Development of a System-wide Predator Control Program: Indexing and Fisheries Evaluation

Prepared by

Howard K. Takata
Martyne J. Reesman
George E. Reed
Les D. Layng
Tucker A. Jones

Oregon Department of Fish and Wildlife
Columbia River Investigations
17330 S.E. Evelyn Street
Clackamas, Oregon 97015

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Summary

The Northern Pikeminnow Management Program (NPMP), a fishery aimed at reducing predation on juvenile salmonids by northern pikeminnow *Ptychocheilus oregonensis*, was implemented for the 16th consecutive year in the mainstem Columbia and Snake rivers. We report on (1) northern pikeminnow exploitation rates, predation estimates, spaghetti tag loss rates, and age validation work; (2) population parameters of northern pikeminnow, smallmouth bass *Micropterus dolomieu*, and walleye *Sander vitreus* in The Dalles and John Day reservoirs, and (3) possible compensatory responses by these species.

To evaluate exploitation, we tagged and released 1,330 northern pikeminnow ≥ 200 mm fork length (FL) throughout the lower Columbia and Snake rivers in 2006, the most since 1996. Of these, 881 were ≥ 250 mm FL. System-wide exploitation of northern pikeminnow ≥ 200 mm FL by the sport-reward fishery was 14.6% (95% confidence bounds 10.5% - 18.6%), which incorporated a tag loss estimate of 9.9%. Additional tag recaptures from the dam angling fishery increased total system-wide exploitation to 14.8%. Sport-reward exploitation of fish ≥ 250 mm FL was 17.1% (11.3% - 22.8%), the third highest exploitation rate since program inception. Based on sport-reward exploitation rates and using our current model, we estimated that 2006 predation levels were 25% (14 - 44%) lower than pre-program levels.

Continuing our age validation study, we aged 279 scale-operculum matched pairs from northern pikeminnow in 2006. Agreement within one year on ages assigned by the two readers was not significantly different for scales (86.7%; 95% confidence bounds 82.8–90.7%) and opercula (83.5%; 95% confidence bounds 79.2-87.9%). We examined 284 operculum samples from northern pikeminnow recaptured by anglers; detectable oxytetracycline (OTC) marks were found in 93% of the samples. We noted the correct number of annuli after the OTC mark 75.7% (95% confidence bounds 70.5–80.9%) of the time; this percentage was significantly higher for good quality marks ($P < 0.05$). Beginning at 8-9 years of age, northern pikeminnow opercula were consistently assigned older ages than corresponding scales.

We continued biological indexing in the lower Columbia River as part of our predator community evaluation. In 2006, northern pikeminnow abundance indices in The Dalles and John Day reservoirs were among the lowest observed to date. The consumption index value for the John Day Dam tailrace was the highest to date, while consumption indices in other areas were generally low. Predation indices were similar to or lower than previous years. Although 66% of northern pikeminnow stomachs were empty, all identifiable fish remains consisted of juvenile salmonids. Relative weight of northern pikeminnow in The Dalles Reservoir has gradually increased over the last 10 years. This type of change could be a potential compensatory response to the NPMP. Year-class analysis indicated that northern pikeminnow in John Day Reservoir may be getting younger, with the proportion of the population consisting of age-3 fish increasing substantially in the past decade. Although this is a desired outcome of the removal program, whether it can be attributed to the NPMP is unclear.

Smallmouth bass relative densities in The Dalles and John Day reservoirs increased during the past decade while northern pikeminnow abundance declined. Relative weights for smallmouth bass also increased during the same time. Although smallmouth bass proportional

stock density (PSD) in The Dalles Reservoir showed that the population there appears to be balanced, PSD in John Day Reservoir indicated a potentially unstable population with higher than optimal recruitment to the stock. Smallmouth bass consumption and predation indices were generally stable, with salmonid predation highest in the middle of John Day Reservoir. Juvenile salmonids comprised 5.4-13.6% of the fish identified in smallmouth bass stomachs, with *Cottus* spp. most commonly consumed.

Walleye abundance was low compared to other predators such as northern pikeminnow and smallmouth bass. The age distribution of walleye has remained relatively stable since 1992, and year-to-year relative weights exhibited little variability. Walleye PSD in John Day Reservoir has decreased in recent years to a level indicating a balanced population. This may be due to improved recruitment of stock size fish. Compared to both northern pikeminnow and smallmouth bass, walleye stomachs contained a higher proportion of juvenile salmonids.

Although there are some signs of possible compensation by predators to the sustained removal of northern pikeminnow by the NPMP, the indicators are localized, and other density-independent factors can have similar effects. At this time, there does not appear to be a system-wide predator response to the removal program; however, continued monitoring is necessary to assess potential long-term impacts of localized changes.

Introduction

The Columbia and Snake rivers once supported large numbers of anadromous salmonids *Oncorhynchus* spp. Declines in adult returns have been attributed to many factors, including habitat degradation and overexploitation (Nehlsen et al. 1991; Wismar et al. 1994), hydroelectric and flood control activities during the 1970s (Raymond 1988), and predation (Rieman et al. 1991; Collis et al. 2002). The mean annual loss of juvenile salmonids to predators can be equivalent to mortality associated with dam passage (Rieman et al. 1991), which in the past could approach 30% at a single dam (Long and Ossiander 1974). The Northern Pikeminnow Management Program (NPMP) is a set of targeted fisheries aimed at reducing predation on juvenile salmonids by northern pikeminnow *Ptychocheilus oregonensis* in the lower Columbia and Snake rivers (Rieman and Beamesderfer 1990; Beamesderfer et al. 1996). The Oregon Department of Fish and Wildlife (ODFW) established baseline levels of predation and northern pikeminnow population characteristics prior to the implementation of the northern pikeminnow fisheries. Abundance, consumption, and predation were estimated in Columbia River reservoirs in 1990 and 1993, Snake River reservoirs in 1991, and the unimpounded lower Columbia River downstream from Bonneville Dam in 1992 (Ward et al. 1995). We sampled northern pikeminnow in areas where adequate sample sizes allowed comparisons among years (Zimmerman and Ward 1999; Zimmerman et al. 2000; Jones et al. 2005) (Appendix Table A-1). This report describes our activities and findings for 2006, and wherever possible, evaluates changes from previous years.

Our objectives in 2006 were to (1) evaluate northern pikeminnow exploitation, potential predation, tag loss, and age validation; (2) define population parameters of northern pikeminnow, smallmouth bass *Micropterus dolomieu*, and walleye *Sander vitreus* in The Dalles and John Day reservoirs, and (3) look for possible compensatory responses by these species.

Objective (1) was modified in 2006 to include evaluation of a dam-angling fishery at Bonneville and The Dalles dams. The tag loss and age validation portions of objective (1) were implemented in 2000 based on recommendations from an independent review of the NPMP (Hankin and Richards 2000). Objectives (2) and (3) are a continuation of population monitoring studies conducted in 1990-1996, 1999, and 2004-2005.

Methods

Fishery Evaluation, Predation Estimates, and Tag Loss

Field Procedures.—The Washington Department of Fish and Wildlife (WDFW) administered the sport-reward fishery from 1 May 2006 (15 May 2006 upstream of John Day Dam) to 15 October 2006 throughout the lower Columbia and Snake rivers. Participating anglers received payment for northern pikeminnow ≥ 230 mm (9 inches) total length (TL). This size limit is approximately equivalent to 200 mm fork length (FL). The payment schedule for 2006 consisted of three tiers: \$4 per fish for "Tier 1" anglers (<100 fish caught), \$5 per fish for "Tier 2" anglers (100-400 fish caught), and \$8 per fish for "Tier 3" anglers (>400 fish caught) (WDFW 2006). Rewards for spaghetti-tagged fish remained at \$500.

The U.S. Department of Agriculture (USDA) Wildlife Services Division conducted dam-angling fisheries at Bonneville and The Dalles dams from 1 May to 6 August 2006. This was a removal fishery designed to further decrease predation in the immediate tailrace area of the dams. To collect biological data from northern pikeminnow caught in this fishery, we sub-sampled the dam-angling catch on several days during May and June.

We tagged and released northern pikeminnow ≥ 200 mm FL with uniquely numbered spaghetti tags to estimate exploitation rates for the sport-reward and dam-angling fisheries. To evaluate spaghetti tag retention, we also injected a passive integrated transponder (PIT) tag into the dorsal sinus of all spaghetti-tagged fish. We used electrofishing boats to collect northern pikeminnow from 3 April to 22 June 2006 (detailed methods are given in Friesen and Ward 1999). Though we attempted to allocate equal sampling effort in all river kilometers (rkm), some deviation was necessary due to sampling logistics and swift river flow in the Hanford Reach of the Columbia River and in the Snake River near Asotin, Washington. We sampled in the Columbia River from rkm 76 (near Clatskanie, Oregon) upstream to rkm 639 (Priest Rapids Dam) and in the Snake River from rkm 112 (Little Goose Dam) to rkm 248 (Figure 1).

We completed northern pikeminnow tagging below Bonneville Dam and in Bonneville Reservoir before the start of the sport-reward fishery. Tagging operations ran concurrently with the fishery in The Dalles, John Day, McNary, Little Goose, and Lower Granite reservoirs.

Data Analysis.—We used mark-and-recapture data to compare exploitation rates of northern pikeminnow ≥ 200 mm FL, 200-249 mm FL, and ≥ 250 mm FL among reservoirs. In areas where tagging was completed prior to the start of the fishery, we used the simple Peterson method (Ricker 1975) to calculate annual exploitation rates. This is given by the equation

$$u = R/M,$$

where

u = annual exploitation estimate,
M = the number of fish that are tagged in a season, and
R = the number of tagged fish that are recaptured in a season.

We calculated 95% confidence intervals for exploitation estimates using the formula

$$(R \pm z^*R^{0.5})/M,$$

where

z = the multiplier from the standard normal distribution,
M = the number of fish that are tagged in a season, and
R = the number of tagged fish that are recaptured in a season (Styer 2003).

FIGURE 1.—The lower Columbia and Snake rivers. Northern pikeminnow were tagged from river kilometer (rkm) 76 to Priest Rapids Dam in the lower Columbia River and from Little Goose Dam forebay to rkm 248 on the Snake River. Biological indexing was conducted in The Dalles Reservoir (The Dalles Dam forebay, mid-reservoir, and John Day Dam tailrace) and in John Day Reservoir (John Day Dam forebay, mid-reservoir, and McNary Dam tailrace) during the spring and summer of 2006.

We calculated multi-year exploitation rates in 2006 from 2003 – 2006 PIT tag return data for the area below Bonneville Dam and Bonneville Reservoir. We used a variable survival method (Everhart and Youngs 1981) to calculate multi-year exploitation rates for northern pikeminnow ≥ 200 mm FL. This is given by the equation

$$f_i = R_i/M_i * C_i/T_i,$$

where

f_i = the minimum estimate of exploitation in year i,
M_i = the number of fish that are tagged in year i,
R_i = the total number of recaptures from a particular tagging release,
C_i = the total number of fish that are recaptured in any particular sample year, and
T_i = $T_{i-1} + R_i - C_{i-1}$ where $T_1 \equiv R_1$.

We used a multiple sample approach to compute exploitation rates in areas where tagging and fishing occurred concurrently (Styer 2003). Weekly estimates of exploitation were calculated by dividing the number of tagged northern pikeminnow recovered by the number of tagged fish at-large. We then summed the weekly exploitation rates to yield total exploitation rates for the season (Beamesderfer et al. 1987).

We calculated 95% confidence intervals for exploitation estimates obtained by the multiple sample method by using the formula

$$u \pm t(k*s)^{0.5},$$

where

u = the annual exploitation estimate,
t = the multiplier from the Student's t-distribution,
k = the number of weeks in the fishing season, and
s = the standard deviation of the weekly exploitation estimates (Styer 2003).

We did not calculate exploitation rates for areas where the number of recaptures was less than four (Styer 2003), and exploitation estimates from previous years where fewer than four tags were recovered were excluded from this report. We adjusted exploitation estimates and confidence intervals for tag loss. An annual tag loss estimate was calculated using the formula

$$L = [m / (m + r)] * 100,$$

where

L = tag loss rate,
m = the number of northern pikeminnow recaptured with a secondary mark (PIT tag) and no spaghetti tag, and
r = the number of northern pikeminnow recaptured with year 2006 spaghetti tags intact.

We used the model of Friesen and Ward (1999) to estimate predation on juvenile salmonids relative to predation prior to implementation of the NPMP. The model incorporates age-specific exploitation rates on northern pikeminnow and resulting changes in age structure to estimate changes in predation. We used a 10-year "average" age structure (based on catch curves) for a pre-exploitation base, and assumed constant recruitment. Age-specific consumption was incorporated; however, potential changes in consumption, growth, and fecundity due to removals were not considered likely (Knutsen and Ward 1999). The model therefore estimates changes in potential predation related directly to removals, allowing us to estimate the effects of removals if all variables except exploitation were held constant. We estimated the potential relative predation in 2006 based on observed exploitation rates and the eventual minimum potential predation assuming continuing exploitation at mean 1995 – 2006 levels.

To explore the effect of river flow on northern pikeminnow harvest, we plotted the arc sin transformed annual (1995 - 2006) system-wide sport-reward exploitation rate for fish ≥ 250 mm FL versus mean Columbia River stage for the period May – September (May – October in 2006) below Bonneville Dam (site number 14128870; USGS 2006). Additionally, because the reward structure of the sport-reward fishery has been modified to increase effort and catch in recent years, we conducted a multiple linear regression of two reward structure variables (pay at the Tier 3 level and the number of Tier 3 anglers) and system-wide exploitation rates for northern pikeminnow ≥ 250 mm FL during 2000-2006.

Age Validation

Field Procedures.—To validate ages of northern pikeminnow, WDFW collected scale and operculum samples from tagged northern pikeminnow recaptured in the 2006 sport-reward fishery. Since 2002, all northern pikeminnow tagged each year have been injected with a solution of oxytetracycline (OTC) at a dosage of 50 mg OTC per kg fish weight (McFarlane and Beamish 1987) to leave a fluorescent mark on aging structures.

Laboratory Procedures.—We aged scale samples from all northern pikeminnow recaptured with an intact spaghetti and/or PIT tag, unless scales were regenerated. Scales were cleaned, mounted on cards, and pressed onto acetate sheets for viewing on a microfiche reader. Parker et al. (1995) described methods of age determination for northern pikeminnow. Two readers independently assigned ages to the scale samples. When the readers disagreed on an age, they reviewed the scale in question together until a final age was agreed upon.

We placed opercula, still in individual sample envelopes, into a water bath and microwaved them on high for 5-6 minutes (per group of 10 samples) to soften tissues and skin covering the opercular bone. We then removed the tissue using a pair of tweezers and a toothbrush. The thickened ridge radiating from the focus on the concave side of each operculum was ground down with a Dremel Tool (Robert Bosch Tool Corporation, Racine, Wisconsin) to enhance viewing of potential annuli near the focus (Scoppettone 1988). Readers used imaging software (Motic Instruments, Incorporated, British Columbia, Canada) to examine each operculum on a computer monitor. A digital video microscope projected the image at 10x magnification using light transmitted from either above or below the operculum, whichever gave the best view of the annuli. One experienced reader and one novice reader aged opercula and the corresponding scale samples in 2006. We used the same technique to resolve operculum age differences as we had for scales. The experienced reader also inspected opercula from each fish tagged between 2002 and 2006 in a dark room under a dissecting microscope, using a desk lamp fitted with a black light to fluoresce potential OTC marks.

Data Analysis.—We continued the age validation study initiated in 2000 (Takata and Ward 2001); evaluating between-reader variation in ages assigned to scales and opercula from northern pikeminnow. Aging discrepancies were calculated as

$$D = A_i - A_j,$$

where

D = age discrepancy,
A_i = age assigned to a scale or operculum by reader i, and
A_j = age assigned to a scale or operculum by reader j.

This analysis allowed us to measure both magnitude and directionality of the discrepancy (e.g. - 2 years, - 1 year, 0 years, + 1 year, etc.), and enabled us to determine if differences were systematic. We then calculated the percentage of samples in each discrepancy category as a measure of between-reader agreement. We analyzed differences between scale and operculum reader discrepancies by looking at the differences in percentages of ± 1 year agreement. We determined reader agreement to be significantly different when 95% confidence intervals did not overlap.

To further evaluate the potential use of opercula for aging northern pikeminnow, we compared the ages assigned to opercula and scales collected from the same fish. We calculated discrepancies using the formula

$$D = A_o - A_S,$$

where

D = age discrepancy,
A_o = age assigned to the operculum, and
A_S = age assigned to the scale.

We used t-tests to analyze operculum-scale age discrepancies.

An experienced reader checked opercula from northern pikeminnow tagged between 2002 and 2006 for the presence of OTC marks, and scored the quality of discernable marks. An easily observed and relatively wide fluorescent band along all or most of the operculum’s edge was considered a “good” mark. If the fluorescent band was thin or patchy but went around one-half or more of the operculum’s edge, the mark was considered “fair.” If the fluorescent marking covered less than half of the operculum’s edge it was considered a “poor” mark. In addition, the reader noted any opercula without any visible mark as having “No mark”. We also continued efforts to validate our ability to detect operculum annuli; counting any visible annuli after the OTC mark. We used Chi-square tests to analyze OTC mark quality, and non-overlapping 95% confidence intervals indicated significant differences in correctly identified annuli by year and mark quality.

Biological Evaluation

Field Procedures.—We used standardized electrofishing to evaluate changes in northern pikeminnow and smallmouth bass relative abundance, consumption and predation indices, population size and age structure, condition, and feeding habits. We also analyzed relative abundance, population size and age structure, condition, and feeding habits of walleye. Biological data were collected in spring (4 - 26 May) and summer (26 June - 16 July) 2006 in The Dalles Dam forebay (rkm 307-313), The Dalles mid-reservoir (rkm 329-334), John Day

Dam tailrace (rkm 341-347), John Day Dam forebay (rkm 347-354), John Day mid-reservoir (rkm 387-394), and McNary Dam tailrace (rkm 461-469) (Figure 1). Sampling methods and gear specifications have been previously described (Ward et al. 1995; Zimmerman and Ward 1999).

We recorded biological data from all northern pikeminnow, smallmouth bass, and walleye collected by electrofishing. We measured all fish collected (mm FL) and recorded total body weight (g) from fish ≥ 200 mm. We collected scales from 25 smallmouth bass per 25 mm FL size increment, and from all northern pikeminnow and walleye. In addition, northern pikeminnow (≥ 425 mm FL) and walleye scales collected during tagging operations in 2006 were used to supplement those collected during the indexing season. We collected and preserved digestive tract contents from northern pikeminnow, smallmouth bass, and walleye ≥ 200 mm FL using methods described by Ward et al. (1995). Northern pikeminnow ≥ 200 mm FL were sacrificed to remove their digestive tract; this also enabled us to establish sex (male, female, or undetermined) and maturity (undetermined, immature, developing, ripe, or spent).

Laboratory Procedures.—We examined digestive tract contents of northern pikeminnow, smallmouth bass, and walleye to measure relative consumption rates of juvenile salmonids. Details of laboratory methods are given in Ward et al. (1995). Parker et al. (1995) described methods of age determination using scales.

Data Analysis.—We used catch per unit effort (CPUE) (Appendix Table C-1) of standardized (900 s) electrofishing runs to calculate northern pikeminnow abundance and predation indices. Abundance indices were calculated as the product of CPUE and reservoir or area-specific surface area (Ward et al. 1995). We compared abundance indices of northern pikeminnow in 2006 with those from 1990-1996, 1999, and 2004 for sampling areas in The Dalles and John Day reservoirs. We used transformed catch ($\log_{10}$ (catch + 1)) as an index of smallmouth bass and walleye relative densities.

We used the following formulas to calculate consumption indices (CI) for northern pikeminnow and smallmouth bass:

$$CI_{NPM} = 0.0209 \cdot T^{1.60} \cdot MW^{0.27} \cdot (S \cdot GW^{-0.61}) \text{ (Ward et al. 1995),}$$

and

$$CI_{SMB} = 0.0407 \cdot e^{(0.15)(T)} \cdot MW^{0.23} \cdot (S \cdot GW^{-0.29}) \text{ (Ward and Zimmerman 1999),}$$

where

CI_{NPM} = consumption index for northern pikeminnow,
CI_{SMB} = consumption index for smallmouth bass,
T = water temperature (^{o}C),
MW = mean predator weight (g),
S = mean number of salmonids per predator, and
GW = mean gut weight (g) per predator.

The consumption index is not a direct estimate of the number of juvenile salmonids eaten per day by an average predator; however, it is linearly related to the consumption rate of northern pikeminnow (Ward et al. 1995) and smallmouth bass (Ward and Zimmerman 1999). We compared spring (May) and summer (June-July) consumption indices for 2006 to those from 1990-1996, 1999, and 2004.

We used the product of abundance and consumption indices to calculate predation indices for northern pikeminnow for spring and summer periods, and compared northern pikeminnow predation among years when data were collected. The daily juvenile salmonid passage indices at John Day and McNary dams were plotted to compare timing of index sampling with concentrations of juvenile salmonids (FPC 2006; Appendix Figure A-1). As in 2004 and 2005, we calculated a predation index for smallmouth bass in response to reports of increased abundance in some areas. Ward and Zimmerman (1999) observed that smallmouth bass densities varied seasonally in the Columbia and Snake rivers; we therefore calculated predation indices using CPUE (Appendix Table C-3) as a season-specific relative abundance index. We multiplied the product of the season-specific CPUE and reservoir or area-specific surface area by its corresponding consumption index to obtain a season-specific predation index.

To evaluate age structure, we examined the change in frequency of age 3-5 northern pikeminnow, age 4-5 smallmouth bass, and age 5-6 walleye from previous years. Because the relative abundances of northern pikeminnow year classes in electrofishing catches were biased by exploitation rates that varied among years (Friesen and Ward 1999), we limited our comparisons to abundance of northern pikeminnow large enough to be effectively sampled and small enough to be excluded from the NPMP (ages 3-5). We constructed smallmouth bass electrofishing catch curves (ODFW, unpublished data) and concluded that younger smallmouth bass (ages 1-3) were not sampled in proportion to their abundance. We therefore limited our comparisons to age 4-5 smallmouth bass. We constructed similar catch curves for walleye (ODFW, unpublished data) and found that age 1-4 fish were underrepresented in the catch, so we limited our analysis to age 5-6 walleye.

Northern pikeminnow exploitation rates are greater for larger fish than for smaller ones (Zimmerman et al. 1995); therefore, sustained fisheries should decrease the abundance of large fish relative to the abundance of smaller fish. We used proportional stock density (PSD; Anderson 1980), where PSD = 100 • (number of fish ≥ quality length / number of fish ≥ stock length) to compare size structure of northern pikeminnow, smallmouth bass, and walleye populations among years in The Dalles and John Day reservoirs. Stock and quality sizes for northern pikeminnow are 250 and 380 mm FL, respectively (Beamesderfer and Rieman 1988; Parker et al. 1995). We also used relative stock density (RSD-P) indices to examine smallmouth bass and walleye populations. Stock, quality, and preferred size classes for smallmouth bass are 180 mm, 280 mm, and 350 mm TL where RSD-P = 100 • (number of fish ≥ preferred length / number of fish ≥ stock length) (Gabelhouse 1984). For walleye, stock, quality, and preferred lengths are 250 mm, 380 mm, and 510 mm TL, respectively (Willis et al. 1985).

Changes in body condition may indicate a response to sustained exploitation. We used relative weight (W_r; Anderson and Gutreuter 1983) to compare the condition of northern pikeminnow, smallmouth bass, and walleye in 2006 with previous years. We used the standard weight (W_s) equations for northern pikeminnow (Parker et al. 1995), smallmouth bass (Kolander et al. 1993), and walleye (Murphy et al. 1990) to calculate relative weight ($W_r = 100[\text{weight}]/W_s$). We calculated median W_r for male and female northern pikeminnow and all smallmouth bass and walleye, which were not sexed. To compare W_r among years, we used a one-way ANOVA and a Holm-Sidak post-hoc test to determine where pair-wise differences occurred. In areas where data were not distributed normally, we used a Kruskal-Wallis one-way ANOVA on ranks and a Dunn's test to determine where pair-wise differences occurred.

Results

Fishery Evaluation, Predation Estimates, and Tag Loss

We tagged and released 1,330 northern pikeminnow ≥ 200 mm FL throughout the lower Columbia and Snake rivers in 2006; 881 were ≥ 250 mm FL (Appendix Table B-1). In 2006, removal fisheries harvested 236,232 northern pikeminnow ≥ 200 mm; 232,883 in the sport-reward fishery (PSMFC 2006) and 3,349 in the dam-angling fishery (USDA, unpublished data). A total of 158 tagged northern pikeminnow were recaptured; 155 in the sport-reward fishery and three in the dam-angling fishery. Fish tagged and recaptured in 2006 were at-large from two to 182 days, and 78% of the recaptures were ≥ 250 mm FL (Appendix Table B-1). However, based on actual sampled catch proportions, an estimated 65% of the sport-reward harvest was ≥ 250 mm FL. Median fork length of northern pikeminnow harvested in the sport-reward fishery was 279 mm (R. Bruce, WDFW, personal communication). Seventeen northern pikeminnow with PIT tags and missing spaghetti tags were recaptured in the sport-reward fishery, yielding a tag loss estimate of 9.9%; we adjusted 2006 exploitation rates accordingly.

System-wide exploitation of northern pikeminnow ≥ 200 mm FL by the sport-reward fishery was 14.6% (95% confidence bounds 10.5% - 18.6%; Appendix Table B-2). Reservoir/area-specific exploitation rates ranged from 10.5% in Bonneville Reservoir to 22.4% in The Dalles Reservoir. Exploitation in Little Goose Reservoir (where we had not tagged since 2000) was 20.0%. We did not calculate exploitation rates in John Day and Lower Granite reservoirs due to an insufficient number of recaptures in these reservoirs ($n < 4$; Appendix Table B-2; Styer 2003). We calculated multi-year exploitation estimates of 15.9% below Bonneville Dam and 10.8% in Bonneville Reservoir using PIT tag data from the last four years; these were slightly higher than the single year estimates of 14.6% and 10.5% for fish ≥ 200 mm.

The system-wide exploitation rate of northern pikeminnow 200 – 249 mm FL was 9.9% for the sport-reward fishery (95% confidence bounds 5.6% - 14.2%; Appendix Table B-3). We had sufficient recaptures ($n \geq 4$) of northern pikeminnow to calculate exploitation rates for Below Bonneville Dam (9.6%), Bonneville Reservoir (6.7%), and Little Goose Reservoir (17.4%).

For northern pikeminnow ≥ 250 mm FL, system-wide exploitation was 17.1% (95% confidence bounds 11.3% - 22.8%; Appendix Table B-4). Exploitation rates ranged from 11.2% in McNary Reservoir to 26.3% in Little Goose Reservoir (Figure 2). Not enough fish were recaptured in John Day and Lower Granite reservoirs to estimate exploitation.

Modeling results indicated potential predation by northern pikeminnow on juvenile salmonids in 2006 ranged from 56% to 86% of pre-program levels, with a median estimate of 75%. Projections through 2011 indicate continued harvest at average 1995-2006 exploitation levels would result in minimal additional reductions in predation.

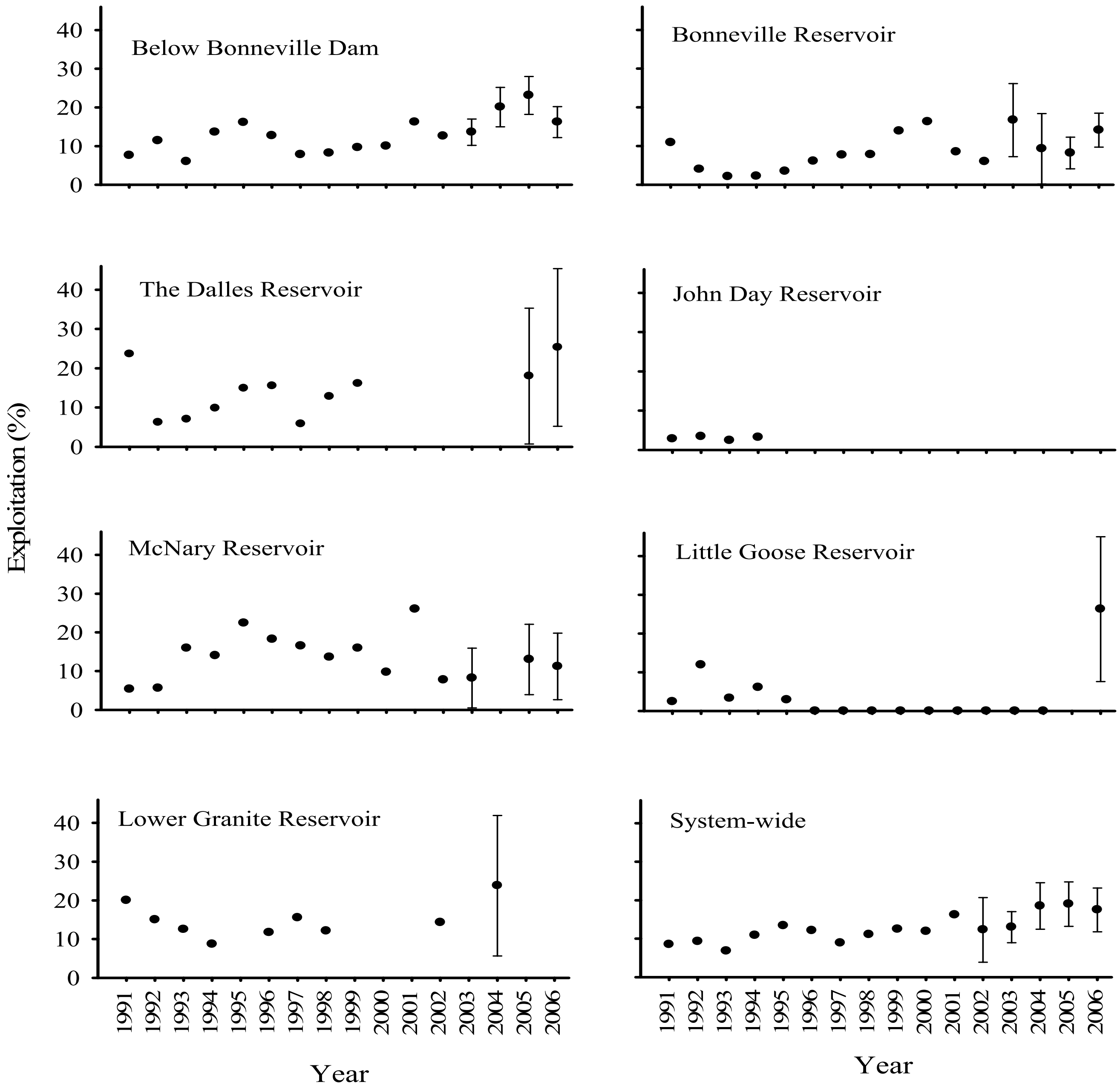

FIGURE 2.—Exploitation rates of northern pikeminnow ≥ 250 mm fork length in each reservoir or area, 1991 – 2006. Exploitation rates were not calculated where the number of recaptured tags was low (*n* < 4). Exploitation rates for 2000 – 2002 were not adjusted for tag loss. Error bars denote the 95% confidence interval.

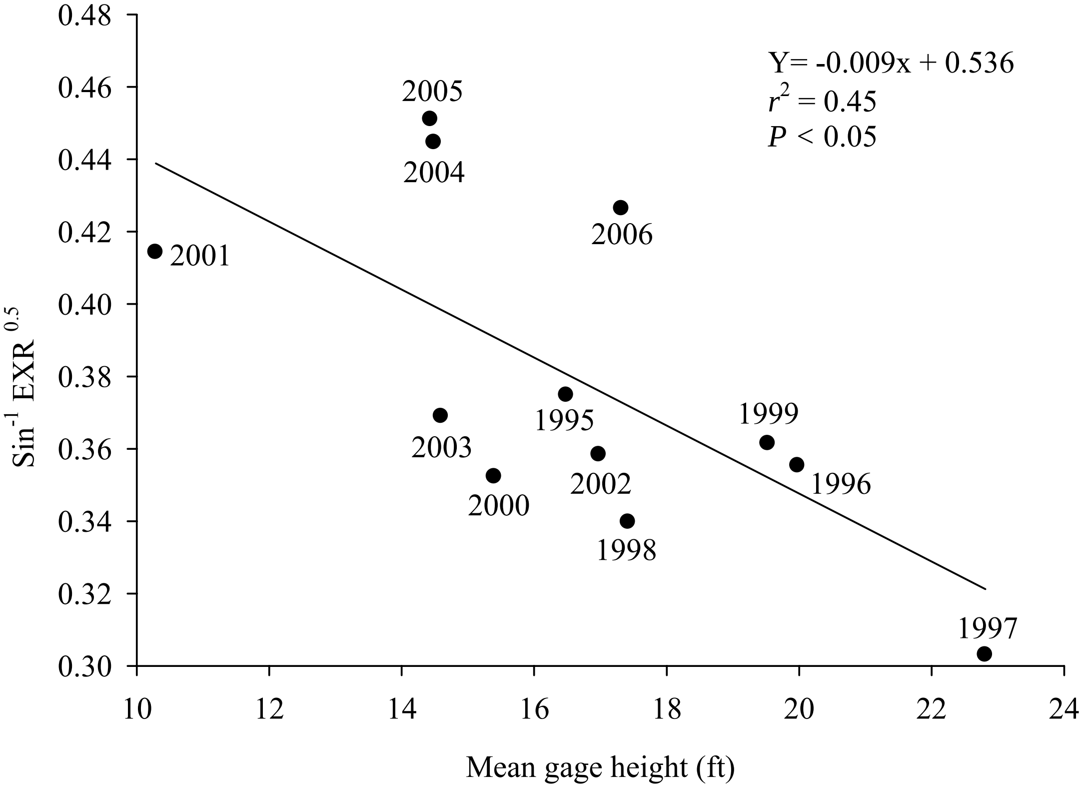

FIGURE 3.—Relationship between system-wide sport-reward exploitation rate ($\mathrm{Sin}^{-1}\ \mathrm{EXR}^{0.5}$) of northern pikeminnow ≥ 250mm FL and mean Columbia River gage height (ft) below Bonneville Dam during the sport-reward season (May – September 1995 – 2005 and May – October 2006).

In 2006 we found a significant relationship between the system-wide sport-reward exploitation rate for northern pikeminnow ≥ 250 mm FL and mean Columbia River gage height measured below Bonneville Dam during the sport-reward season. ($r^2 = 0.45$; $P = 0.02$; Figure 3). We also found that Tier 3 pay and the number of Tier 3 anglers explained 99% of the variation in exploitation of northern pikeminnow ≥ 250 mm FL ($r^2 = 0.99$; $P < 0.001$).

We sampled 299 (8.9% of the total catch) northern pikeminnow captured in the dam-angling fishery; most (74%) were from The Dalles Dam. Mean fork length was 379 ± 4 mm (mean ± SE). Three tagged northern pikeminnow were recovered, two at Bonneville Dam and one at The Dalles Dam. We were unable to calculate an exploitation rate specific to dam-angling due to the low number of recaptures. However, we included these fish in calculations of total system-wide exploitation, increasing the estimate from 14.6% to 14.8% for fish ≥ 200 mm. Weekly exploitation estimates for areas of concurrent tagging and sport-reward fishing are given in Appendix B (Tables B-5 through B-10).

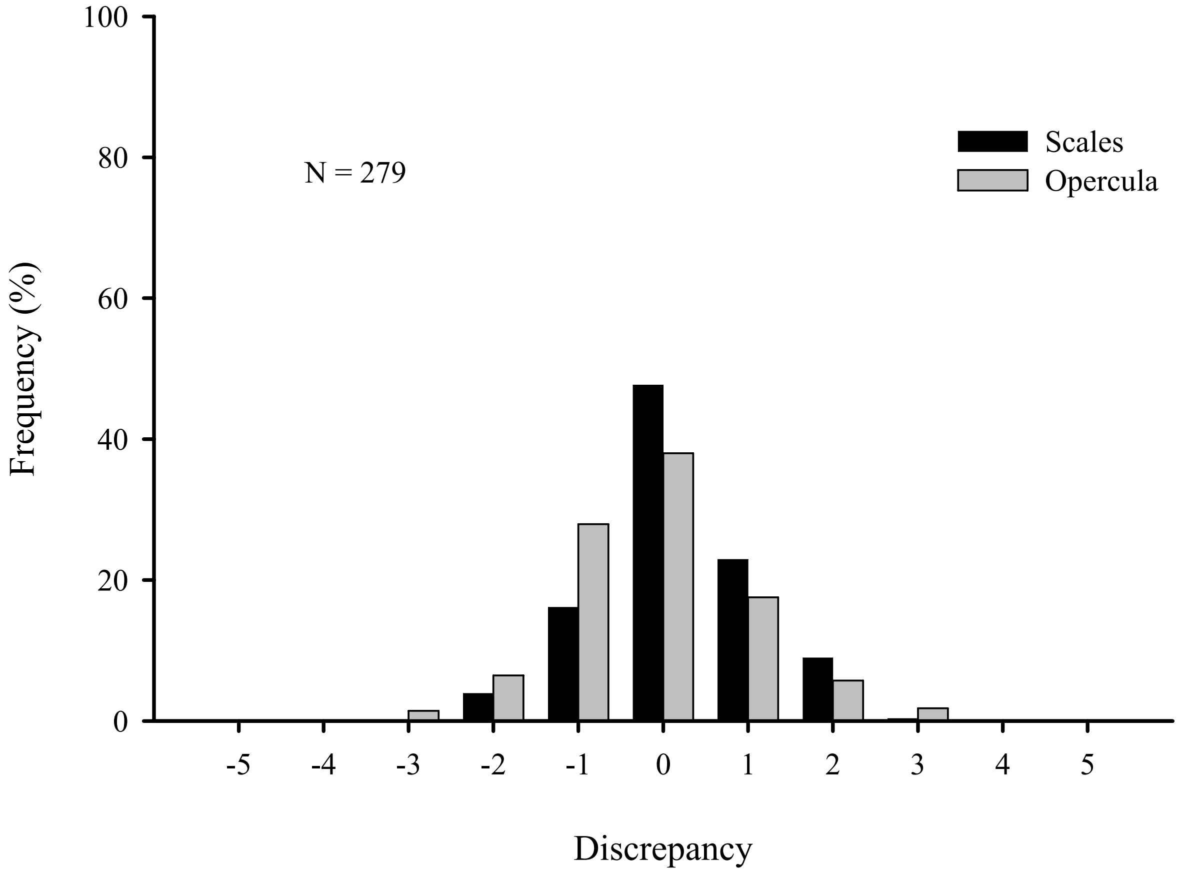

FIGURE 4.—Distribution of aging discrepancies between readers for northern pikeminnow scales and opercula collected in 2006.

Age Validation

We aged 279 corresponding pairs of scale and operculum samples from northern pikeminnow recaptured in the sport-reward fishery in 2006 for age validation purposes. Complete agreement (i.e., zero discrepancy) on scale ages assigned by the two readers was 47.7%, and when discrepancies occurred, there was a slight tendency for the experienced reader to age older than the novice reader (Figure 4). Complete agreement on operculum ages was slightly lower at 38.0%, with the novice reader aging older than the experienced reader (Figure 4). Agreement within one year for scales was 86.7% (95% confidence bounds 82.8–90.7%), and was not significantly different from reader agreement for opercula (83.5%; 95% confidence bounds 79.2-87.9%).

Corresponding scale and operculum age discrepancies in 2006 were dependent on the size (FL) of northern pikeminnow (F = 18.96, $P < 0.05$). Northern pikeminnow ≥ 350 mm FL were aged significantly older on opercula relative to scales than fish < 350 mm FL (t = 4.35, $P < 0.05$). For fish < 350 mm FL, ages assigned to scales matched ages assigned to corresponding opercula within one year 73.2% of the time (Figure 5, panel A), but age discrepancies were significantly different from zero (t = 8.57, $P < 0.05$). For fish ≥ 350 mm FL, scale ages matched with corresponding operculum ages within one year 50.0% of the time (Figure 5, panel B), and discrepancies were also significantly different from zero (t = 10.25, $P < 0.05$). In addition, we found a significant positive relationship between scale and operculum age (F = 99.34, $P < 0.05$; $r^2 = 0.62$; Y = 1.07x + 1.96), regardless of FL, with opercula assigned ages older than corresponding scales 62% of the time (Figure 6).

We examined 284 operculum samples from northern pikeminnow recaptured in 2006. We found 263 (93%) exhibited a detectable OTC mark and were examined for mark quality; of these, 18 were from 2003, 28 from 2004, 58 from 2005, and 159 were from northern pikeminnow that had been tagged in 2006. We found no relationship between OTC mark failure and mark year ($\chi^2 = 0.86$, df = 2, $P = 0.65$), and mark quality of the 263 fish that exhibited an OTC mark was not dependent on the tagging year ($\chi^2 = 8.94$, df = 6, $P = 0.18$). However, mark quality of fish recaptured in 2006 was not distributed randomly ($\chi^2 = 7.76$, df = 2, $P < 0.05$; Figure 7, panel A), with OTC marks more likely to be of fair quality than poor ($\chi^2 = 7.20$, df = 1, $P < 0.05$).

In 2006, we noted the correct number of annuli after the OTC mark 75.7% (95% confidence bounds 70.5–80.9%) of the time, with this percentage significantly higher for good quality marks (Figure 7, panel B). Our ability to successfully identify the correct number of annuli after an OTC mark was dependent on mark year (Figure 8), with the probability of correctly identifying the correct number of annuli in 2006 (zero) significantly higher than identifying the correct number in 2004 (two) or 2005 (one). The probability of correctly identifying the correct number of annuli in 2003 (3) was similar to 2006. When we incorrectly identified the number of annuli after the OTC mark, we usually underestimated (nine out of 17 misidentifications) the number of annuli for fish marked in 2004 or earlier, and overestimated (35 out of 47) the number of annuli in northern pikeminnow marked in 2005 or later.

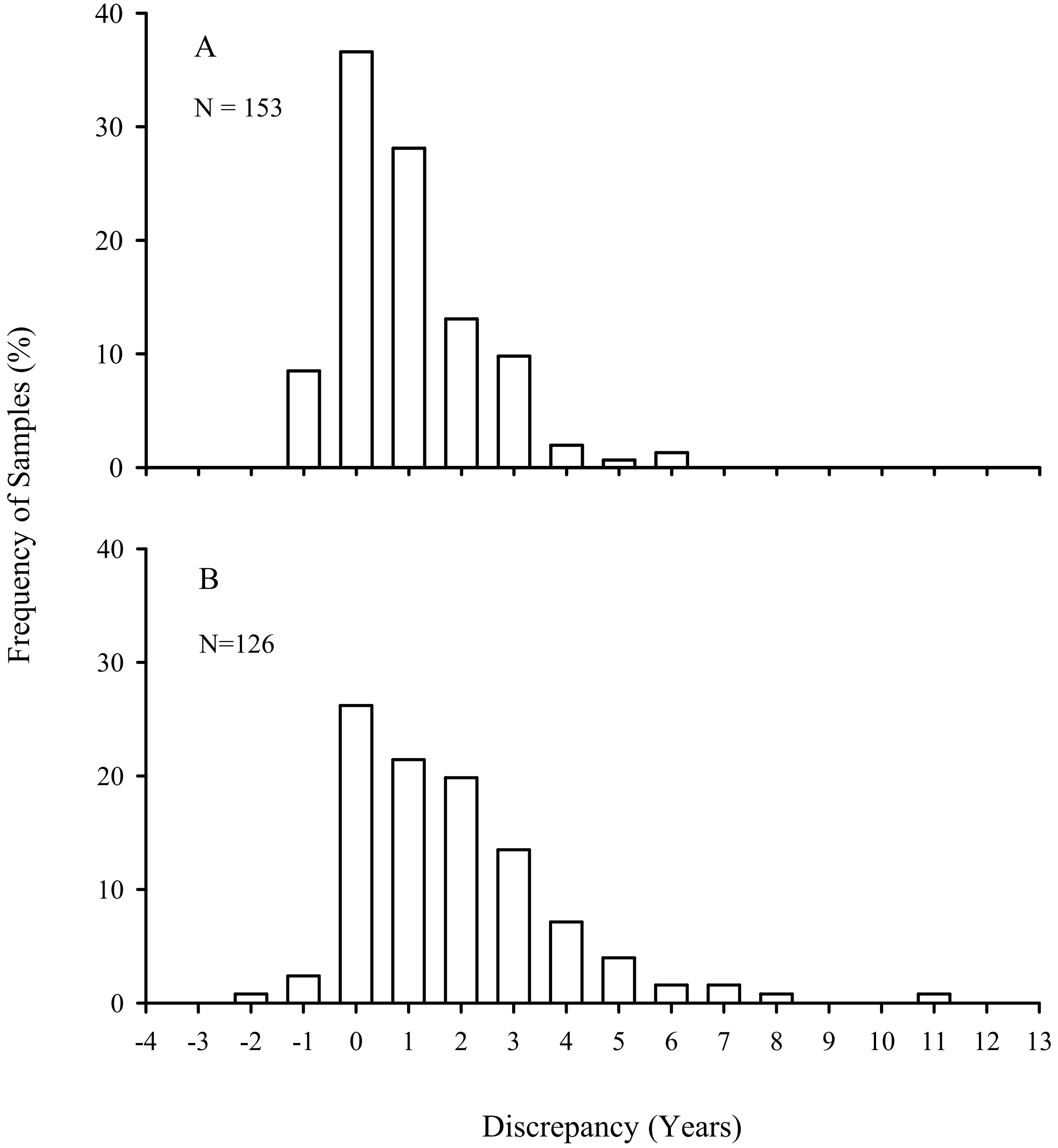

FIGURE 5.—Frequency distribution of aging discrepancies between scales and opercula taken from the same fish in 2006: northern pikeminnow < 350 mm fork length (A), northern pikeminnow ≥ 350 mm fork length (B). A discrepancy is defined as the scale age subtracted from the operculum age.

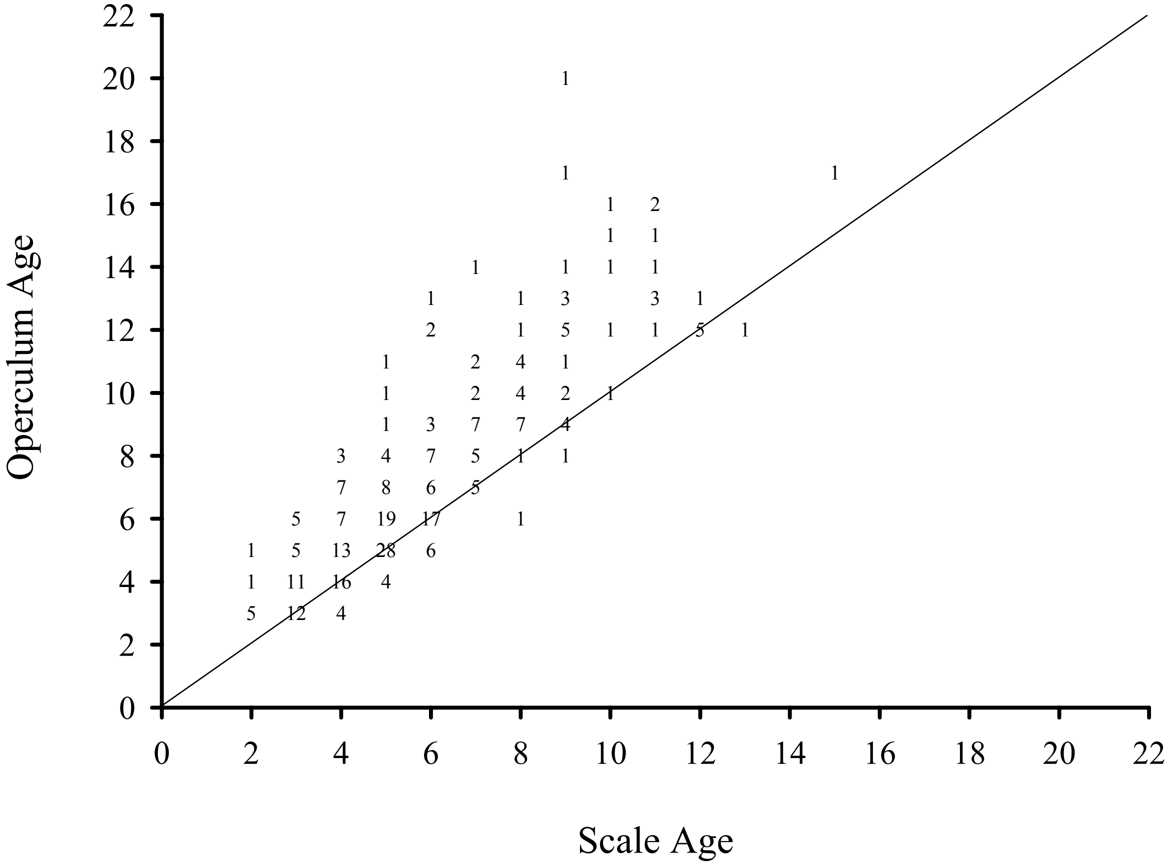

FIGURE 6.—Plot of ages assigned to corresponding scales and opercula from northern pikeminnow recaptured in 2006. The 45° line represents the point where scale and operculum ages would be the same. Numbers denote the quantity at each scale/operculum combination (*n* = 279).

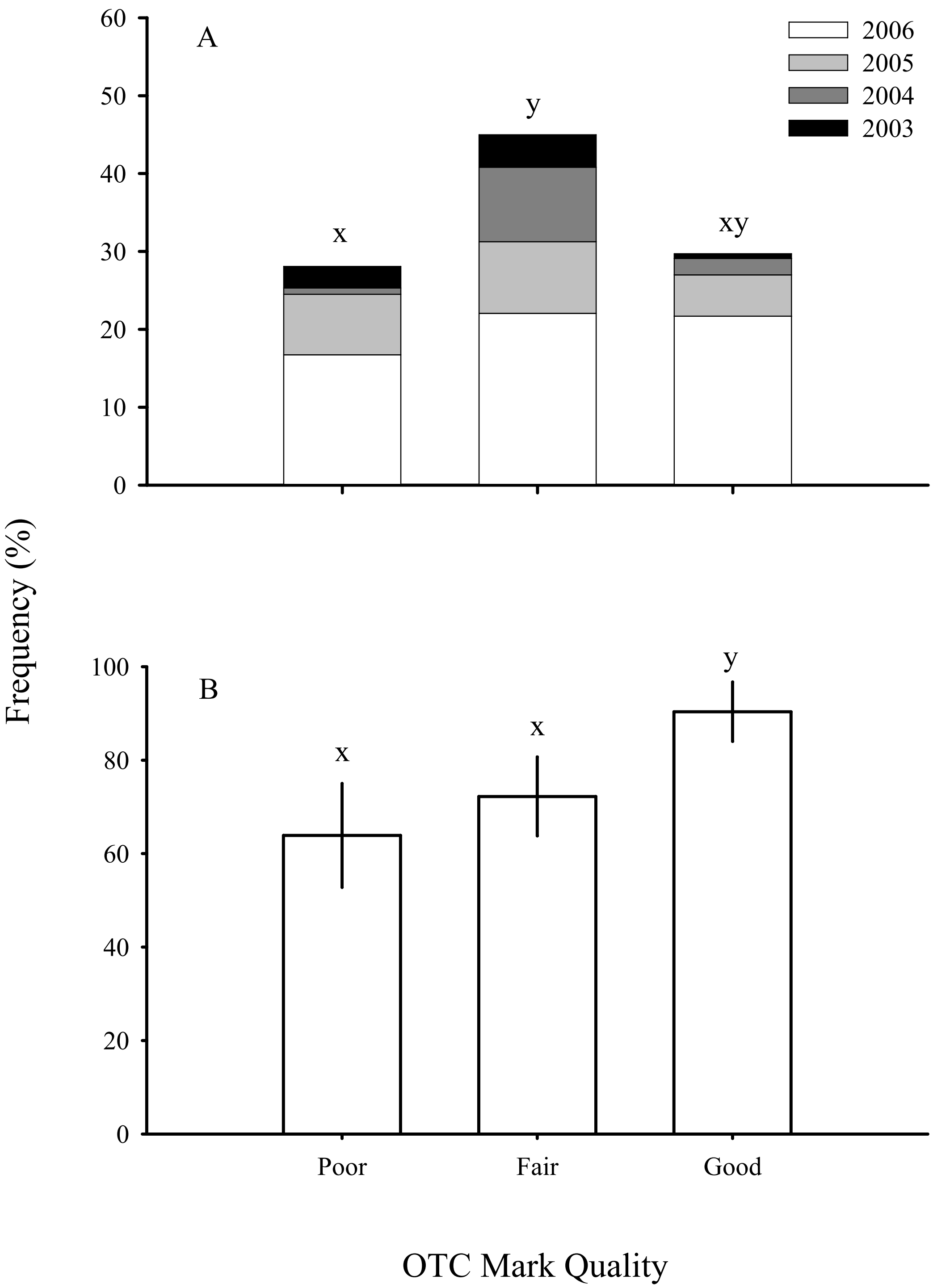

FIGURE 7.—Frequency distribution of OTC mark quality on opercula from northern pikeminnow tagged between 2003 and 2006 and recaptured in 2006 (A) and correctly identified annuli after the OTC mark (B). Bars without a letter in common are significantly different ($P < 0.05$). Error bars represent 95% confidence intervals.

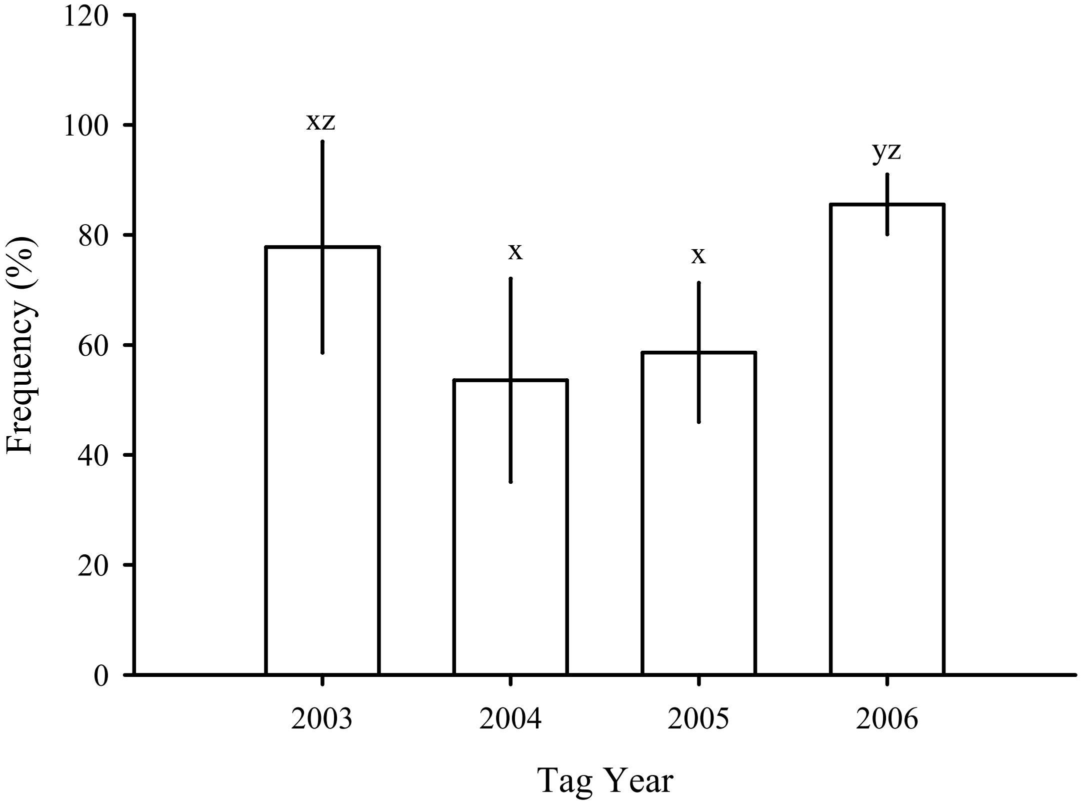

FIGURE 8.—Frequency distribution by tagging year of correctly identified annuli after the OTC mark on opercula from northern pikeminnow recaptured in 2006. Bars without a letter in common are significantly different ($P < 0.05$). Error bars represent 95% confidence intervals.

Biological Evaluation

Predator sampling near lower Columbia River dams in 2006 generally coincided with peaks in juvenile salmonid passage indices (Appendix Figure A-1). The abundance index values for northern pikeminnow in The Dalles Reservoir forebay and tailrace areas were the lowest since sampling began in 1990 (Appendix Table C-5). The mid-reservoir area of The Dalles Reservoir was sampled for the first time since 1993 and its abundance index was over three times higher than in the forebay and tailrace. Abundance index values for all areas of John Day Reservoir were among the lowest to date (Appendix Table C-5). Like in The Dalles Reservoir, the mid-reservoir portion of John Day Reservoir had the highest northern pikeminnow abundance index.

In spring 2006, smallmouth bass relative densities in The Dalles and John Day reservoirs were among the highest to date (Appendix Table C-6). Densities were highest in the forebay and mid-reservoir areas of both reservoirs. Summer smallmouth bass densities in 2006 were higher than any previous year, except in the John Day forebay (Appendix Table C-7). The John Day mid-reservoir had the highest overall smallmouth bass densities during both seasons.

We report walleye relative densities for the first time in 2006. Since sampling began in the early 1990s, both spring and summer walleye densities have been relatively low in The Dalles and John Day reservoirs (Appendix Table C-8; Appendix Table C-9). The exception to this is in the John Day Reservoir tailrace, where walleye densities were highest, and where abundance appears to have slightly increased in recent years.

Of the 62 northern pikeminnow digestive tracts examined, 33% contained food (e.g. crayfish, insects, and fish) (Appendix Table C-10). All identifiable fish remains found in northern pikeminnow digestive tracts were *Oncorhynchus* spp. (Appendix Table C-11). During both seasons, John Day Reservoir had a higher percentage of northern pikeminnow stomach samples containing *Oncorhynchus* spp. than did The Dalles Reservoir (Appendix Table C-10).

We examined 1,840 smallmouth bass stomach samples; 84.5% contained food items (Appendix Table C-10). The species composition of identifiable fish remains in smallmouth bass stomach samples varied little among reservoirs. In The Dalles and John Day reservoirs, sculpin *Cottus* spp. (81.3% and 68.2%, respectively), *Oncorhynchus* spp. (5.4% and 13.6%), and *Micropterus* spp. (4.5% and 5.7%) were identified most often (Appendix Table C-11). Additionally, we found mountain whitefish *Prosopium williamsoni*, lamprey *Lampetra* spp., peamouth *Mylocheilus caurinus*, suckers *Catostomus* spp., catfish *Ictaluridae*, and yellow perch *Perca flavescens*. Smallmouth bass in all areas and seasons contained 13% fish; however, less than 3% contained *Oncorhynchus* spp. (Appendix Table C-10).

Walleye consumed *Oncorhynchus* spp. in all areas and seasons, with the exception of The Dalles Reservoir during summer (Appendix Table C-10). *Oncorhynchus* spp. accounted for 63.6% and 70.8% of identified fish in walleye stomachs in The Dalles and John Day reservoirs, respectively. *Catostomus* spp. and *Cottus* spp. were found to a lesser extent, comprising 18.2% and 20.0% of identified fish (Appendix Table C-11).

The spring 2006 CI value for northern pikeminnow in The Dalles mid-reservoir was 0.5 (Appendix Table C-12). Spring CI values in the John Day Reservoir tailrace varied among years, with no apparent trend. In 2006, summer consumption was the highest to date for The Dalles Reservoir tailrace (Appendix Table C-13). In the remaining locations, we either did not sample or were unable to calculate indices due to insufficient sample sizes ($n \leq 5$).

Spring consumption indices for smallmouth bass in The Dalles and John Day reservoirs were low and varied little among areas (Appendix table C-14). The summer CI value for the John Day forebay was higher than in 2004 (Appendix Table C-15). However, the summer CI value for the John Day Reservoir tailrace was lower than in 2004.

We calculated a predation index for The Dalles mid-reservoir for the first time in 2006. The spring PI value for northern pikeminnow was 0.4 (Appendix Table C-16). In the John Day Reservoir tailrace, the PI value during the spring was 73% lower than the average for 1995 – 1996, 1999, and 2004. The summer PI value for The Dalles Reservoir tailrace was 45% lower than in 2004 (Appendix Table C-17). In all other areas, northern pikeminnow predation indices were either similar to past years or were not calculated due to insufficient sample sizes ($n \leq 5$).

We calculated smallmouth bass predation indices for the first time in The Dalles forebay and mid-reservoir areas (Appendix Table C-18). In 2006, the summer PI value was 95% lower in The Dalles Reservoir tailrace than in 2004. In the John Day forebay, the spring PI value dropped from 1.6 in 2004 to zero in 2006, and decreased 50% from 2004 in the summer. The spring PI value for the mid-reservoir was 52% lower than in 2004. Conversely, the summer PI value was notably higher than in 2004. In the John Day Reservoir tailrace, summer PI values were 60% lower than in 2004. In The Dalles Reservoir tailrace, during the summer, northern pikeminnow predation was much higher than smallmouth bass predation (Appendix Table C-19). Differences in other areas were negligible or incomparable due to insufficient sample sizes.

Northern pikeminnow year-class analysis in The Dalles Reservoir showed that age-5 fish made up a larger percentage of the population than did age-3 or age-4 fish in three out of the four years that data are available (Figure 9). In John Day Reservoir, for most years from 1990 to 1996, age-5 fish also tended to predominate within the age 3-5 group. However, in the three years sampled since 1996 (1999, 2004, and 2006), the proportion of age-3 fish has increased substantially (Figure 9). In addition, the percentage of the population consisting of age 3-5 northern pikeminnow in John Day Reservoir was, on average, twice as high during 1999 – 2006 compared to 1990 - 1996.

We collected scales from smallmouth bass in The Dalles Reservoir for the first time in 2006. A total of 158 bass scales were read, 11.4% of which were age-4 fish and 15.2% age-5 fish. Year-class analysis in John Day Reservoir indicated that in 2006 the percentage of age 4-5 smallmouth bass in the population returned to a level similar to that observed in 1995, after a slight increase during 1996 – 2004 (Figure 10). Age-4 smallmouth bass continued to predominate within the age 4-5 group in John Day Reservoir.

We assessed walleye year-class strength for the first time in 2006. The percentage of age 5-6 walleye in the lower Columbia River appeared to be relatively stable (Figure 11). Lower percentages in 2004 and 2005 might be attributed to small sample sizes. Age-5 walleye predominated within the age 5-6 group.

The 2006 northern pikeminnow PSD value for The Dalles Reservoir was 55% higher than in 1999; however, it was only slightly higher than the average for all previous years. Furthermore, stock density in The Dalles Reservoir did not show any discernable trend during the sampling time frame (Figure 12). We could not calculate a northern pikeminnow PSD for John Day Reservoir in 2006 due to an inadequate sample size ($n < 20$ for stock size fish).

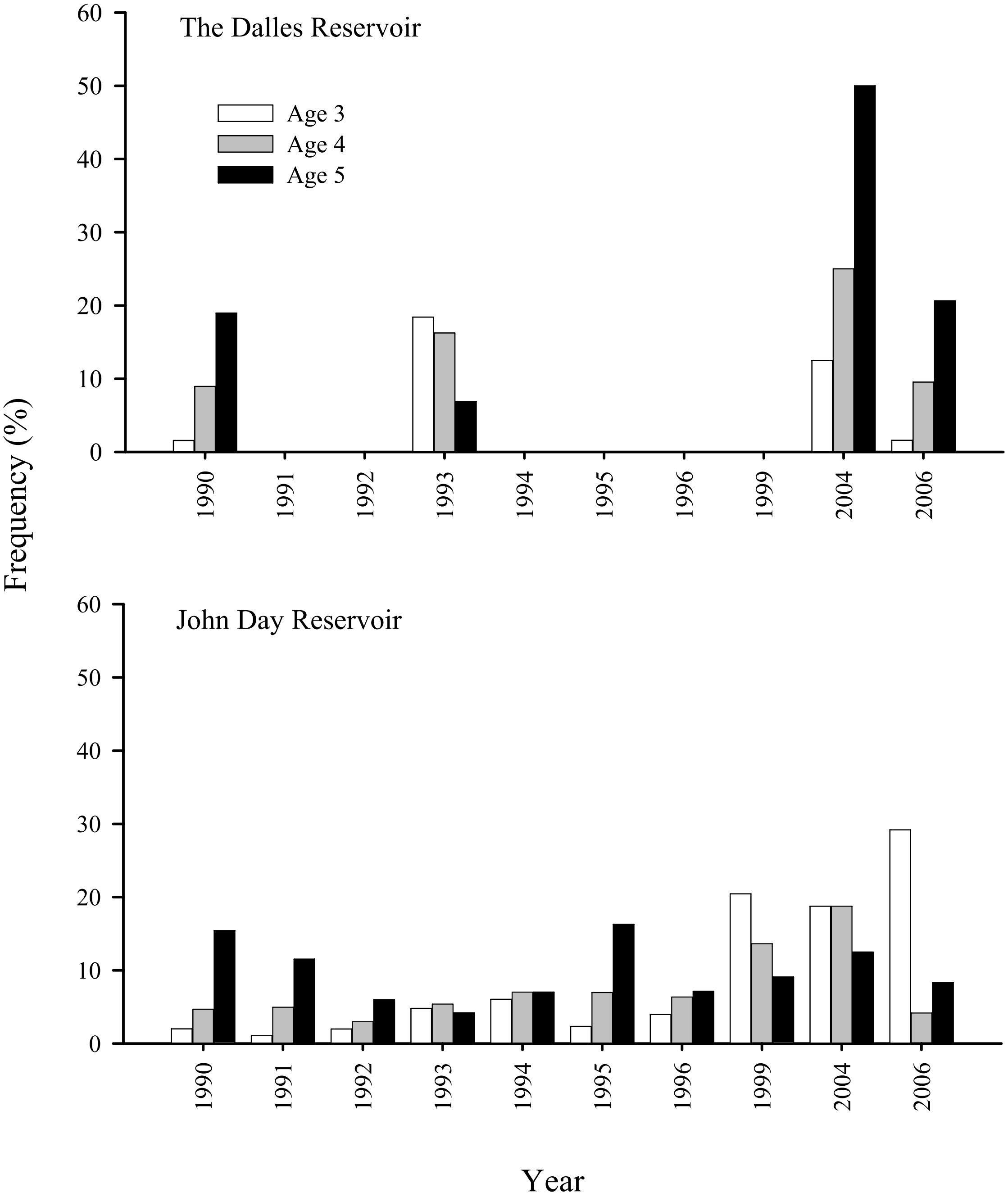

FIGURE 9.—Percent composition of age 3-5 northern pikeminnow, relative to the total sample, in the The Dalles and John Day reservoirs, 1990-1996, 1999, 2004, and 2006.

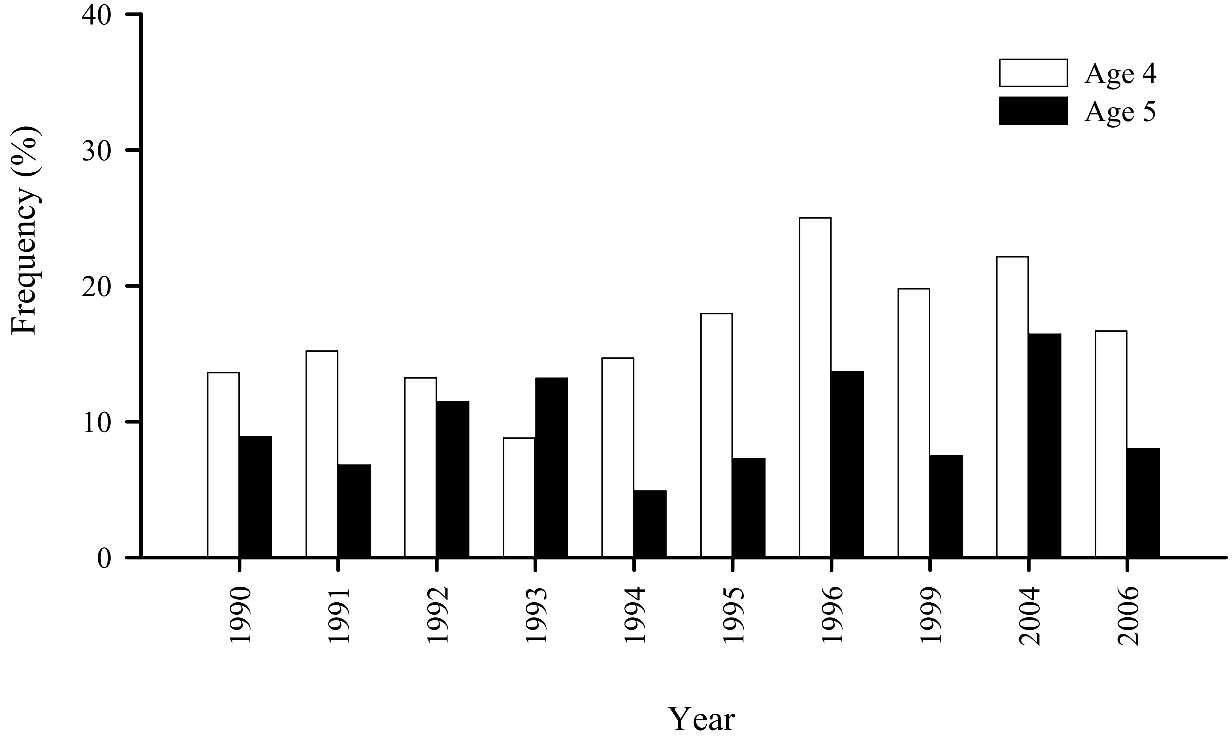

FIGURE 10.—Percent composition of age 4-5 smallmouth bass, relative to the total sample, in John Day Reservoir, 1990-1996, 1999, 2004, and 2006.

For The Dalles Reservoir, smallmouth bass PSD in 2006 was slightly lower than the average for all previous years while RSD-P was the highest since sampling began. Both PSD and RSD-P values for smallmouth bass in John Day Reservoir were similar to previous year averages. Stock densities in both reservoirs appeared to vary randomly with no apparent trends (Figure 13).

We report walleye PSD and RSD-P for the first time in 2006. In The Dalles Reservoir, PSD has fluctuated while RSD-P was slightly higher in 2006 compared to previous years. Walleye PSD and RSD-P in John Day Reservoir decreased in recent years, with values lowest in 2006 (Figure 14).

Median relative weights for male and female northern pikeminnow in the The Dalles Reservoir in 2006 were significantly higher ($P < 0.05$) than previous years, except for male northern pikeminnow in 1994 (Figure 15). Both sexes exhibited a similar pattern, with relative weights generally increasing in the last 10 years. In John Day Reservoir, relative weights have slightly increased in recent years (Figure 16); however, female northern pikeminnow W_r in 2006 was only significantly higher than 1991 ($P < 0.05$), and male northern pikeminnow W_r in 2006 did not significantly differ from any previous year.

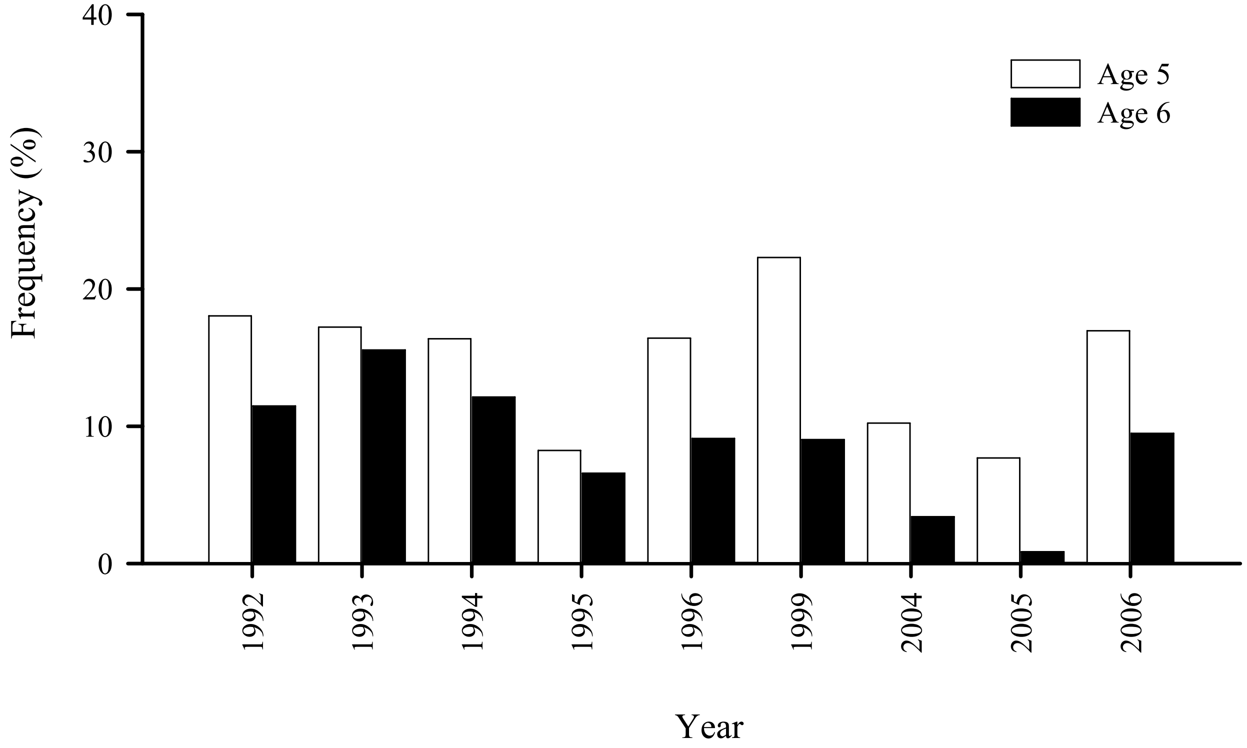

FIGURE 11.—Percent composition of age 5-6 walleye, relative to the total sample, in the lower Columbia River, 1992 - 1996, 1999, and 2004 - 2006.

Relative weights for smallmouth bass appear to fluctuate moderately in The Dalles and John Day reservoirs (Figure 17). In both reservoirs, relative weights were lowest in 1996 and have increased since then. Relative weights in 2006 were significantly higher than in 1996 ($P < 0.05$).

We report walleye relative weights for the first time in 2006. In contrast to northern pikeminnow and smallmouth bass, relative weights for walleye were less variable from year to year (Figure 18). Relative weight in The Dalles Reservoir in 2006 was significantly higher than in 1993 ($P < 0.05$); however, relative weight in John Day Reservoir did not vary by year ($P = 0.053$). In both reservoirs, all median W_r values for walleye were below 100.

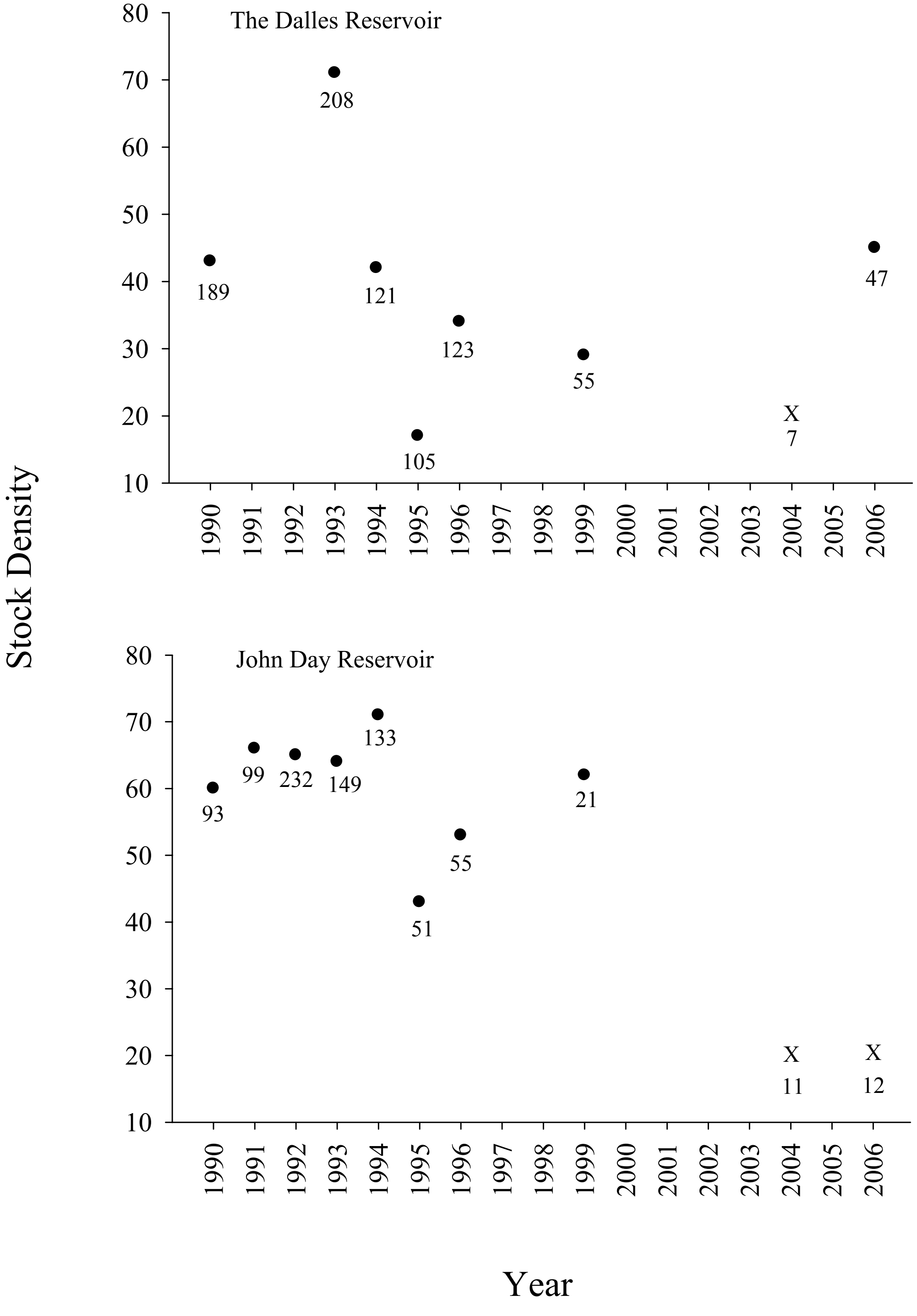

FIGURE 12.—Proportional stock density (PSD) and sample size (N) of northern pikeminnow in The Dalles and John Day reservoirs, 1990 – 1996, 1999, 2004, and 2006. X = insufficient sample size to estimate stock density.

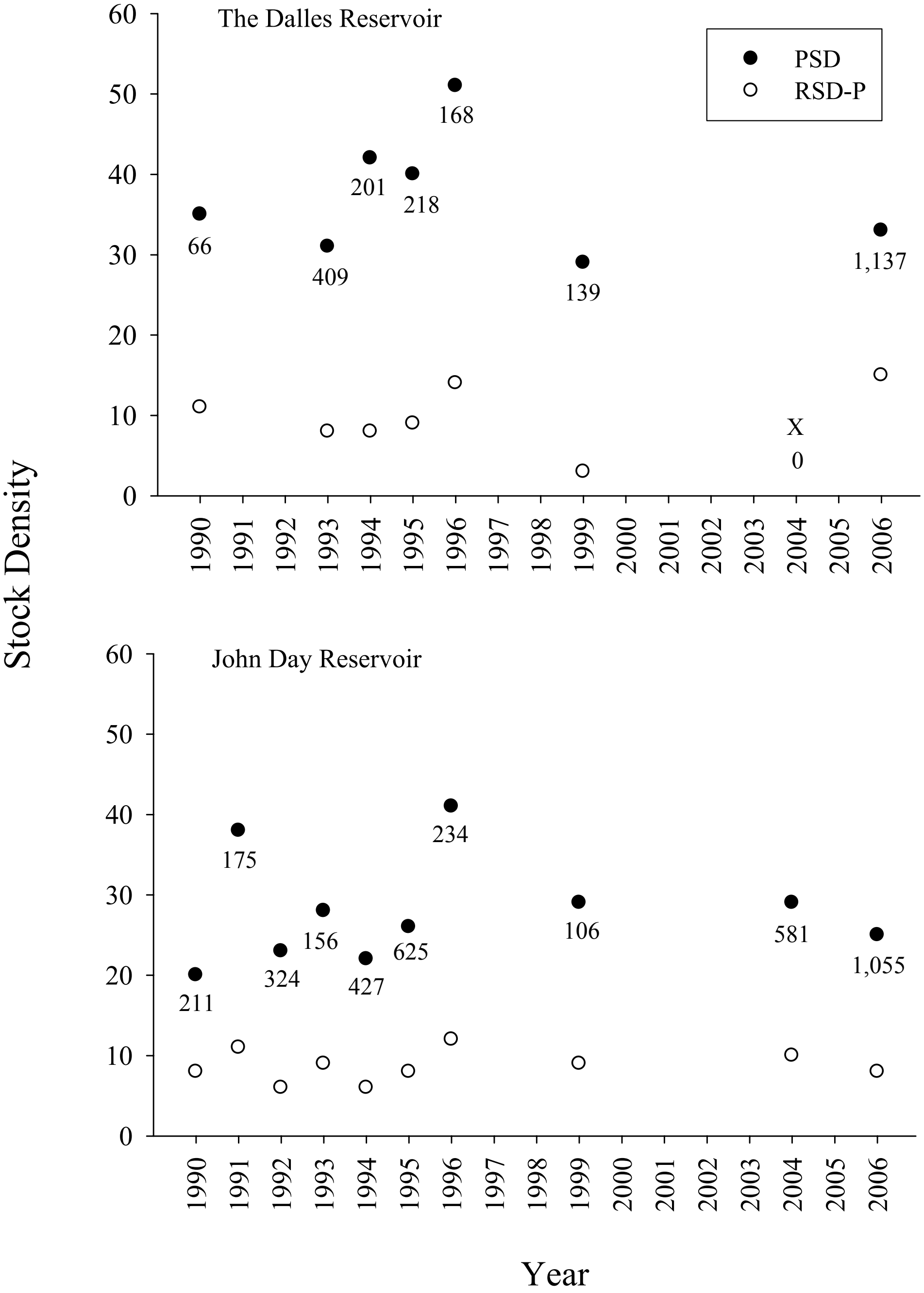

FIGURE 13.—Proportional stock density (PSD), relative stock density (RSD-P), and sample size (N) of smallmouth bass in the The Dalles and John Day reservoirs, 1990 – 1996, 1999, 2004, and 2006. X = insufficient sample size to estimate stock density.

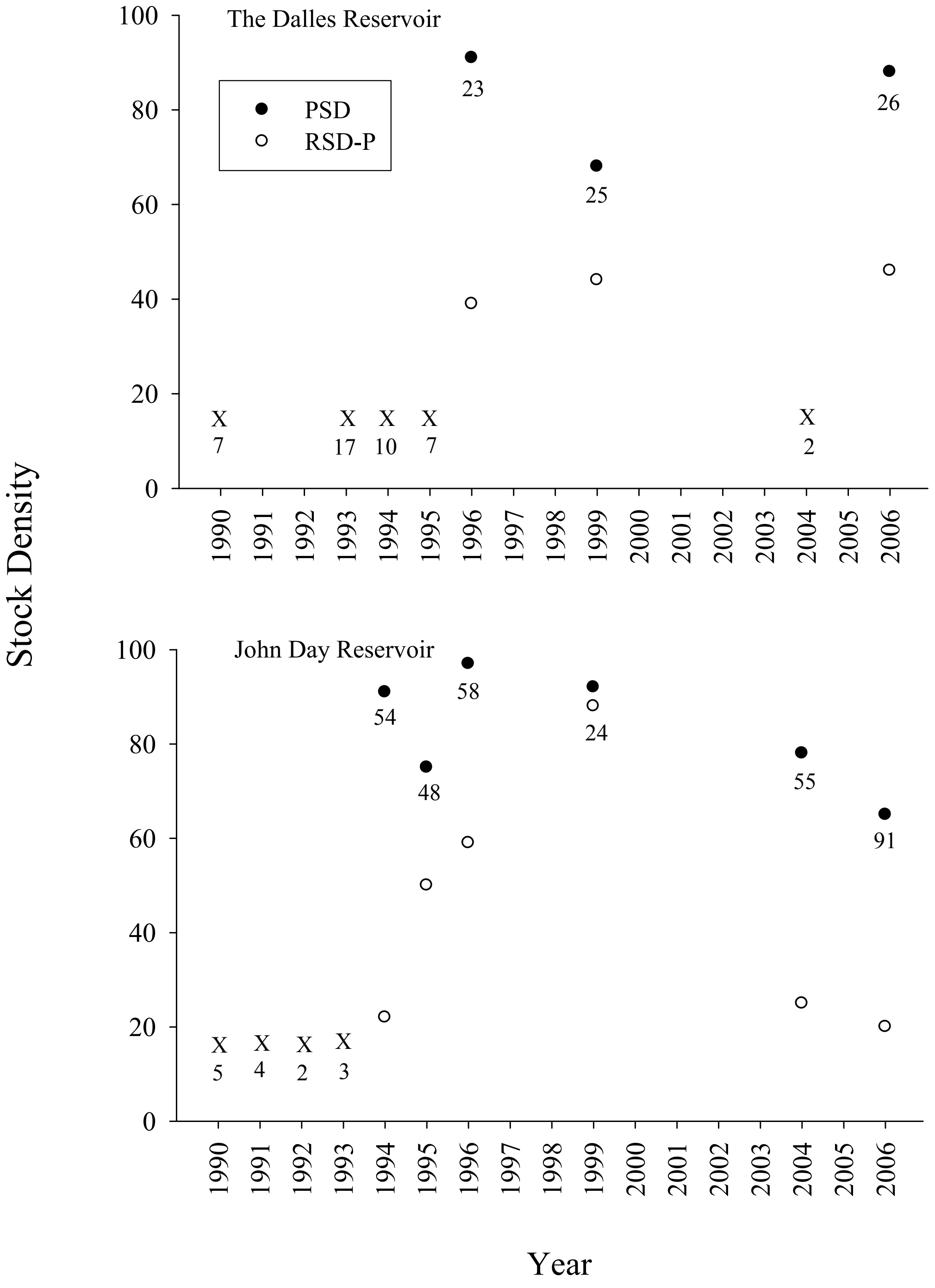

FIGURE 14.—Proportional stock density (PSD), relative stock density (RSD-P), and sample size (N) of walleye in The Dalles and John Day reservoirs, 1990 – 1996, 1999, 2004, and 2006. X = insufficient sample size to estimate stock density.

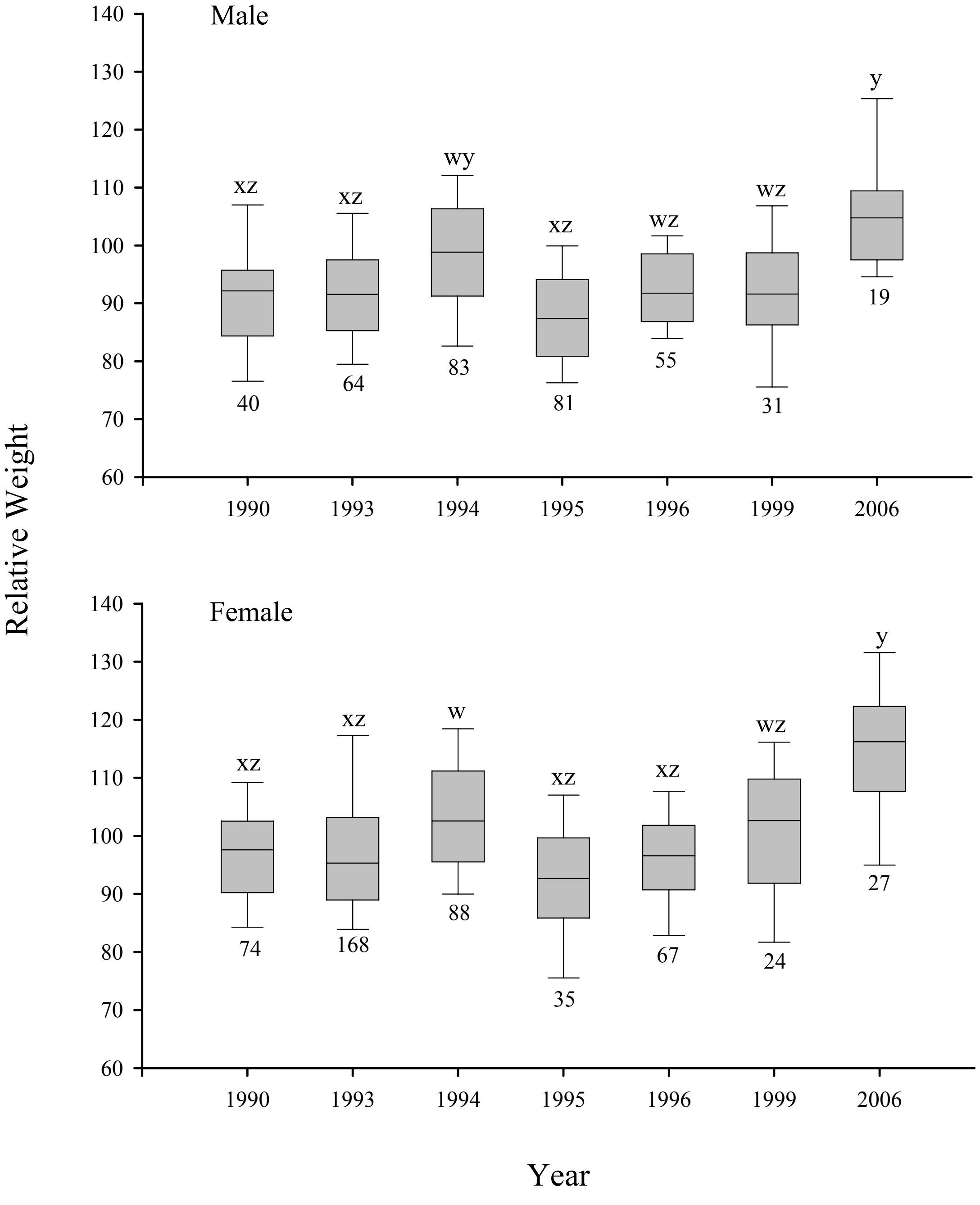

FIGURE 15.—Relative weight of male and female northern pikeminnow in The Dalles Reservoir, 1990, 1993-1996, 1999, and 2006. The horizontal line near the center of each bar is the median, the ends of the bar are 25th and 75th percentiles, and the whiskers are the 10th and 90th percentiles. Bars without a letter in common differ significantly ($P < 0.05$); numbers below the bars are the sample size.

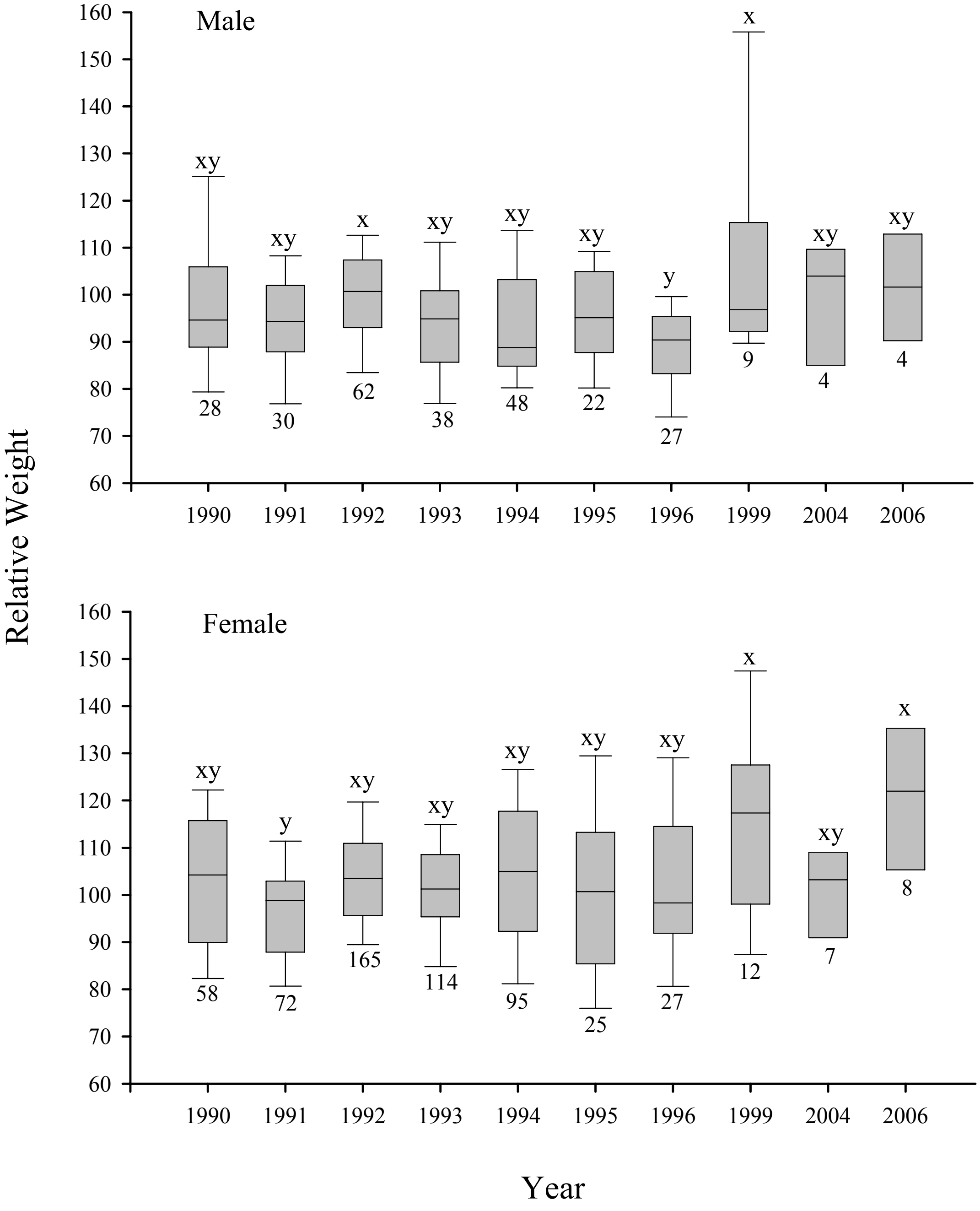

FIGURE 16.—Relative weight of male and female northern pikeminnow in John Day Reservoir, 1990-1996, 1999, 2004, and 2006. The horizontal line near the center of each bar is the median, the ends of the bar are 25th and 75th percentiles, and the whiskers are the 10th and 90th percentiles. Bars without a letter in common differ significantly ($P < 0.05$); numbers below the bars are the sample size.

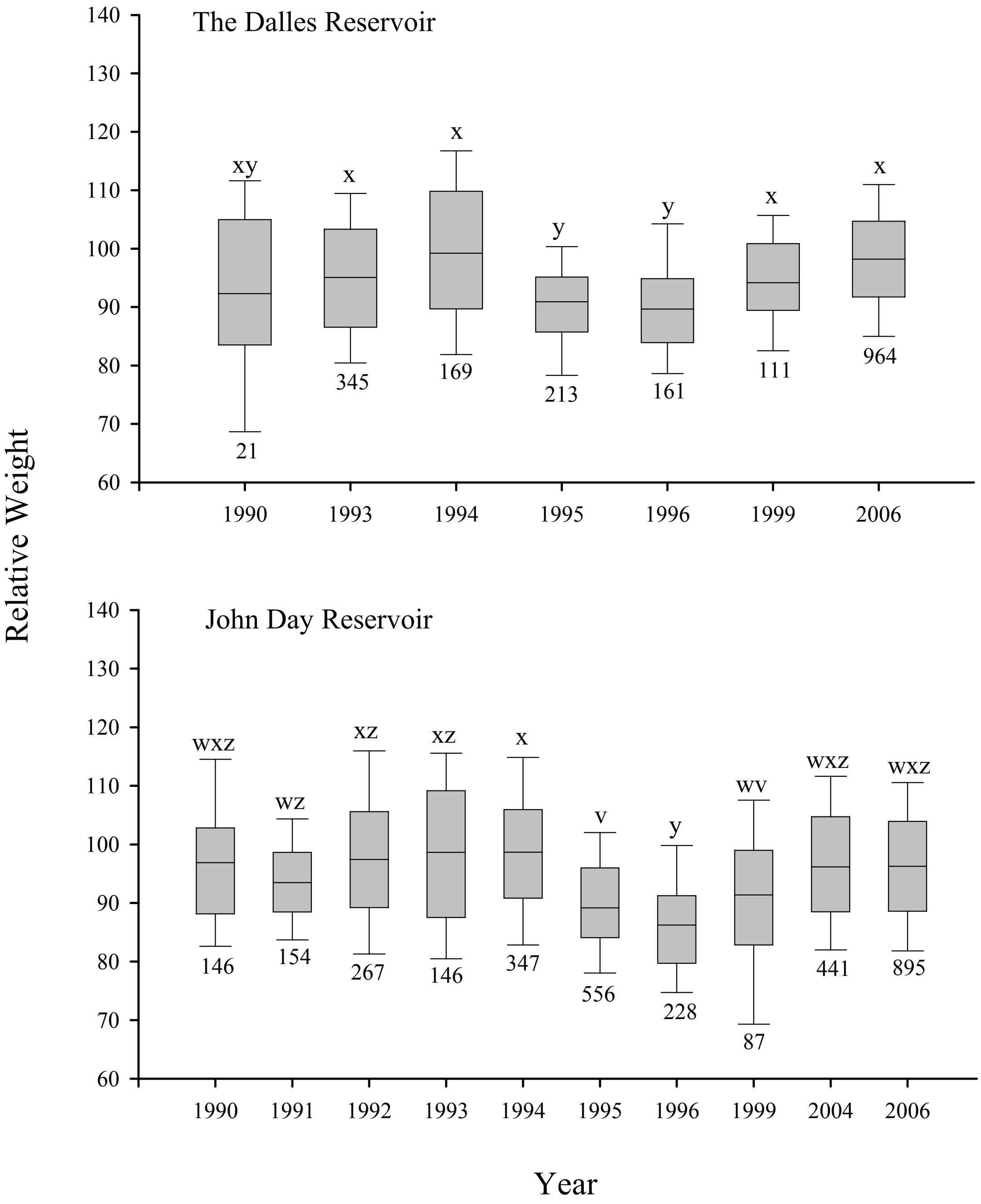

FIGURE 17.—Relative weight of smallmouth bass in The Dalles and John Day reservoirs, 1990-1996, 1999, 2004, and 2006. The horizontal line near the center of each bar is the median, the ends of the bar are 25th and 75th percentiles, and the whiskers are the 10th and 90th percentiles. Bars without a letter in common differ significantly ($P < 0.05$); numbers below the bars are the sample size.

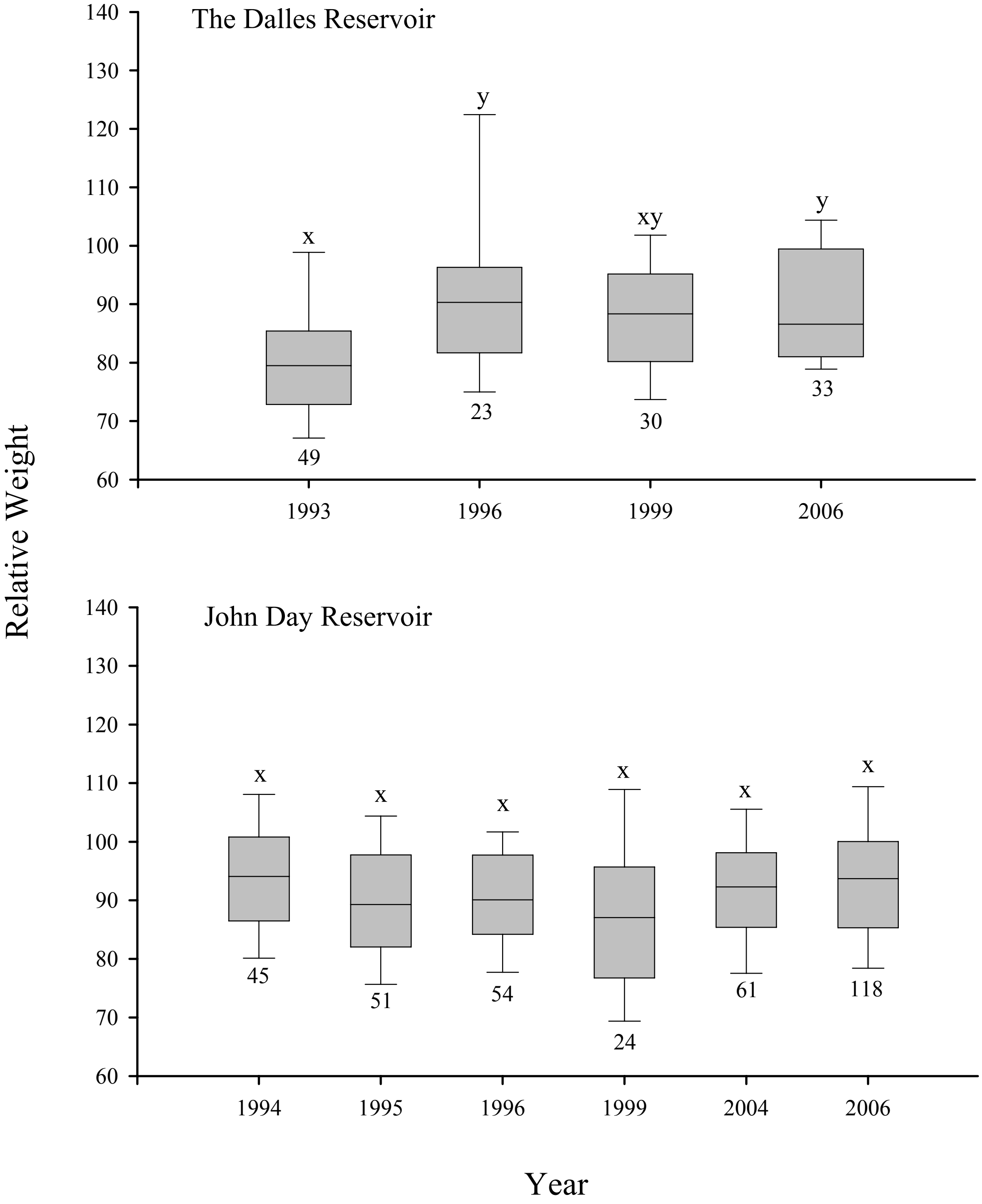

FIGURE 18.—Relative weight of walleye in The Dalles and John Day reservoirs, 1993-1996, 1999, 2004, and 2006. The horizontal line near the center of each bar is the median, the ends of the bar are 25th and 75th percentiles, and the whiskers are the 10th and 90th percentiles. Bars without a letter in common differ significantly ($P < 0.05$); numbers below the bars are the sample size.

Discussion

Fishery Evaluation, Predation Estimates, and Tag Loss

In 2006, we tagged and released more northern pikeminnow than we had since 1996; resulting in narrower exploitation rate confidence intervals. System-wide exploitation of northern pikeminnow ≥ 250 mm FL (17.1%) by the sport-reward fishery was higher than the 2001-2005 average exploitation rate (15.8%), and was the third highest in program history. Furthermore, total system-wide exploitation has been within the target range of 10-20% (Rieman and Beamesderfer 1990) in 14 of 16 years.

We continue to observe variability in both system-wide and area-specific exploitation rates. In previous years, sport-reward exploitation of northern pikeminnow ≥ 250 mm FL appeared to be driven by river flow (Takata and Koloszar 2004), with exploitation increasing as river levels decreased. However, the amount of variability explained by river flow weakened during 2006, and the last couple of years (Jones et al. 2005; Reesman et al. 2006), suggesting that other factors may play a role in determining exploitation rates. Our analysis in 2006 indicated that reward structure variables such as Tier 3 pay and the number of Tier 3 anglers had a strong influence on exploitation rates during 2000-2006. Therefore, it appears that modifications to the reward structure of the sport-reward fishery in recent years may have reduced the effect of river flow on exploitation. Another factor that probably contributes to the weakening of the river flow model is angler skill. While variables such as river flow fluctuated from year to year, sport-reward anglers have steadily become more proficient as a group. In 2000, 65% of anglers caught < 10 northern pikeminnow during the season, but by 2006, that percentage had dropped to 45% (PSMFC, unpublished data). An increase in skill would likely influence both the number and pay of Tier 3 anglers, and may be one reason why catch and exploitation rates remained high in 2006 despite relatively high river flow. We will continue to evaluate changes in the reward structure and angler skill, as well as explore other exploitation rate predictors.

For the 10th time in 13 years, we have been unable to calculate exploitation rates in John Day Reservoir. This is likely due to low densities of northern pikeminnow, but may also be related to the large size of the reservoir and light fishing pressure. We tagged 125 northern pikeminnow in Little Goose Reservoir and were able to calculate exploitation rates for all size classes there for the first time since 2000. Among reservoirs/areas, Little Goose Reservoir had the highest exploitation rates for fish that were ≥ 250 mm and 200-249 mm. We will continue to tag and monitor northern pikeminnow in Little Goose Reservoir in 2007.

Tagged northern pikeminnow 200-249 mm FL continue to be recovered in the fishery at a lower rate than untagged fish of the same size and larger tagged fish. In 2006, these smaller fish comprised about 34% of the northern pikeminnow tagged and released. Although 35% of the untagged northern pikeminnow harvested by the sport-reward fishery in 2006 consisted of fish 200-249 mm FL, only 22% of the recaptured tagged fish were of this size. Higher mortality or other factors may prevent smaller fish from being recaptured in the fishery at a rate more consistent with their share of the overall catch (Takata and Koloszar 2004). We may need to re-assess our current practice of tagging fish in this size category as differential mortality or behavior between marked and unmarked fish violates central assumptions of the Petersen mark-recapture protocol (Ricker 1975).

The dam-angling fishery accounted for only 1.4% of the northern pikeminnow harvest, compared to 11.2% during 1991-1996 (Friesen and Ward 1999). In 2006, the dam-angling fishery recaptured three tagged fish; no recaptures occurred during 2001 and 2002, the last two seasons before the fishery was suspended in 2003 (Takata and Friesen 2003). Northern pikeminnow sampled from the dam-angling fishery in 2006 were smaller (379 mm vs. 401 mm) than those reported by Friesen and Ward (1999) during 1990 - 1996. Our sample size was relatively small and Friesen and Ward (1999) collected data from a greater number of dams; however, the size difference we observed would be expected if the NPMP is functioning as intended (i.e., the northern pikeminnow population consists of fewer large fish). We will continue to monitor dam-angling activities in 2007, scheduled this year at The Dalles and John Day dams.

We calculated a tag loss estimate of 9.9% in 2006, which was higher than the 8.1% estimated in 2005 (Reesman et al. 2006) and the 4.2% used to adjust exploitation estimates prior to 2000 (Zimmerman et al. 2000). Although spaghetti tags are designed for a long retention time, they are prone to snagging due to their loop configuration (Guy et al. 1996). Timmons and Howell (1995) observed a 50% tag loss rate in two catostomid species after 190 days. Our estimated tag loss rate in 2006 seems reasonable considering the reported tag loss range (5 – 25%) of similar studies (Ebener and Copes 1982; Muoneke 1992). We were able to accurately discern the year each tag loss fish was marked between 2003 and 2006 by utilizing PIT tags as secondary marks for our tag loss study, allowing us to calculate multi-year exploitation rates. We plan to employ PIT tags as our secondary mark again in 2007.

Our 2006 estimated reduction in potential predation (75% of pre-program levels) was based on the Friesen and Ward (1999) predation model. This is a slightly greater reduction than observed in 2005 (78%; Reesman et al. 2006), and is likely related to the higher than average exploitation rates we have seen in the last couple of years. However, these levels should be considered cautiously. The Friesen and Ward (1999) model is based on the average pre-program northern pikeminnow population age structure, and may suffer from age validation related issues. We have developed a new model based on fish size rather than age, and though preliminary results from this updated model indicate that actual reductions may be higher than previously thought, it has not yet been subjected to peer review.

Age Validation

In 2006, reader agreement within one year for scale ages (86.7%) was very similar to the 2002 - 2004 average (86.5%). Within one year agreement for opercula (83.5%) was also similar to the 2002 – 2004 average (82.0%). In most years of this study, reader agreement has been comparable between the two aging structures. The exceptions were in 2001 and 2005 when reader agreement differed by 15% and 64%, respectively (Takata and Ward 2002; Reesman et al. 2006). However, 2001 was the first year that we aged opercula, and insufficient training may have contributed to the unusual results in 2005 (Reesman et al. 2006). Nevertheless, aging precision for scales has always been greater than that for opercula. These results contrast with those of Baker and McComish (1998) who determined that opercula were aged more precisely than scales in yellow perch *Perca flavescens*. In their study, yellow perch ranged in age from 0 to 10 years, while we have aged northern pikeminnow to over 20 years. Older fish often have annuli crowded near the edge of the operculum, making it difficult to distinguish between true and false annuli (Baker and McComish 1998). In addition, we have far less experience aging opercula compared to scales, which may explain why aging precision has been lower for opercula in our study.

Comparisons between scale and operculum derived ages have been consistent among the six years we have conducted this analysis. Beyond 8-9 years of age, northern pikeminnow opercula are consistently aged older than corresponding scales. Studies by Campbell and Babaluk (1979), Scoppettone (1988), Donald et al. (1992), and the Washington Department of Fish and Wildlife (J. Sneva, WDFW, personal communication) have also found that ages derived from opercula tended to be older than those from scales. Methods that provide older estimates of fish age, such as opercula, are generally thought of as more accurate relative to true fish age than those methods that yield younger estimates (Dubois and Lagueux 1968; Donald et al. 1992). We found a significant positive linear relationship between scale and operculum ages; therefore, ages assigned to opercula could be predicted from scale ages, within a certain degree of error.

In 2006, we again utilized fluorescent OTC marks as an operculum age validation tool. The percentage of OTC mark failures in 2006 was lower than in 2005, but did not vary by tagging year. The presence of a discernible OTC mark in 2006 (93%) was similar to that reported by Rien and Beamesderfer (1994) in white sturgeon (98%). Although mark quality was not randomly distributed, we did not find evidence that scores were related to the tagging year. The percentage of “good” quality OTC marks in 2006 (~ 32%) was higher than in 2004 and 2005; however, the mark quality evaluator in 2006, although experienced, was different than the person who evaluated OTC marks in 2004 and 2005. Even with established criteria for assessing mark quality, qualitative evaluations are always more subjective than quantitative measurements, and this may lead to variation in mark scoring among years when evaluators differ.

Our ability to detect the correct number of annuli after the successful OTC marks was influenced by mark quality, with 90% of “good” quality samples having the correct number of annuli identified. This was significantly higher than samples with “fair” (72%) or “poor” (64%) marks. As in 2005, correctly detecting the appropriate number of annuli was related to the tagging year, and we were significantly more likely to misidentify fish marked in 2004 or 2005 than in 2006. Rien and Beamesderfer (1994) saw a similar decline in the accuracy of OTC age interpretations as time at-large increased in white sturgeon. In contrast to the opercula marked in 2004 and 2005, our ability to detect the correct number of annuli in 2003 samples was almost as good as it was with samples marked in 2006. This was an unexpected result, especially since only 17% of the 2003 samples had good quality OTC marks. The sample size for opercula marked in 2003 was relatively small (n = 18), so random variation in correctly identified annuli might explain the unusually high success rate for that year’s samples. Though we do not intend to mark any additional northern pikeminnow with OTC, we will continue our evaluation of marks currently at-large to see if this result was an isolated incident.

Opercula may provide a more accurate representation of the true age in certain fish species than scales (Donald et al. 1992), and aging precision can be as good, or better, than that for scales (Baker and McComish 1998). In addition, several European and North American researchers have found annuli easier to identify on opercula (Le Cren 1947; Frost and Kipling 1959; Campbell and Babaluk 1979; Donald et al. 1992). Our findings suggest that opercula have good potential to be used for aging northern pikeminnow in the Columbia River; however, our attempts to validate ages derived from opercula have met with mixed results. We have been able to mark northern pikeminnow opercula with OTC, but it has proven difficult to consistently get good quality marks. Because our ability to correctly identify annuli distal to the OTC mark is dependent on the quality of the mark, we have only had moderate success. Our comparisons of scale ages to ages obtained from opercula have consistently shown that we may be underestimating northern pikeminnow ages based on scales. Also, when we incorrectly identified annuli on OTC-marked opercula, we usually underestimated the number of annuli. Our tendency to underestimate age, even with opercula, could lead us to overestimate growth and natural mortality rates (Leaman and Nagtegaal 1987; Casey and Natanson 1992; Rien and Beamesderfer 1994), and may impact our northern pikeminnow exploitation rate estimates. We will continue to utilize both structures in our aging analysis while working to modify procedures to increase accuracy and precision. Until we can improve the precision and accuracy of ages assigned to northern pikeminnow, we should be cautious about any age related interpretations we make.

Biological Evaluation

Reductions in the northern pikeminnow population may improve outmigrating salmonid survival if an equal compensatory response by the remaining northern pikeminnow or other predators does not minimize the benefits (Beamesderfer et al. 1996; Friesen and Ward 1999). An increase in the abundance, population size structure, condition factor, or consumption and predation indices of remaining predators might indicate such a response (Knutsen and Ward 1999). Sustained exploitation should decrease the proportion of large (older) fish to small (younger) fish (Zimmerman et al. 1995), and smaller northern pikeminnow consume fewer salmonids than their larger counterparts (Vigg et al. 1991).

Northern pikeminnow stock density and year class strength have been relatively stable in The Dalles Reservoir with no apparent trends over time. On the other hand, relative weight of northern pikeminnow in The Dalles Reservoir has increased in the past decade. Northern pikeminnow abundance in The Dalles Reservoir has decreased since the mid-1990s; improved condition in remaining northern pikeminnow could be a sign of a density dependent response to exploitation. Sass et al. (2004) found that body condition of walleyes within individual lakes in northern Wisconsin was density dependent. However, Reesman et al. (2006) suggested that density independent factors such as prey availability could also affect condition. It may be noteworthy that the annual passage index for juvenile salmonids at John Day Dam has also increased in the last ten years (FPC 2007).

In John Day Reservoir, we have not had sufficient data to estimate stock density for northern pikeminnow since 1999, and although relative weight data show a slight increase since 1996, sample sizes in 1999, 2004, and 2006 were small. However, pooled age composition data for northern pikeminnow in John Day Reservoir appear to indicate that the population may be getting younger. Between 1990 and 1996, most of the population was comprised of fish older than age 5, but since 1996, the largest segment of the population has been in the age 3-5 group. Within this group, the dominant age class has also shifted from age 5 to age 3. Furthermore, abundance of northern pikeminnow in John Day Reservoir has declined since 1996. These changes would suggest that the removal fishery might be having the desired effect; however, exploitation rates in John Day Reservoir have been relatively low since the early 1990s (Figure 2). Therefore, some other factor(s) may be affecting the age structure and abundance of northern pikeminnow in John Day Reservoir.

Increased northern pikeminnow consumption and predation indices might also be signs of compensation by remaining northern pikeminnow to prolonged exploitation by the NPMP (Zimmerman and Ward 1999). In 2006, we collected very few northern pikeminnow in The Dalles and John Day reservoirs (*n* = 62), and 66% of the northern pikeminnow collected had empty stomachs. However, all of the identifiable fish remains in northern pikeminnow stomachs from both reservoirs were juvenile salmonids. Although northern pikeminnow consumption indices remained relatively consistent with previous years, the localized increase observed in the tailrace of John Day Dam may be a compensatory response. Reesman et al. (2006) attributed increased consumption indices in the tailraces of Bonneville and The Dalles dams to the discontinuation of dam angling in 2003. Dam angling, while contributing less to exploitation, harvested localized concentrations of northern pikeminnow that may have aggregated to feed on juvenile salmonids (Beamesderfer and Rieman 1991; Poe et al. 1991; Collis et al. 1995). In addition, the dam-angling fishery was able to harvest northern pikeminnow in boat restricted zones below dams that are inaccessible to sport-reward anglers (Takata and Ward 2001). Dam angling was reinitiated at Bonneville and The Dalles dams in 2006, and will continue in 2007 at The Dalles and John Day dams. Effort was shifted from Bonneville to John Day Dam in 2007 because of sampling difficulties at Bonneville; there are no plans to expand the fishery to other dams. In 2006, predation indices were variable but showed an overall decline in predation from previous years. However, we could not calculate northern pikeminnow predation indices in several areas due to insufficient sample sizes.

The efficacy of the NPMP also depends, in part, on the lack of response by other piscivores in the Columbia Basin to the sustained removal of northern pikeminnow (Ward and Zimmerman 1999). Smallmouth bass in The Dalles and John Day reservoirs have increased in abundance since sampling began in 1990. Jones et al. (2005) observed a particularly large increase in the forebay area of John Day Reservoir in 2004. These increases coincided with a decline in northern pikeminnow abundance during the same time. Smallmouth bass PSD in The Dalles Reservoir indicates that the population there appears to be balanced (Anderson and Weithman 1978). However, in John Day Reservoir, PSD values for smallmouth bass have usually been below 30%, potentially a sign of an unstable population experiencing higher than optimal recruitment to the stock (Anderson and Weithman 1978). Similar to northern pikeminnow, smallmouth bass relative weights in The Dalles and John Day reservoirs have increased in the past decade. However, because smallmouth bass have become more abundant during this time, improved body condition may be due to some density independent factor such as prey availability. In the past, juvenile salmonids have composed small but consistent portions of smallmouth bass diets in the Columbia River (Poe et al. 1991; Zimmerman 1999; Naughton et al. 2004). This was true again in 2006; however, the fish primarily consumed by smallmouth bass were *Cottus* spp. Smallmouth bass consumption indices in the lower Columbia River have remained relatively stable, and predation was minimal, except in the John Day mid-reservoir, which continued to show high rates of predation. Ward and Zimmerman (1999) suggested the first evidence of any response by smallmouth bass would likely be a change in diet; therefore, smallmouth bass should continue to be monitored.

The abundance of walleye in The Dalles and John Day reservoirs is low compared to other predators such as northern pikeminnow and smallmouth bass, but has increased in the McNary Dam tailrace in recent years. While walleye PSD in The Dalles Reservoir continues to be relatively high, PSD in John Day Reservoir has decreased in the past several years, approaching the 30-60% range indicative of a balanced population (Anderson and Weithman 1978). This may be due to improved recruitment of stock-size fish in recent years. Relative weights for walleye have ranged from 79 to 94 in the two reservoirs, slightly on the low end of the range considered to be "ideal" for walleye (SDGFP 2007; TWRA 2007). Nevertheless, walleye W_r values have been relatively stable compared to northern pikeminnow and smallmouth bass. The age distribution of walleye system-wide also appears to be stable. In The Dalles and John Day reservoirs, we found *Oncorhynchus* spp. most often in walleye digestive tracts. Poe et al. (1991), Vigg et al. (1991), and Zimmerman (1999) found juvenile salmonids to be an important component of lower Columbia River walleye diets. Although walleye abundance in the lower Columbia River is generally low, some areas such as the McNary Dam tailrace have relatively high concentrations of walleye. Therefore, the impact of walleye predation on salmonid populations likely varies from area to area, and further monitoring of walleye population parameters and diets would be prudent.

Previous evaluations of the NPMP have not detected responses by the predator community to the sustained removal of northern pikeminnow (Ward et al. 1995; Ward and Zimmerman 1999; Zimmerman and Ward 1999). In 2006, we found some indications of possible localized responses to the removal program such as increased northern pikeminnow condition in The Dalles Reservoir, increased consumption indices for northern pikeminnow in The Dalles Reservoir tailrace, and high predation indices for smallmouth bass in the mid-reservoir area of John Day Reservoir. However, whether these changes occurred due to reductions in the northern pikeminnow population or increases in the number of migrating smolts, or a combination of factors, is difficult to determine. Density dependent compensatory responses by fish populations can be hard to identify (Rose et al. 2001), and a system-wide response difficult to ascertain. Additionally, observable responses to fishery management programs have been known to lag by more than 15 years from project inception (Hilborn and Winton 1993; Beamesderfer et al. 1996). It is possible that, although we are seeing potential localized responses, not enough time has elapsed for a system-wide response to be detected. Therefore, it is critical to continue monitoring to properly assess the impact of the NPMP.

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Appendix A

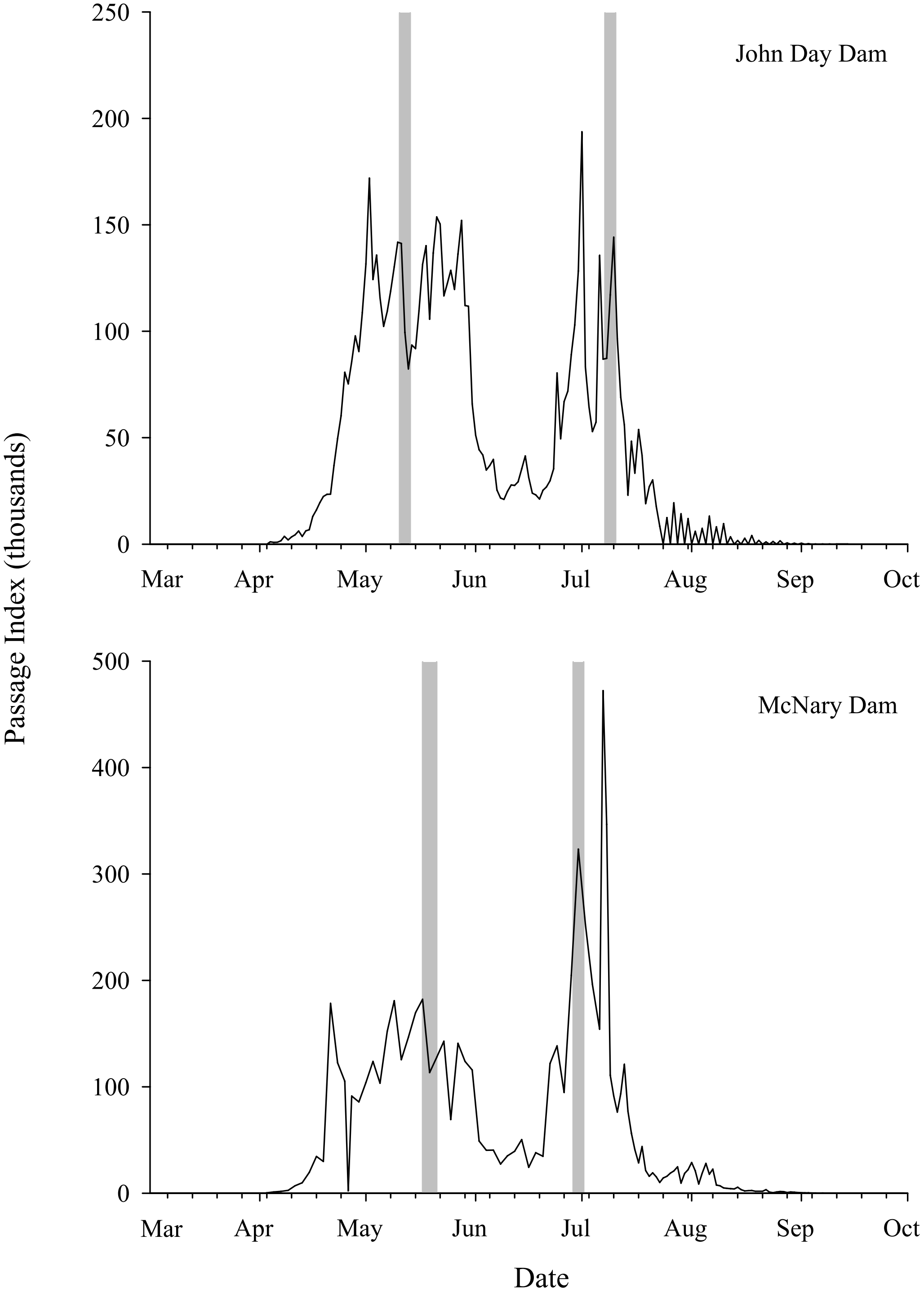
Sampling Effort and Timing in the Lower Columbia and Snake Rivers

APPENDIX TABLE A-1.—Dates of 2006 sampling weeks.

Sampling Week	Dates
13	20 March - 26 March
14	27 March - 2 April
15	3 April - 9 April
16	10 April - 16 April
17	17 April - 23 April
18	24 April - 30 April
19	1 May - 7 May
20	8 May - 14 May
21	15 May - 21 May
22	22 May - 28 May
23	29 May - 4 June
24	5 June - 11 June
25	12 June - 18 June
26	19 June - 25 June
27	26 June - 2 July
28	3 July - 9 July
29	10 July - 16 July
30	17 July - 23 July
31	24 July - 30 July
32	31 July - 6 August
33	7 August - 13 August
34	14 August - 20 August
35	21 August - 27 August
36	28 August - 3 September
37	4 September - 10 September
38	11 September - 17 September
39	18 September - 24 September
40	25 September - 1 October
41	2 October - 8 October
42	9 October - 15 October

APPENDIX TABLE A-2. —Sampling effort (number of 15-minute electrofishing runs) for biological indexing in the lower Columbia and Snake rivers, 1990-1996, 1999, and 2004-2006. rkm = river kilometer and "–" = area not sampled.

Reservoir/area, reach	Effort										
	1990	1991	1992	1993	1994	1995	1996	1999	2004	2005	2006
Below Bonneville Dam											
rkm 114-121	–	–	68	–	36	45	43	44	22	48	–
rkm 172-178	–	–	65	–	33	36	35	47	31	48	–
rkm 190-197	–	–	64	–	43	40	40	40	32	48	–
Tailrace	39	–	60	25	35	24	31	29	55	82	–
Bonneville											
Forebay	47	–	–	35	97	79	80	62	35	101	–
Mid-reservoir	52	–	–	28	84	45	57	57	35	58	–
Tailrace	52	–	–	31	68	80	69	71	43	74	–
The Dalles											
Forebay	62	–	–	31	92	62	59	–	–	–	78
Mid-reservoir	–	–	–	–	–	–	–	–	–	–	95
Tailrace	56	–	–	26	48	35	31	71	5	–	74
John Day											
Forebay	56	61	68	44	91	75	75	52	28	–	75
Mid-reservoir	61	58	62	43	43	94	94	–	15	–	80
Tailrace	55	59	64	46	74	80	80	62	51	–	76
Lower Monumental											
Tailrace	–	56	–	–	44	46	32	14	30	–	–
Little Goose											
Tailrace	–	57	–	–	39	40	37	29	30	–	–
Lower Granite											
rkm 222-228	–	55	–	–	85	89	89	75	34	–	–



APPENDIX FIGURE A-1.—Timing of index sampling in 2006 with respect to juvenile salmonid passage (all species) at John Day and McNary dams. Shaded areas indicate dates of sampling in the vicinity of each dam. The passage index is the number of fish passing the dam, adjusted for river flow.

Appendix B

Exploitation Rates for Northern Pikeminnow

APPENDIX TABLE B-1.—Number of northern pikeminnow tagged and recaptured in the sport-reward fishery during 2006.

Area or reservoir	≥ 200 mm FL		200 - 249 mm FL		≥ 250 mm FL	
	Tagged	Recaptured	Tagged	Recaptured	Tagged	Recaptured
Below Bonneville Dam	467	64[a]	80	7	387	57[a]
Bonneville	501	49[a]	229	14	272	35[a]
The Dalles	48	10[a]	5	0	43	10[a]
John Day	41	0	18	0	23	0
McNary	106	8	6	0	100	8
Little Goose	125	22[a]	88	13	37	9[a]
Lower Granite	42	2	23	0	19	2
All areas	1,330	155	449	34	881	121

[a] Includes fish recaptured in a different area or reservoir than originally tagged and not included in area or reservoir-specific exploitation rate calculations.

APPENDIX TABLE B-2.—Exploitation rates (%) of northern pikeminnow ≥ 200 mm FL for the sport-reward fishery, 2001 – 2006. Exploitation rates were not corrected for tag loss in 2001 and 2002. X = no exploitation rate calculated (*n* < 4) and "–" = area not sampled.

Area or reservoir	2001	2002	2003	2004	2005	2006
Below Bonneville Dam	15.9	10.8	11.8	18.8	21.6	14.6
Bonneville	8.6	5.0	11.0	11.7	8.0	10.5
The Dalles	X	X	X	X	14.9	22.4
John Day	X	X	X	X	X	X
McNary	26.0	7.6	6.6	X	9.6	10.7
Little Goose	–	–	–	–	–	20.0
Lower Granite	9.4	11.6	X	19.6	X	X
All areas	15.5	10.6	10.5	17.0	16.3	14.6

APPENDIX TABLE B-3.—Exploitation rates (%) of northern pikeminnow 200 - 249 mm FL for the sport-reward fishery, 2001 – 2006. Exploitation rates were not corrected for tag loss in 2001 and 2002. X = no exploitation rate calculated (*n* < 4) and "–" = area not sampled.

Area or reservoir	2001	2002	2003	2004	2005	2006
Below Bonneville Dam	X	3.1	X	X	X	9.6
Bonneville	X	X	X	X	X	6.7
The Dalles	X	X	X	X	X	X
John Day	X	X	X	X	X	X
McNary	X	X	X	X	X	X
Little Goose	–	–	–	–	–	17.4
Lower Granite	X	X	X	X	X	X
All areas	10.6	3.4	X	10.9	X	9.9

APPENDIX TABLE B-4.—Exploitation rates (%) of northern pikeminnow ≥ 250 mm FL for the sport-reward fishery, 2001 – 2006. Exploitation rates were not corrected for tag loss in 2001 and 2002. X = no exploitation rate calculated (*n* < 4) and "–" = area not sampled.

Area or reservoir	2001	2002	2003	2004	2005	2006
Below Bonneville Dam	16.2	12.6	13.6	20.1	23.1	15.6
Bonneville	8.5	6.0	16.7	9.3	8.2	13.7
The Dalles	X	X	X	X	18.0	25.3
John Day	X	X	X	X	X	X
McNary	26.0	7.7	8.2	X	13.0	11.2
Little Goose	–	–	–	–	–	26.3
Lower Granite	X	14.3	X	23.8	X	X
All areas	16.2	12.3	13.0	18.5	19.0	17.1

APPENDIX TABLE B-5.—System-wide weekly exploitation rates of northern pikeminnow ≥ 200 mm FL for the sport-reward fishery in 2006. Dashes indicate either no tagging effort, no recapture effort, or no exploitation calculated.

Sampling Week	Tagged	Recaptured	At-Large	Exploitation[a] (%)
12	–	–	--	–
13	1	–	--	–
14	–	–	1	–
15	36	–	1	–
16	121	–	37	–
17	363	–	158	–
18	447	–	521	–
19	55	6	968	0.7
20	11	2	1017	0.2
21	23	7	1026	0.8
22	5	4	1042	0.4
23	30	2	1043	0.2
24	131	13	1071	1.3
25	36	14	1189	1.3
26	71	15	1210[b]	1.4
27	–	16	1265[b]	1.4
28	–	10	1248[b]	0.9
29	–	5	1237[b]	0.4
30	–	6	1232	0.5
31	–	5	1226	0.4
32	–	0	1221	0.0
33	–	5	1221	0.5
34	–	9	1216	0.8
35	–	5	1207	0.5
36	–	2	1202	0.2
37	–	8	1200	0.7
38	–	5	1192	0.5
39	–	5	1187	0.5
40	–	5	1182	0.5
41	–	3	1177	0.3
42	–	3	1174	0.3
Total	1330	155	1171	14.6

[a] Exploitation rates adjusted for tag loss (9.9%).

[b] Additional fish subtracted from at-large pool due to removal by other fisheries.

APPENDIX TABLE B-6.—The Dalles Reservoir weekly exploitation rates of northern pikeminnow ≥ 200 mm FL for the sport-reward fishery in 2006. Dashes indicate either no tagging effort, no recapture effort, or no exploitation calculated.

Sampling Week	Tagged	Recaptured	At-Large	Exploitation[a] (%)
12	–	–	–	–
13	–	–	–	–
14	–	–	0	–
15	–	–	0	–
16	–	–	0	–
17	–	–	0	–
18	–	–	0	–
19	48	0	0	0.0
20	–	0	48	0.0
21	–	1	48	2.3
22	–	0	47	0.0
23	–	0	47	0.0
24	–	0	47	0.0
25	–	2	47	4.7
26	–	2	45	4.9
27	–	2	43	5.1
28	–	0	41	0.0
29	–	1	40	2.7
30	–	0	39	0.0
31	–	1	39	2.7
32	–	0	39	0.0
33	–	0	39	0.0
34	–	0	39	0.0
35	–	0	39	0.0
36	–	0	39	0.0
37	–	0	39	0.0
38	–	0	39	0.0
39	–	0	39	0.0
40	–	0	39	0.0
41	–	0	39	0.0
42	–	0	39	0.0
Total	48	9	39	22.4

[a] Exploitation rates adjusted for tag loss (9.9%).

APPENDIX TABLE B-7.—John Day Reservoir weekly exploitation rates of northern pikeminnow ≥ 200 mm FL for the sport-reward fishery in 2006. Dashes indicate either no tagging effort, no recapture effort, or no exploitation calculated.

Sampling Week	Tagged	Recaptured	At-Large	Exploitation[a] (%)
12	–	–	0	–
13	–	–	0	–
14	–	–	0	–
15	–	–	0	–
16	–	–	0	–
17	–	–	0	–
18	–	–	0	–
19	7	–	0	0.0
20	11	–	7	0.0
21	23	0	18	0.0
22	–	0	41	0.0
23	–	0	41	0.0
24	–	0	41	0.0
25	–	0	41	0.0
26	–	0	40[b]	0.0
27	–	0	40	0.0
28	–	0	40	0.0
29	–	0	40	0.0
30	–	0	40	0.0
31	–	0	40	0.0
32	–	0	40	0.0
33	–	0	40	0.0
34	–	0	40	0.0
35	–	0	40	0.0
36	–	0	40	0.0
37	–	0	40	0.0
38	–	0	40	0.0
39	–	0	40	0.0
Total	41	0	40	0.0

[a] Exploitation rates adjusted for tag loss (9.9%).

[b] Additional fish subtracted from at-large pool due to removal by other fisheries.

APPENDIX TABLE B-8.—McNary Reservoir weekly exploitation rates of northern pikeminnow ≥ 200 mm FL for the sport-reward fishery in 2006. Dashes indicate either no tagging effort, no recapture effort, or no exploitation calculated.

Sampling Week	Tagged	Recaptured	At-Large	Exploitation[a] (%)
12	–	–	0	–
13	–	–	0	–
14	–	–	0	–
15	–	–	0	–
16	–	–	0	–
17	–	–	0	–
18	–	–	0	–
19	–	–	0	–
20	–	–	0	–
21	–	0	0	0.0
22	5	0	0	0.0
23	30	0	5	0.0
24	–	1	35	3.1
25	–	0	34	0.0
26	71	0	34	0.0
27	–	1	105	1.0
28	–	1	104	1.1
29	–	0	103	0.0
30	–	0	103	0.0
31	–	1	103	1.1
32	–	0	102	0.0
33	–	2	102	2.2
34	–	0	100	0.0
35	–	0	100	0.0
36	–	0	100	0.0
37	–	1	100	1.1
38	–	0	99	0.0
39	–	0	99	0.0
40	–	1	99	1.1
41	–	0	98	0.0
42	–	0	98	0.0
Total	106	8	98	10.7

[a] Exploitation rates adjusted for tag loss (9.9%).

APPENDIX TABLE B-9.—Little Goose Reservoir weekly exploitation rates of northern pikeminnow ≥ 200 mm FL for the sport-reward fishery in 2006. Dashes indicate either no tagging effort, no recapture effort, or no exploitation calculated.

Sampling Week	Tagged	Recaptured	At-Large	Exploitation[a] (%)
12	–	–	0	–
13	–	–	0	–
14	–	–	0	–
15	–	–	0	–
16	–	–	0	–
17	–	–	0	–
18	–	–	0	–
19	–	–	0	–
20	–	–	0	–
21	–	0	0	0.0
22	–	0	0	0.0
23	–	0	0	0.0
24	125	2	123	1.8
25	–	0	123	0.0
26	–	0	123	0.0
27	–	0	123	0.0
28	–	3	123	2.7
29	–	1	120	0.9
30	–	2	119	1.8
31	–	2	117	1.9
32	–	0	115	0.0
33	–	0	115	0.0
34	–	3	115	2.9
35	–	0	112	0.0
36	–	1	112	1.0
37	–	3	111	3.0
38	–	1	108	1.0
39	–	0	107	0.0
40	–	1	107	1.0
41	–	0	106	0.0
42	–	2	106	2.1
Total	125	21	104	20.0

[a] Exploitation rates adjusted for tag loss (9.9%).

APPENDIX TABLE B-10.—Lower Granite Reservoir weekly exploitation rates of northern pikeminnow ≥ 200 mm FL for the sport-reward fishery in 2006. Dashes indicate either no tagging effort, no recapture effort, or no exploitation calculated.

Sampling Week	Tagged	Recaptured	At-Large	Exploitation[a] (%)
12	–	–		–
13	–	–		–
14	–	–	0	–
15	–	–	0	–
16	–	–	0	–
17	–	–	0	–
18	–	–	0	–
19	–	0	0	0.0
20	–	0	0	0.0
21	–	0	0	0.0
22	–	0	0	0.0
23	–	0	0	0.0
24	6	0	0	0.0
25	36	0	6	0.0
26	–	0	42	0.0
27	–	0	42	0.0
28	–	0	42	0.0
29	–	0	42	0.0
30	–	1	42	2.6
31	–	0	41	0.0
32	–	0	41	0.0
33	–	0	41	0.0
34	–	0	41	0.0
35	–	1	41	2.7
36	–	0	40	0.0
37	–	0	40	0.0
38	–	0	40	0.0
39	–	0	40	0.0
40	–	0	40	0.0
41	–	0	40	0.0
42	–	0	40	0.0
Total	42	2	40	5.3

[a] Exploitation rates adjusted for tag loss (9.9%).

Appendix C

Biological Evaluation of Northern Pikeminnow, Smallmouth Bass, and Walleye in the Lower Columbia and Snake Rivers, 1990 – 2006

APPENDIX TABLE C-1.—Catch per 15-minute electrofishing run (CPUE) of northern pikeminnow ≥ 250 mm fork length captured during biological indexing of the lower Columbia River in 1990-1996, 1999, 2004, and 2006. "–" = area not sampled.

	The Dalles Reservoir			John Day Reservoir		
	Forebay	Mid-reservoir	Tailrace	Forebay	Mid-reservoir	Tailrace
1990	1.1	0.6	2.8	0.7	0.3	0.8
1991	–	–	–	0.7	0.2	0.8
1992	–	–	–	1.3	0.3	0.1
1993	1.2	0.5	0.7	0.6	0.2	0.5
1994	0.6	–	0.7	0.7	0.1	0.3
1995	0.6	–	1.6	0.3	0.1	0.3
1996	0.4	–	3.7	0.3	0.1	0.5
1999	–	–	0.8	0.2	–	0.2
2004	–	–	0.4	<0.1	0.0	0.1
2006	0.2	0.2	0.2	<0.1	<0.1	0.1

APPENDIX TABLE C-2.—Spring and summer catch per 15-minute electrofishing run (CPUE) of northern pikeminnow ≥ 250 mm FL captured in 2006 during biological indexing in the lower Columbia River.

Area, reach	CPUE	
	Spring	Summer
The Dalles		
Forebay	0.3	0.1
Mid-reservoir	0.3	0.0
Tailrace	0.1	0.3
John Day		
Forebay	0.1	0.0
Mid-reservoir	0.1	0.0
Tailrace	0.2	0.1

APPENDIX TABLE C-3.—Spring and summer catch per 15-minute electrofishing run (CPUE) of smallmouth bass ≥ 200 mm FL captured in 2006 during biological indexing in the lower Columbia River.

Area, reach	CPUE	
	Spring	Summer
The Dalles		
Forebay	4.9	3.0
Mid-reservoir	5.2	3.0
Tailrace	2.5	4.6
John Day		
Forebay	2.8	2.9
Mid-reservoir	6.1	6.8
Tailrace	1.6	2.5

APPENDIX TABLE C-4.—Spring and summer catch per 15-minute electrofishing run (CPUE) of walleye ≥ 200 mm FL captured in 2006 during biological indexing in the lower Columbia River.

Area, reach	CPUE	
	Spring	Summer
The Dalles		
Forebay	0.1	0.0
Mid-reservoir	0.1	<0.1
Tailrace	0.5	0.2
John Day		
Forebay	0.0	0.0
Mid-reservoir	0.0	0.1
Tailrace	2.0	1.1

Appendix Table C-5.—Abundance index values for northern pikeminnow $\geq$ 250 mm fork length in the lower Columbia River, 1990-1996, 1999, 2004, and 2006. ”–” = not sampled.

	The Dalles Reservoir			John Day Reservoir		
	Forebay	Mid-reservoir	Tailrace	Forebay	Mid-reservoir	Tailrace
1990	1.4	2.4	2.7	1.4	5.1	1.4
1991	–	–	–	1.3	4.7	1.4
1992	–	–	–	2.4	6.7	0.2
1993	1.6	2.0	0.7	1.2	3.1	0.9
1994	0.7	–	0.6	1.4	2.4	0.5
1995	0.5	–	1.5	0.5	1.0	0.6
1996	0.6	–	3.6	0.6	1.1	1.0
1999	–	–	0.8	0.3	–	0.4
2004	–	–	0.4	0.1	0.0	0.3
2006	0.2	0.7	0.2	<0.1	0.5	0.2

Appendix Table C-6.—Spring relative density of smallmouth bass $\geq$ 200 mm fork length in the lower Columbia River, 1990-1996, 1999, 2004, and 2006. “–” = not sampled. Relative density is mean transformed catch ($\log_{10}$(catch+1)) per 15-minute electrofishing run.

	The Dalles Reservoir			John Day Reservoir		
	Forebay	Mid-reservoir	Tailrace	Forebay	Mid-reservoir	Tailrace
1990	0.2	–	0.2	0.5	0.5	<0.1
1991	–	–	–	0.3	0.6	0.1
1992	–	–	–	0.4	0.2	0.2
1993	0.5	0.6	0.4	–	–	–
1994	0.3	–	–	0.3	0.3	0.1
1995	0.6	–	–	0.4	0.4	0.1
1996	0.5	–	–	0.3	0.5	<0.1
1999	–	–	0.2	0.1	--	<0.1
2004	–	–	0.0	1.0	0.5	<0.1
2006	0.7	0.7	0.4	0.5	0.8	0.3

APPENDIX TABLE C-7.—Summer relative density of smallmouth bass ≥ 200 mm fork length in the lower Columbia River, 1990-1996, 1999, 2004, and 2006. "–" = not sampled. Relative density is mean transformed catch ($\log_{10}$ (catch+1)) per 15-minute electrofishing run.

	The Dalles Reservoir			John Day Reservoir		
	Forebay	Mid-reservoir	Tailrace	Forebay	Mid-reservoir	Tailrace
1990	0.1	0.1	0.1	0.4	0.2	0.1
1991	–	–	–	0.3	0.1	0.1
1992	–	–	–	0.3	0.3	0.1
1993	0.3	0.4	0.3	0.4	0.4	0.3
1994	0.3	–	0.2	0.5	0.2	0.1
1995	0.4	–	0.1	0.4	0.6	0.1
1996	0.2	–	0.2	0.3	0.4	0.1
1999	–	–	0.4	0.4	–	0.1
2004	–	–	0.0	0.9	–	0.3
2006	0.5	0.5	0.6	0.4	0.8	0.4

APPENDIX TABLE C-8.—Spring relative density of walleye ≥ 200 mm fork length in the lower Columbia River, 1990-1996, 1999, 2004, and 2006. "–" = not sampled. Relative density is mean transformed catch ($\log_{10}$ (catch+1)) per 15-minute electrofishing run.

	The Dalles Reservoir			John Day Reservoir		
	Forebay	Mid-reservoir	Tailrace	Forebay	Mid-reservoir	Tailrace
1990	0.0	–	0.1	0.0	0.0	0.1
1991	–	–	–	0.0	<0.1	0.1
1992	–	–	–	0.0	0.0	<0.1
1993	0.1	0.1	0.2	–	–	–
1994	0.0	–	–	0.0	0.0	0.2
1995	<0.1	–	–	<0.1	0.0	0.1
1996	<0.1	–	–	0.0	0.0	0.2
1999	–	–	0.1	0.0	–	0.1
2004	–	–	0.0	0.0	<0.1	0.2
2006	<0.1	<0.1	0.1	0.0	0.0	0.3

APPENDIX TABLE C-9.—Summer relative density of walleye ≥ 200 mm fork length in the lower Columbia River, 1990-1996, 1999, 2004, and 2006. "–" = not sampled. Relative density is mean transformed catch ($\log_{10}$ (catch+1)) per 15-minute electrofishing run.

	The Dalles Reservoir			John Day Reservoir		
	Forebay	Mid-reservoir	Tailrace	Forebay	Mid-reservoir	Tailrace
1990	0.0	0.0	<0.1	0.0	0.0	<0.1
1991	–	–	–	0.0	0.0	0.0
1992	–	–	–	0.0	0.0	<0.1
1993	0.0	<0.1	<0.1	0.0	0.0	<0.1
1994	<0.1	–	<0.1	0.0	0.0	0.1
1995	<0.1	–	<0.1	0.0	<0.1	0.1
1996	<0.1	–	0.1	0.0	<0.1	0.1
1999	–	–	0.1	0.0	–	0.1
2004	–	–	<0.1	<0.1	–	0.2
2006	0.0	<0.1	<0.1	0.0	<0.1	0.2

APPENDIX TABLE C-10.—Number (*N*) of northern pikeminnow, smallmouth bass, and walleye digestive tracts examined from the lower Columbia River in 2006, and percent that contained food, fish, and *Oncorhynchus* spp. (Sal).

	Northern pikeminnow				Smallmouth bass				Walleye			
		Percent				Percent				Percent		
Season, area	*N*	Food	Fish	Sal	*N*	Food	Fish	Sal	*N*	Food	Fish	Sal
Spring												
The Dalles Reservoir	28	39	11	7	509	79	14	<1	26	65	35	15
John Day Reservoir	5	40	20	20	379	87	11	1	73	64	49	29
All areas	33	39	12	9	888	82	13	1	99	65	47	25
Summer												
The Dalles Reservoir	19	21	16	16	448	86	13	1	7	43	29	0
John Day Reservoir	10	30	20	20	504	86	15	2	46	57	52	22
All areas	29	24	17	17	952	86	14	1	53	55	49	19

APPENDIX TABLE C-11.—Percent species composition of fish consumed by northern pikeminnow, smallmouth bass, and walleye in the lower Columbia River, 2006. TDA = The Dalles Reservoir, JDY = John Day Reservoir, and *n* = number of samples containing identifiable fish.

	Northern pikeminnow		Smallmouth bass		Walleye	
Genus, species	TDA (*n*=5)	JDY (*n*=3)	TDA (*n*=97)	JDY (*n*=80)	TDA (*n*=8)	JDY (*n*=46)
Oncorhynchus spp.	100.0	100.0	5.4	13.6	63.6	70.8
Prosopium williamsoni	0.0	0.0	0.0	3.4	0.0	3.1
Cottus spp.	0.0	0.0	81.3	68.2	0.0	20.0
Lampetra spp.	0.0	0.0	0.9	1.1	0.0	3.1
Mylocheilus caurinus	0.0	0.0	1.8	1.1	9.1	1.5
Ptylocheilus oregonensis	0.0	0.0	0.0	0.0	9.1	0.0
Catostomus spp.	0.0	0.0	1.8	2.3	18.2	1.5
*Ictaluridae**	0.0	0.0	1.8	2.3	0.0	0.0
Micropterus spp.	0.0	0.0	4.5	5.7	0.0	0.0
Perca flavescens	0.0	0.0	2.7	2.3	0.0	0.0

* Both *Ameiurus spp.* and *Ictalurus spp.* may be included in this category

APPENDIX TABLE C-12.—Spring consumption indices for northern pikeminnow ≥ 250 mm fork length in the lower Columbia River in 1990-1996, 1999, 2004, and 2006. FB = Forebay, M = Mid-Reservoir, TR = Tailrace, TR BRZ = Tailrace Boat Restricted Zone, X = no consumption index calculated ($n \leq 5$), a = no northern pikeminnow collected, and "–" = area not sampled.

	The Dalles Reservoir				John Day Reservoir			
	FB	M	TR	TR BRZ	FB	M	TR	TR BRZ
1990	0.8	–	0.7	0.9	1.5	0.0	1.5	2.5
1991	–	–	–	–	1.9	0.5	0.9	1.5
1992	–	–	–	–	1.9	0.0	0.0	0.9
1993	0.1	–	0.0	X	1.5	X	2.0	–
1994	0.1	–	--	–	1.0	X	0.3	0.7
1995	0.0	–	--	–	1.7	X	0.8	–
1996	0.0	–	--	–	X	X	0.5	–
1999	–	–	0.5	–	1.2	–	1.7	–
2004	–	–	X	–	a	a	0.0	–
2006	0.0	0.5	X	–	X	X	0.3	–

APPENDIX TABLE C-13.—Summer consumption indices for northern pikeminnow ≥ 250 mm fork length in the lower Columbia River in 1990-1996, 1999, 2004, and 2006. FB = Forebay, M = Mid-Reservoir, TR = Tailrace, TR BRZ = Tailrace Boat Restricted Zone, X = no consumption index calculated (*n* ≤ 5), a = no northern pikeminnow collected, and "–" = area not sampled.

	The Dalles Reservoir				John Day Reservoir			
	FB	M	TR	TR BRZ	FB	M	TR	TR BRZ
1990	1.0	–	0.0	6.4	2.4	0.9	2.6	11.7
1991	–	–	–	–	3.1	X	0.0	2.8
1992	–	–	–	–	0.7	0.0	X	4.6
1993	0.0	–	0.0	0.5	0.6	0.6	0.0	0.6
1994	0.0	–	0.8	1.2	1.2	0.6	X	1.9
1995	0.0	–	0.0	2.2	2.0	X	0.6	–
1996	0.0	–	0.7	X	0.4	X	0.3	–
1999	–	–	0.0	--	X	–	0.0	–
2004	–	–	5.5	a	X	–	X	–
2006	X	X	5.7	–	a	a	X	–

APPENDIX TABLE C-14.—Spring consumption indices for smallmouth bass ≥ 200 mm fork length in the lower Columbia River in 1990-1996, 1999, 2004, and 2006. FB = Forebay, M = Mid-Reservoir, TR = Tailrace, X = no consumption index calculated (*n* ≤ 5), a = no smallmouth bass collected, and "–" = area not sampled.

	The Dalles Reservoir			John Day Reservoir		
	FB	M	TR	FB	M	TR
1990	a	a	a	0.1	0.0	a
1991	a	a	a	0.0	0.0	X
1992	a	a	a	0.1	0.0	X
1993	a	a	a	0.0	0.0	X
1994	a	a	a	0.1	0.0	0.0
1995	a	a	a	0.0	0.0	0.0
1996	a	a	a	0.0	0.0	0.0
1999	a	a	a	0.1	–	X
2004	a	a	a	0.1	0.0	a
2006	0.0	<0.1	0.0	0.0	<0.1	<0.1

APPENDIX TABLE C-15.—Summer consumption indices for smallmouth bass ≥ 200 mm fork length in the lower Columbia River in 1990-1996, 1999, 2004, and 2006. FB = Forebay, M = Mid-Reservoir, TR = Tailrace, X = no consumption index calculated (*n* ≤ 5), a = no smallmouth bass collected, and "–" = area not sampled.

	The Dalles Reservoir			John Day Reservoir		
	FB	M	TR	FB	M	TR
1990	a	a	a	0.3	0.3	0.0
1991	a	a	a	0.5	0.0	0.1
1992	a	a	a	0.2	X	0.0
1993	a	a	a	0.7	0.1	0.0
1994	a	a	a	0.2	0.0	0.0
1995	a	a	a	0.3	0.0	0.0
1996	a	a	a	0.1	0.0	0.0
1999	a	a	a	0.2	–	0.0
2004	a	a	a	<0.1	–	0.2
2006	0.0	<0.1	<0.1	0.1	<0.1	<0.1

APPENDIX TABLE C-16.—Spring predation indices for northern pikeminnow ≥ 250 mm fork length in The Dalles and John Day reservoirs, 1990-1996, 1999, 2004, and 2006. "–" = not sampled, a = no northern pikeminnow collected, and X = no predation index calculated (*n* ≤ 5).

	The Dalles Reservoir			John Day Reservoir		
	Forebay	Mid-reservoir	Tailrace	Forebay	Mid-reservoir	Tailrace
1990	1.1	–	1.9	2.1	0.0	2.2
1991	–	–	–	2.5	2.4	1.3
1992	–	–	–	4.7	0.0	0.0
1993	0.2	–	0.0	1.9	X	1.8
1994	0.1	–	–	1.3	X	0.2
1995	0.0	–	–	0.9	X	0.5
1996	0.0	–	–	X	X	0.3
1999	–	–	0.4	0.4	–	0.7
2004	–	–	X	a	a	0.0
2006	0.0	0.4	X	X	X	0.1

APPENDIX TABLE C-17.—Summer predation indices for northern pikeminnow ≥ 250 mm fork length in The Dalles and John Day reservoirs, 1990-1996, 1999, 2004, and 2006. "–" = area not sampled, a = no northern pikeminnow collected, and X = no predation index calculated (*n* ≤ 5).

	The Dalles Reservoir			John Day Reservoir		
	Forebay	Mid-reservoir	Tailrace	Forebay	Mid-reservoir	Tailrace
1990	1.4	–	0.0	3.4	4.6	3.7
1991	–	–	–	4.0	X	0.0
1992	–	–	–	1.7	0.0	X
1993	0.0	–	0.0	0.7	1.9	0.4
1994	0.0	–	0.5	1.6	1.4	X
1995	0.0	–	0.0	1.0	X	0.4
1996	0.0	–	2.5	0.2	X	0.2
1999	–	–	0.0	X	–	0.0
2004	–	–	2.0	X	–	X
2006	X	X	1.1	a	a	X

APPENDIX TABLE C-18.—Spring and summer predation indices for smallmouth bass ≥ 200 mm fork length in The Dalles and John Day reservoirs, 2004 and 2006. "–" = area not sampled.

	Predation index			
	Spring		Summer	
Area, reach	2004	2006	2004	2006
The Dalles				
Forebay	–	0.0	–	0.0
Mid-reservoir	–	0.3	–	0.4
Tailrace	0.0	0.0	2.0	0.1
John Day				
Forebay	1.6	0.0	0.8	0.4
Mid-reservoir	2.3	1.1	0.0	2.8
Tailrace	0.0	0.1	0.5	0.2

APPENDIX TABLE C-19.—Spring and summer predation indices for northern pikeminnow ≥ 250 mm fork length and smallmouth bass ≥ 200 mm fork length in The Dalles and John Day reservoirs, 2006. X = no predation index calculated (*n* ≤ 5) and a = no northern pikeminnow collected.

	Predation index			
	Northern pikeminnow		Smallmouth bass	
Area, reach	Spring	Summer	Spring	Summer
The Dalles				
Forebay	0.0	X	0.0	0.0
Mid-reservoir	0.4	X	0.3	0.4
Tailrace	X	1.1	0.0	0.1
John Day				
Forebay	X	a	0.0	0.4
Mid-reservoir	X	a	1.1	2.8
Tailrace	0.1	X	0.1	0.2