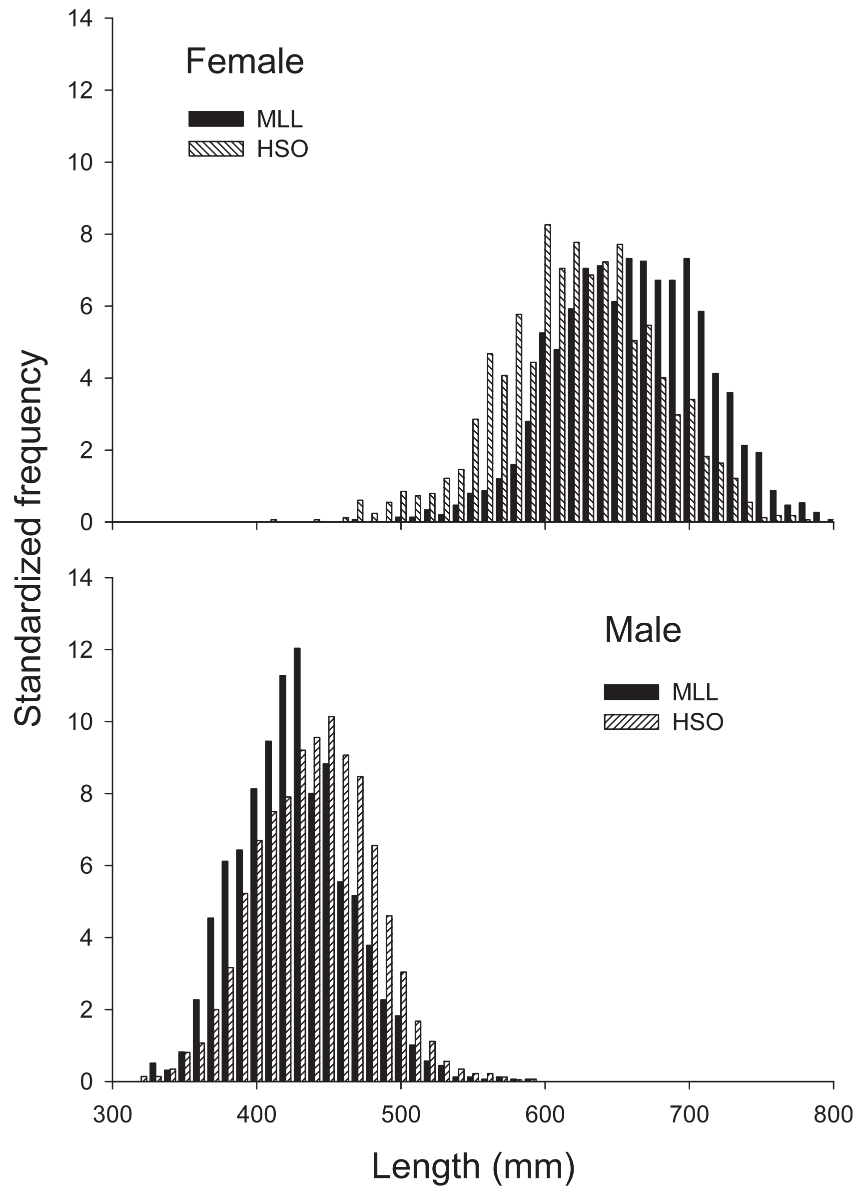

Figure 2. Length frequency distribution (1-cm length bins) of walleye *Sander vitreus* collected during the minimum length limit (MLL; 2000–2008) and the harvest slot one over (HSO; 2009–2014) regulations at Sherman Reservoir, Nebraska. The female histogram is standardized by the total number collected with gill nets during the MLL (n = 1,504) and the HSO (n = 1,298). The male histogram is standardized by the total number collected with electrofishing during the MLL (N = 1,021) and the HSO (N = 5,895).

and attain greater lengths than males (Schoenebeck and Brown 2011; Uphoff and Schoenebeck 2012). The HSO regulation was designed to protect female walleye broodstock, and it has been successful in doing so, but because the population exhibits female-biased sexual size dimorphism males were not afforded the same protection. Under the HSO, the majority of mature males were vulnerable to angler harvest due to their slower growth and lower maximum lengths, which may have contributed to the increase in walleye harvest and the subsequent decrease in male abundance. Sexual size dimorphism combined with the inability of anglers to identify sex can make it difficult to structure regulations; however, the HSO represents an example of a regulation that takes sexual size dimorphism

Table 2. Mean number of mature male walleye *Sander vitreus* per hour of electrofishing (CPUE) collected with boat electrofishing during broodstock collections at Sherman Reservoir, Nebraska, from standardized stations along the dam during the harvest slot one over regulation (2010–2014; n = 5). Letters indicate that means are significantly different at the $P \leq 0.10$ level.

Year	Mean ± SE
2010	579 ± 47 A
2011	510 ± 30 A
2012	560 ± 46 A
2013	324 ± 19 B
2014	206 ± 15 C

Table 3. Mean of the annual estimates of total angler effort, angler effort seeking walleye *Sander vitreus*, total angler catch of walleye and total angler harvest of walleye from creel surveys conducted at Sherman Reservoir, Nebraska, during the minimum length limit (1996–2007; $n = 9$) and during the harvest slot one over (2009–2013; $n = 5$). Letter indicates that means are significantly different at the $P \leq 0.10$ level.

	MLL (1996–2007)	HSO (2009–2013)
Total angler effort (h)	94,273.5 ± 11,235.0	71,489.9 ± 14,824.0
Angler effort seeking walleye (h)	28,458.1 ± 7,340.0	32,702.1 ± 5,198.1
Total angler catch (no.)	18,729 ± 5,652	12,767 ± 4,199
Total angler harvest (no.)	1,691 ± 228 A	3,893 ± 1,037 B

into account to protect female broodstook and does not require anglers to identify sex. Thus, sex-specific impacts of this and other length-based regulations emphasize the importance of sex-specific considerations in fisheries management (Venturelli et al. 2010).

Regulation evaluations are helpful as fisheries managers attempt to maintain the balance between an adequate population for broodstock needs and angler satisfaction as was called for by Gwinn et al. (2013). This case study represents the first HSO evaluation and provides insight into the sex-specific responses of a unique length-based regulation. We suggest future evaluations incorporate sex- and size-specific growth and angler catch and harvest information to further elucidate regulation impacts. This study has followed the HSO regulation for 6 y, and further monitoring will be needed to determine whether female walleye can continue to recruit to the protected slot and male walleye can maintain acceptable abundance for broodstock operations because population responses to a regulation may take longer. Overall, the HSO regulation has accomplished the objective of protecting female broodstock without negatively impacting angling participation.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Data S1. Percentage of female walleye *Sander vitreus* sampled during broodstock collections with gill nets that were protected from harvest by the minimum length limit (MLL; 2000–2008) and harvest slot one over regulation (HSO; 2009–2014) at Sherman Reservoir, Nebraska. Length frequency distribution (1-cm length bins) of walleye collected during the MLL and the HSO regulations. The female histogram is standardized by the total number collected with gill nets during the MLL ($n =$ 1,504) and the HSO ($n = 1{,}298$).

Found at DOI: http://dx.doi.org/10.3996/102014-JFWM-074.S1 (14 KB XLSX).

Data S2. Percentage of male walleye *Sander vitreus* sampled during broodstock collections with electrofishing that were protected from harvest by the minimum length limit (MLL; 2000–2008) and harvest slot one over regulation (HSO; 2009–2014) at Sherman Reservoir, Nebraska. Length frequency distribution (1-cm length bins) of walleye collected during the MLL and the HSO regulations. The male histogram is standardized by the total number collected with boat electrofishing during the MLL ($n =$ 1,021) and the HSO ($n = 5{,}895$).

Found at DOI: http://dx.doi.org/10.3996/102014-JFWM-074.S2 (12 KB XLSX).

Data S3. Mean number of mature male walleye *Sander vitreus* per hour of electrofishing collected with boat electrofishing during broodstock collections at Sherman Reservoir, Nebraska, during the harvest slot one over regulation (2010–2014).

Found at DOI: http://dx.doi.org/10.3996/102014-JFWM-074.S3 (17 KB XLSX).

Data S4. Mean of the annual estimates of total angler effort (hours), angler effort seeking walleye *Sander vitreus* (hours), total angler catch (number) of walleye, and total angler harvest (number) of walleye from creel surveys conducted at Sherman Reservoir, Nebraska, during the minimum length limit (1996–2007; $n = 9$) and during the harvest slot one over (2009–2013; $n = 5$).

Found at DOI: http://dx.doi.org/10.3996/102014-JFWM-074.S4 (10 KB XLSX).

Reference S1. Jacobson PC. 1994. Population dynamics of large walleye in Big Sand Lake. Investigational Report 436, Section of Fisheries, Minnesota Department of Natural Resources, St. Paul, Minnesota.

Found at DOI: http://dx.doi.org/10.3996/102014-JFWM-074.S5 (1403 KB PDF).

Acknowledgments

We thank Calamus State Fish Hatchery staff, Brad Newcomb, Nic Fryda, and Brian Peterson, along with staff from the Nebraska Game and Parks Commission, University of Nebraska–Kearney, and the public volunteers that assisted with field operations. We thank Jonathan Meerbeek for a friendly review. We also thank the Associate Editor and two anonymous reviewers for many helpful comments on the manuscript.

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