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Assessing Fish Biomass and Prey Availability in Ohio Reservoirs

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Abstract.—In Ohio reservoirs, a perceived excess of available gizzard shad *Dorosoma cepedianum* prey and poor recruitment of stocked walleyes *Sander vitreus* during the 1970s resulted in research to develop and expand a program to stock saugeyes (walleye × sauger *S. canadensis*), a hybrid better suited for shallow, productive, and turbid reservoirs with short water-residence times. Development of successful production techniques increased saugeye stocking from fewer than 1.2 million to 6–10 million fingerlings (28–42 mm) per year during 1980 through 1990, presenting the challenge of determining stocking rates suited to available prey. To improve *Sander* spp. stocking practices, we assessed prey supply by quantifying fish biomass in Ohio reservoirs using acoustic technology. Fish biomass varied from 10 to 897 kg/ha as estimated by 53 acoustic surveys conducted on 16 reservoirs during 1999–2006. Among 15 variables associated with reservoir productivity, 84% of the variability in fish biomass was explained by watershed area, trophic state, reservoir area, and reservoir volume; watershed area plus trophic state explained 77% of this variability. Dominance of fish prey smaller than 150 mm, which represented more than 80% of fishes sampled in acoustic surveys, revealed that reservoir fish biomass largely reflected the upper limit of prey fish biomass morphologically available to age-1 and older *Sander* spp. Gizzard shad represented more than 50% of the fishes captured in 92% of gill-netting surveys conducted in conjunction with

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acoustic surveys. Unexpectedly, reservoirs with extensive prey biomass occasionally had poor recruitment for *Sander* spp., and these reservoirs often were stocked at lower rates than ones with better recruitment. Fisheries managers in Ohio can improve stocking practices by using acoustic surveys to predict reservoir capacity for stocked sport fish based on reservoir attributes, then applying these results to details of reservoir-specific recruitment of stocked fishes and their consumptive demand. Refining this supply and demand approach will require continual progress in understanding reservoir ecosystems and their watersheds.

Introduction

Gizzard shad *Dorosoma cepedianum* is often the most abundant fish in shallow, fertile reservoirs of the Midwest and southeastern United States. As the primary prey of piscivores, their availability can be constrained by their abundance, spatial distribution within a reservoir, and population size structure (Noble 1981; Ney 1990). Quantifying whole-reservoir fish biomass, partitioning it into available prey consisting of gizzard shad and other fishes, and relating it to predator demand has been pursued by fisheries managers since the 1960s. Early assessments of predator–prey balance in reservoirs suggested that nearly 50% of 23 southeastern reservoirs sampled for prey biomass were deficient in prey (Jenkins and Morais 1978), largely due to rapid growth of gizzard shad. By understanding the potential of reservoirs to produce prey, fisheries managers can improve stocking practices. In this manuscript, we estimated fish biomass in Ohio reservoirs using acoustic surveys with the goal of better informing sport fish stocking practices to match available prey biomass.

In Ohio, gizzard shad exist in nearly all reservoirs throughout the state. In these typically shallow, fertile reservoirs, only a dense population of largemouth bass *Micropterus salmoides* (33 kg/ha) can account for complete consumption of a conservative estimate of annual gizzard shad production (118 kg/ha/year), a scenario that was unlikely to persist (Carline et al. 1984). Similarly, a multiple predator complex (largemouth bass, two *Sander* spp., and three *Esox* spp.) consumed only 20% of age-0 gizzard shad production in fertile Kokosing Lake, Ohio (Johnson et al. 1988a). Base on these results, the Ohio Department of Natural Resources (ODNR) increased predator stocking during the 1980s in an attempt to expand sportfishing opportunities by capitalizing on a perceived surplus of prey.

Expanding predator stocking in Ohio reservoirs required a re-evaluation of historical walleyes *S. vitreus* fisheries. Popular among anglers, walleyes rarely reproduce in Ohio reservoirs. Stocking was primarily successful in large impoundments with clean gravel shoals and gradual water-level changes, but these conditions were uncommon in a region dominated by flood-control reservoirs (Erickson and Stevenson 1972). Comparisons of walleyes with saugeyes (walleye × sauger *S. canadense*) revealed that saugeyes would be more successful in reservoirs with short water-retention times (Johnson et al. 1988b), and efforts began to expand saugeye stocking. A nearly 10-year commitment to fish production research resolved problems associated with rearing adequate numbers of fingerling saugeyes (Culver et al. 1993), and in 1990, saugeye stocking increased dramatically from fewer than 1.2 million to 6–10 million fingerlings (28–42 mm) per year (Figure 1A). From this point onward, more Ohio reservoirs were stocked with saugeyes than walleyes (Figure 1 B) and fishing opportunities for *Sander* spp. were expanded. At present, about 9%

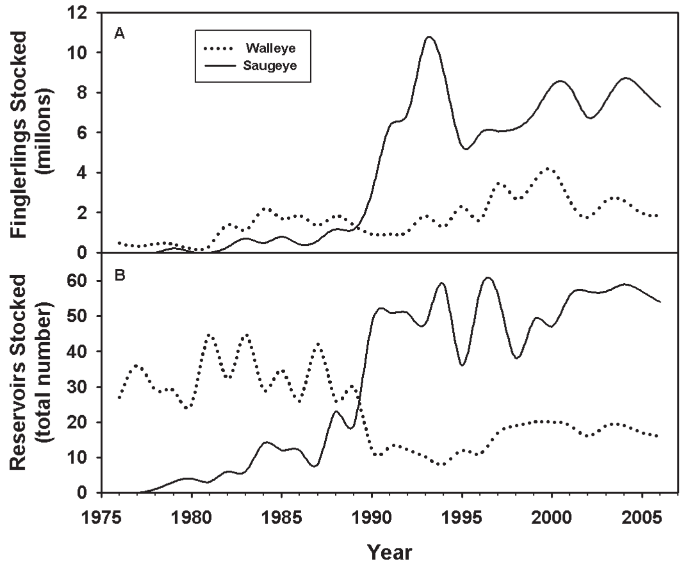

Figure 1. Number of fingerling walleyes and saugeyes stocked in Ohio reservoirs (upper panel) and number of Ohio reservoirs stocked with walleyes and saugeyes (lower panel), 1976–2006.

of fishing trips made to Ohio reservoirs target stocked walleyes or saugeyes compared to 23% for black bass *Micropterus* spp., 14% for crappie Pomoxis spp., and 8% for bluegill *Lepomis macrochirus* and other *Lepomis* spp. that are not stocked (Ohio Department of Natural Resources, unpublished data). In addition, in some reservoirs, from 20% to 25% of all trips target saugeyes (Ohio Department of Natural Resources, unpublished data). Recent creel surveys reveal that saugeye catch rates routinely ranged from 0.2 to 1.3 fish/h and compare favorably with black bass *Micropterus* spp. catch rates, which average 0.44 fish/h (top reservoirs ranged from 0.6 to 1.4 fish/h) (Ohio Department of Natural Resources, unpublished data).

With increased availability of saugeyes, the challenge emerged of determining where stocking these fish would be most beneficial and at what rates. Saugeye fingerlings are stocked in reservoirs of varying productivity at rates of 20–200 fingerlings/ha. Within these reservoirs, naturally reproducing predators include black bass, crappies, white bass *Morone chrysops*, and channel catfish *Ictalurus punctatus*; other stocked predators can include walleyes, muskellunge *Esox masquinongy*, and hybrid striped bass (white bass × striped bass *M. saxatilis*). Central to this challenge was identifying reservoirs with the potential for good survival of stocked saugeyes and determining stocking rates that fully capitalize on available prey. Clearly, this equation demands quantification of reservoir fish biomass.

In reservoirs dominated by gizzard shad, we also must determine the proportion of gizzard shad available as prey. As prey, gizzard shad provide the primary food for piscivores, and even though their importance may vary seasonally (Horton and Gilliland 1992; Sieber Denlinger et al. 2006; Aman 2007), availability of age-0 gizzard shad strongly influences piscivore growth and success (Stahl and Stein 1994; Donovan et al. 1997; Michaletz 1998a, 1998b). As planktivores, gizzard shad exploit zooplankton resources

(Dettmers and Stein 1992; Garvey and Stein 1998) with potential consequences for sport fish recruitment through an intermediate role in reservoir food webs (Stein et al. 1995). As detritivores, gizzard shad persist during periods of limited zooplankton availability by relying on reservoir sediments (Jackson et al. 1992; Yako et al. 1996) through which they may contribute significantly to reservoir productivity by excreting sediment-derived nutrients (Schaus et al. 2002; Vanni et al. 2006). Because these complex roles of gizzard shad affect the potential of reservoirs as sport fisheries, meaningful estimates of biomass for gizzard shad and other fishes available as prey allows us to align stocking strategies with prey resources and better understand reservoir ecosystems.

Estimating reservoir fish biomass has become less daunting due to dramatic improvements in, and reduced costs of, acoustic survey technology. Acoustic surveys provide precise and cost-effective estimates of fishes relative to other sampling gear (Van Den Avyle et al. 1995; Vondracek and Degan 1995; Brandt 1996). Starting in 1999, we used acoustic surveys to assess fish biomass in reservoirs with the goals of better understanding the availability of prey fish to stocked predators and the role of gizzard shad in reservoir ecosystems. Lacking the ability to conduct acoustic surveys on all reservoirs, we apply results from a subset of reservoirs to watershed and limnological information to glean insights into the potential of Ohio reservoirs to produce fish biomass. In this manuscript we seek to (1) quantify reservoir fish biomass and relate these estimates to watershed characteristics to better understand fish biomass potential of Ohio reservoirs; (2) interpret prey fish biomass, a subset of fish biomass available to stocked saugeyes and walleyes; and (3) identify challenges of improving saugeye and walleye stocking strategies by quantifying prey availability. Through assessment of fish biomass and prey fish availability, we hope to develop *Sander* spp. stocking strategies that match reservoir prey production.

Study Areas

Ohio reservoirs are small, shallow, and fertile and thus are exceptionally well suited for gizzard shad. Only 18% of Ohio reservoirs ≥ 20 ha exceeded 400 ha, mean depth ranged from 2 to 10 m, (Renwick and Andereck 2005), and 76% were either eutrophic or hypereutrophic (Davic et al. 1996). Land use of Ohio reservoir watersheds was primarily agricultural (64%, tributary reservoir mean). Sedimentation rates ranged from 50 to 500 m^3/km^2/year, typical for the Midwestern United States. (Renwick and Andereck 2006).

Our study sites were 16 tributary reservoirs ranging from 159 to 1,348 ha that spanned a productivity gradient from mesotrophic to hypereutrophic (Table 1; Renwick and Andereck 2005). They were located throughout Ohio, except the northwest where tributary reservoirs are uncommon due to topography, and representative of Ohio reservoirs ≥ 40 ha based on surface area and watershed area (Figure 2). Mean depths ranged from 1.9 to 9.2 m, maximum depths ranged from 3.8 to 36.3 m, and littoral areas (shoreline areas ≤ 2 m deep) contributed from 9% to 44% of surface area. Watershed land use was primarily agriculture for all reservoirs with less in forest, residential, or wetland uses, except Burr Oak, Tappan, and West Branch, which had mostly forested watersheds. Fish populations varied but typically included centrarchids, percids, ictalurids, esocids, *Morone* spp., cyprinids, and catastomids; however, all had substantial populations of gizzard shad (Ohio Department of Natural Resources, unpublished data). Gizzard shad represented 94% of the

Table 1. Attributes of Ohio reservoirs where fish abundance, size, and biomass were assessed during 1999–2006 (Renwick and Andereck 2005).

Reservoir	Area (ha)	Volume (1,000 × m^3)	Mean depth (m)	Maximum depth (m)	Littoral area (% ≤ 2 m)	Watershed area (km^2)	Flushing rate (per year)	Watershed land use (%)		
								Agriculture	Forest	Other
Acton	240	9,280	3.4	9.5	23	270	8.7	90	9	1
Alum Creek	1,348	95,725	6.6	19.3	17	327	1.0	71	24	5
Berlin	1,266	55,414	4.4	18.2	29	642	3.5	58	29	13
Burr Oak	277	9,934	4.1	10.7	32	86	2.6	11	89	4
C.J. Brown	797	37,921	5.1	12.1	21	236	1.9	86	9	5
Caesar Creek	1,133	117,749	9.2	36.3	11	616	1.6	88	9	3
Deer Creek	526	23,182	4.4	12.0	16	720	9.3	92	7	3
Delaware	480	11,768	2.9	10.0	44	1,012	25.8	82	14	4
Dillon	511	13,015	3.3	9.7	42	1,633	37.7	60	36	4
Hoover	1,140	77,478	5.7	20.9	9	495	1.9	72	24	4
Kiser	159	3,035	1.9	3.8	40	23	2.2	73	20	8
O'Shaughnessy	363	16,498	3.8	15.1	22	2,539	46.2	86	11	3
Piedmont	958	36,192	4.0	9.8	29	221	1.8	38	53	9
Pleasant Hill	317	12,449	4.4	12.1	24	516	12.4	52	44	4
Tappan	908	34,931	3.6	8.5	24	185	1.6	26	68	7
West Branch	1,059					208		40	46	14

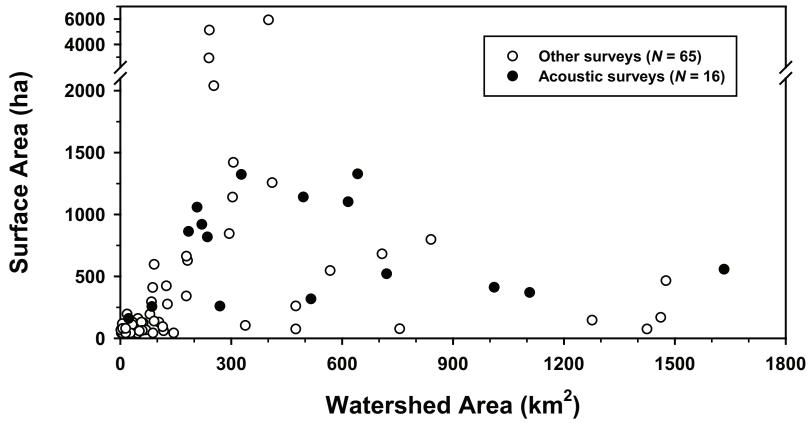

Figure 2. Reservoir surface area plotted against watershed area for 16 study reservoirs and 65 additional tributary reservoirs in Ohio ≥ 40 ha where fisheries surveys have been conducted.

fish sampled during electrofishing surveys at meostrophic Burr Oak, eutrophic Pleasant Hill, and hypereutrophic Acton reservoirs in areas ≥ 1.5 m deep during 1998–2001 (Vanni et al. 2006). Fingerling saugeyes were annually stocked in all study reservoirs except Berlin and C.J. Brown (where walleyes were stocked); West Branch (where walleyes naturally reproduced); and Kiser, Burr Oak, and Dillon (where saugeye stockings were discontinued in 1991, 2005, and 2006, respectively).

Methods

Acoustic Surveys

Mobile acoustic surveys were conducted during 1999–2006 to estimate fish abundance, size, and biomass. We assumed that our limnetic surveys characterized fish populations, gizzard shad were the most abundant fish species, and mean acoustic backscattering cross section (σ_{bs}) adequately provided mean size (length and weight) of these fish. Each year, 3–10 reservoirs were surveyed during late July, August, or early September, when most reservoirs were thermally stratified. Three reservoirs spanning a productivity gradient, Acton, Burr Oak, and Pleasant Hill, were surveyed every year to provide insight into interannual variation. All surveys began 0.5 h after sunset along a fixed cruise track and used a programmed Global Positioning System for navigation of zig-zag or parallel transects at speeds of 8–9 km/h. We used BioSonics DT-4000, DT-6000, or DT-X echosounders and 200-kHz splitbeam, 6-degree transducers. Subsurface data were collected with a transducer deployed 0.5 m below the surface aimed vertically, and data from the surface to 2 m deep were collected with a transducer deployed 1 m below the surface and aimed parallel to the surface. Echo-integration parameters were set to process vertical data from 2 m below the surface to 0.25 m above the bottom and to process horizontal data 1–20 m from the transducer. Surveys conducted during 1999–2001 required two complete cruises of each reservoir each evening, one to collect horizontal data and the other to collect vertical data; after 2001, multiplexing allowed horizontal and vertical data to be collected simultaneously. Equipment was routinely calibrated to U.S. Navy standards by BioSonics, Inc., Seattle. Before each survey, field calibration was conducted by use of a tungsten carbide reference sphere (Foote and MacLennan 1984). We sampled at 4–10 pings/s, thresholds of −60, −65, or −70-decibels (dB), pulse width of 0.2 ms, start range of 1 m, and a stop range that varied 5–25 m depending upon the reservoir sampled and the transducer position (vertical or horizontal).

Abundance, size, and biomass were estimated through target strength (TS) analysis and echo integration. We used Echoview software, versions 3.0, 3.1, 3.2, and 3.25 (SonarData, Inc., Hobart, Tasmania, Australia) to analyze all data. Vertical data were processed with 1-m strata from 2 m below the surface to near bottom and horizontal data were processed with a single range stratum. Vertical and horizontal data were manually edited to remove bottom signals or noise. We generated single fish targets that met the following criteria: a −60-dB threshold, a pulse length of 0.4–2.0 times the transmitted pulse length at −6 dB within 4 dB of the center of the transducer beam, and a standard deviation of the angles (minor and major axis) of all samples within the pulse envelope of less than 0.6. Echo integration provided total reflected voltages that were converted to absolute areal abundance through scaling voltages by σ_{bs}, conducted separately for vertical and horizontal data (Simmonds and MacLennan 2005). Fish target lengths were derived by converting TS to fish length (millimeters) via Love's dorsal aspect equation (Love 1971), then converting fish length to weight (g) using a length–weight equation for gizzard shad in Ohio reservoirs ($\log_e[\text{weight}] = 2.7875 \times \log_e[\text{length}] - 10.546$).

Length–frequency distributions were developed by estimating fish length (millimeters) from individual TS results from vertical data. These data were transformed to fish length (millimeters) via Love's dorsal aspect equation (Love 1971). This approach provides an approximation of length–frequency distributions but not an appropriate mean length for scaling echo integration. Because TS is a log10 transformation of σ_{bs}, a mean length derived from TS will underestimate mean length compared to that derived from mean σ_{bs} converted to TS, then converted to fish length (Jim Dawson, BioSonics, Inc.), as demonstrated by Ohio data from 69 acoustic surveys conducted during 1999–2006 (Figure 3). Relations between mean fish length derived from mean σ_{bs} and those derived from mean TS indicate that a mean σ_{bs}-derived length of 150 mm is equivalent to a mean TS-derived length of 115 mm. Based on these relations and prey-consumption literature from Ohio reservoirs (Johnson et al. 1988b; Sieber Denlinger et al. 2006), we used these results to consider all individual targets less than 115 mm to be available prey to age-1 and older saugeyes.

Areal abundance and biomass of fish were obtained for 250-m transects within each cruise track. Random sampling of transects stratified by upper and lower reservoir sections provided final estimates of mean and standard error of fish abundance and biomass in each reservoir.

Gill Netting

To identify species that may be acoustic survey targets and estimate lengths of all fish in sample populations and those of gizzard shad, gill-net surveys were conducted concurrently with each acoustic survey during 2004–2006. Six 44-m-long, 7-panel experimental nets with 10-, 13-, 16-, 19-, 25-, 32-, and 38-mm mesh of either 1.8 or 3.7 m depth were fished the evening of each acoustic survey. Two nets were set floating from the surface in upper, middle, and lower portions of the reservoir, one nearshore and one offshore. Nearshore nets generally covered the water column from the surface to near-bottom and offshore nets often sampled from the surface to the thermocline and below. We assumed that most fish occur in the epilim-

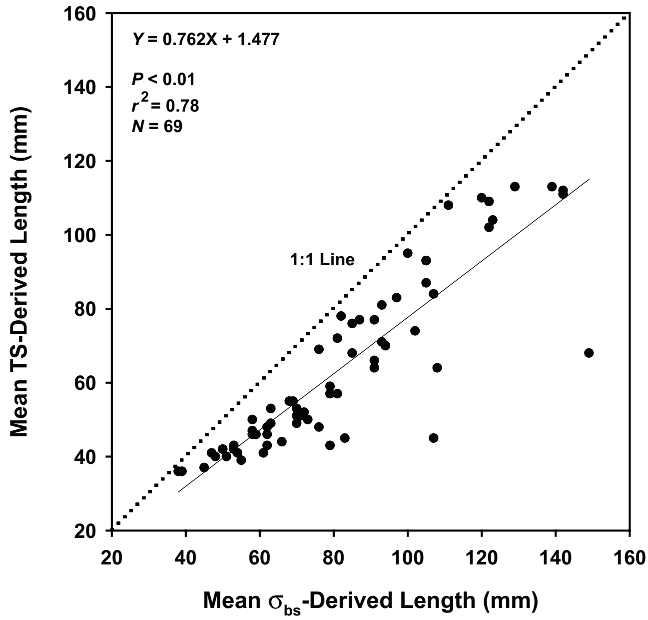

Figure 3. Acoustic estimates of mean fish length determined from the mean of acoustic backscattering cross section (σ_{bs}) converted to target strength (TS) plotted against fish length determined from mean of TS. Results were used to estimate an individual TS equivalent to a mean σ_{bs}-derived length.

nion because these reservoirs have anoxic hypolimnia. Nets were set 2 h before sunset and fished for 1.5–2.5 h. All fish were identified and measured to the nearest millimeter (total length).

Watershed and Lower Trophic Data

Watershed and lower trophic level data provided insights into reservoir potential for fish production. Watershed size and landuse data for Ohio reservoirs were obtained from Renwick and Andereck (2005), who completed a recent survey of reservoir attributes and watershed characteristics of public reservoirs in Ohio ≥ 10 ha. Based on these data, hydraulic flushing rate (hererafter flushing rate), the average number of times per year reservoir volume is completely exchanged, was calculated using the formula: F_T = (300,000 × watershed area)/reservoir volume, where watershed area is squared kilometers, reservoir volume is in cubed meters, and 300,000 is based on an approximate statewide average rate of runoff of 0.3 m/year (U.S. Geological Survey 1997). Measures of total phosphorus and chlorophyll *a* were obtained from recently published historical data (Knoll et al. 2003; Vanni et al. 2005, 2006). Results presented herein were means from water samples collected monthly from the photic zone near the reservoir outflow (dam) during May through October. Reservoir trophic level status was described with the Carlson Trohpic State Index (TSI), calculated with the equation TSI = 14.42 LN(TP) + 4.15 (Carlson 1977), where we used mean annual total phosphorus (μg TP/L) across survey years. Reservoirs with TSI values less than 38 were considered oligotrophic, whereas those 38–47 were mesotrophic, those 48–66 were eutrophic, and those greater than 66 were hypereutrophic.

Analyses

To better understand differences in fish biomass potential among reservoirs, and annual variation in fish biomass, we explored relations between mean fish biomass and reservoir attributes. Relations between reservoir attributes and fish biomass and abundance were evaluated for 15 variables. Reservoir attributes included TSI, reservoir area, volume, mean depth, maximum depth, percent of surface area ≤ 2 m (i.e., littoral area), shoreline length/reservoir area, watershed area, reservoir area/watershed area, volume/watershed area, flushing rate, sedimentation rate, and the percentage of watershed in agriculture, forest, or other uses. A subset of attributes most strongly related to fish biomass, where alpha ≤ 0.15, were considered in a model selection procedure to seek the best suite of independent variables to describe fish biomass. The explanatory power of various models and their relative rank were determined using Akaike's Information Criteria (AIC) and model weight, w_i, a measure of relative importance of each model i within a set of candidate models, calculated as

$$w_i = \frac{\exp(-\frac{1}{2}\Delta \mathrm{AIC}_i)}{\sum_{r=1}^{R}\exp(-\frac{1}{2}\Delta \mathrm{AIC}_r)},$$

where R is the total number of models within the acceptable model set (Burnham and Anderson 1998).

Available Prey

Size of fishes collected in gill nets, and particularly the size of gizzard shad, in conjunction with acoustic survey results could provide insight regarding the availability of prey fish biomass. Gizzard shad larger than 150 mm are rarely consumed by age-1 and older predators in Ohio reservoirs, but fish less than this size should be readily available in these compact and homogenous habitats during periods of peak consumptive demand (Johnson et al. 1988b; Sieber Denlinger et al. 2006). Therefore, the mean size of fishes determined from single target detection and the percent of small individual acoustic targets from each survey may reveal prey availability. The influence of prey availability, as a subset of fish biomass, on saugeye and walleye populations and fisheries was explored using historical data from the ODNR standardized sampling program (Sieber Denlinger 2007). We attempted to identify overall stocking success by considering mean fish biomass for a particular reservoir from all years, assuming that it reflected typical prey availability, rather than accessing annual variation in particular metrics in relation to fish biomass. Data included saugeye and walleye relative weight, mean length at age (ages 0–3), and recruitment (as an index: age-0 catch per effort/stocking rate × 100, obtained from standardized fall electrofishing surveys) collected during 1999–2006. In addition, we used creel surveys from 2004 to 2006 for estimates of directed angler catch per effort for *Sander* spp. and percent of angler trips made for these fish (i.e., percent seeking *Sander* spp.), and stocking records during 1999–2006. The importance of prey fish biomass on saugeye and walleye success was considered among these reservoirs, although a variety of factors may strongly influence stocking success.

Results

Reservoir-specific and survey-specific fish abundance, mean fish length, and fish biomass varied considerably among 16 Ohio reservoirs during 1999–2006. Among 53 surveys, fish abundance (fish/ha) ranged from 658 ± 130 (Burr Oak 2001) to 267,960 ± 32,527 (O'Shaughnessy 2002), mean fish length (mm) ranged from 38 (West Branch 2002) to 149 (Burr Oak 2004), and fish biomass (kg/ha) ranged from 10 ± 2 (West Branch 2002) to 897 ± 41 (Dillon 2005). As expected, estimates of fish abundance and biomass were influenced by reservoir and year (fish abundance: analysis of variance [ANOVA]: reservoir [$P < 0.01$, $F = 6.01$, df = 15, 52], year [$P < 0.01$, $F = 3.72$, df = 7, 52]) (fish biomass [ANOVA: reservoir {$P < 0.01$, $F = 5.37$, df = 15,52}, year [$P < 0.02$, $F = 3.06$, df = 7, 52]).

Among 16 reservoirs sampled across various years, mean fish biomass ranged from 10 to 717 kg/ha (Table 2). Fish biomass increased with flushing rate, watershed area, and TSI and decreased as the ratios of reservoir area to watershed area and reservoir volume to watershed area increased, indicating that the larger the watershed relative to the area or volume of a reservoir, the greater the fish biomass (Table 3; Figure 4). Two subsets of variables were used to explore variation in fish biomass with reservoir limnology, bathymetry, and watersheds. The first included watershed area, trophic state, reservoir area, reservoir volume, and mean depth, and the second included flushing rate, reservoir area, reservoir volume, and mean depth. Variables were divided into two groups, one that included trophic state and another that did not because we sought to determine if fish biomass could be sufficiently predicted in reservoirs where we lacked data to determine trophic state.

Watershed size and TSI were keys to understanding variation in fish biomass among reservoirs. Models including trophic state explained the greatest amount of variability (Table 4). Among them, the first-ranked model based on AIC_c included watershed area, TSI, reservoir area, and reservoir volume ($AIC_c = 137.26$, $\sigma^2 = 4{,}837$ $r^2 = 0.84$); the second-ranked model included water-

Table 2. Carlson Trophic State Index (TSI) and acoustic survey estimates of mean abundance (±SE), fish length (±SE), and biomass (±SE) estimated in 16 Ohio reservoirs, 1999–2006. Sample size (*N*) is reservoir years of data, and SE represents variation among years.

Reservoir	*N* (years)	Carlson TSI[a]	Abundance (fish/ha)	Mean fish length (mm)	Biomass (kg/ha)
Acton	8	71	83,826 ± 2,420	81 ± 8	315 ± 57
Alum Creek	1	47	15,385	62	41
Berlin	4	54	74,548 ± 2,045	58 ± 2	164 ± 30
Burr Oak	8	49	9,252 ± 309	105 ± 10	82 ± 30
C.J. Brown	1	57	43,917	51	66
Caesar Creek	1	60	3,900	105	44
Deer Creek	1	68	46,693	91	355
Delaware	5	69	58,603 ± 1,064	82 ± 6	317 ± 79
Dillon	2	86	141,099 ± 3,747	79 ± 0	717 ± 180
Hoover	2	59	91,341 ± 941	64 ± 6	253 ± 44
Kiser	4	74	40,060 ± 1,812	76 ± 10	129 ± 50
O'Shaughnessy	1	70	267,960	50	380
Piedmont	2	46	23,990 ± 1,100	62 ± 15	49 ± 5
Pleasant Hill	8	63	27,292 ± 550	88 ± 7	157 ± 21
Tappan	4	57	40,276 ± 932	75 ± 13	174 ± 64
West Branch	1	61[a]	15,209	38	10

[a] Calculated from Secchi transparency (Carlson 1977).

Table 3. Correlations of fish biomass and abundance with characteristics of reservoirs and watersheds in 16 Ohio reservoirs. Biomass and abundance are means of 1–8 years of surveys per reservoir that vary among reservoirs, 1999–2006. Results presented include *r*, *P*, and *N* = reservoir years.

	Fish biomass			Fish abundance		
Variable	*r*	*P*	*N*	*r*	*P*	*N*
Trophic State Index (TSI)—Figure 3A	0.80	<0.01	16	0.52	0.04	16
Area	−0.41	0.11	16	−0.28	0.29	16
Volume	−0.43	0.11	15	−0.29	0.30	15
Mean depth	−0.41	0.13	15	−0.30	0.28	15
Maximum depth	−0.27	0.34	15	−0.09	0.74	15
Littoral area (% ≤ 2 m)	0.34	0.22	15	0.07	0.81	15
Shore length/reservoir area	0.22	0.41	16	0.15	0.58	16
Watershed area—Figure 3B	0.83	<0.01	16	0.65	<0.01	16
Reservoir area/watershed area	−0.64	<0.01	16	−0.51	0.04	16
Reservoir volume/watershed area	−0.71	<0.01	15	−0.54	0.04	15
Hydraulic flushing rate—Figure 3C	0.78	<0.01	15	0.83	<0.01	15
Sedimentation rate	−0.37	0.21	13	−0.40	0.17	13
% watershed in agriculture	0.29	0.28	16	0.34	0.19	16
% watershed in forest	−0.11	0.69	16	−0.23	0.39	16
% watershed in other uses	−0.34	0.19	16	−0.34	0.19	16

shed area, TSI, reservoir area, reservoir volume, and mean depth (AIC_c = 138.22, σ^2 = 4,514 r^2 = 0.85). The third-ranked model included only watershed area and TSI (AIC_c= 139.26, σ^2 = 7,215 r^2 = 0.77); however, all seven top-ranked models explained at least 77% of variability in fish biomass. Model weights (w_i) supported use of the top two models, but not greatly compared to others. Models excluding TSI also were explored because TSI data are often unavailable. Among these, the first-ranked model included only flushing rate (AIC_c = 144.83, σ^2 = 11,951 r^2= 0.61), the second-ranked model included flushing rate and mean depth (AIC_c = 145.89, σ^2 = 11,227 r^2 = 0.64), and the third-ranked model included only flushing rate and volume (AIC_c = 146.39, σ^2 = 11,600 r^2= 0.62). Similar to models including trophic state, model weights did not strongly favor a particular model, and all top-ranked models explained at least 61% of the variability in fish biomass.

Annual estimates of fish biomass varied most at Acton, compared to Pleasant Hill or Burr Oak. Acton fish biomass was lowest during 1999 (74 ± 6 kg/ha) and greatest during 2004 (509 ± 28 kg/ha) and sometimes doubled or tripled from 1 year to the next. Pleasant Hill and Burr Oak varied from year to year but within smaller ranges (Figure 5). Acton exceeded 300 kg/ha 5 of 8 years, but Pleasant Hill never exceeded 300 kg/ha, ranging from 100 to 200 kg/ha during 6 of 8 years, and only during 2 of 8 years did Burr Oak exceed 100 kg/ha. Annual estimates of fish biomass among these reservoirs appeared out of phase with changes in total phosphorus and chlorophyll *a*, suggesting a lag in the relations among these variables.

Twenty-five gill-net surveys were conducted in habitats where acoustic data were collected to identify species that may be acoustic survey targets and estimate their

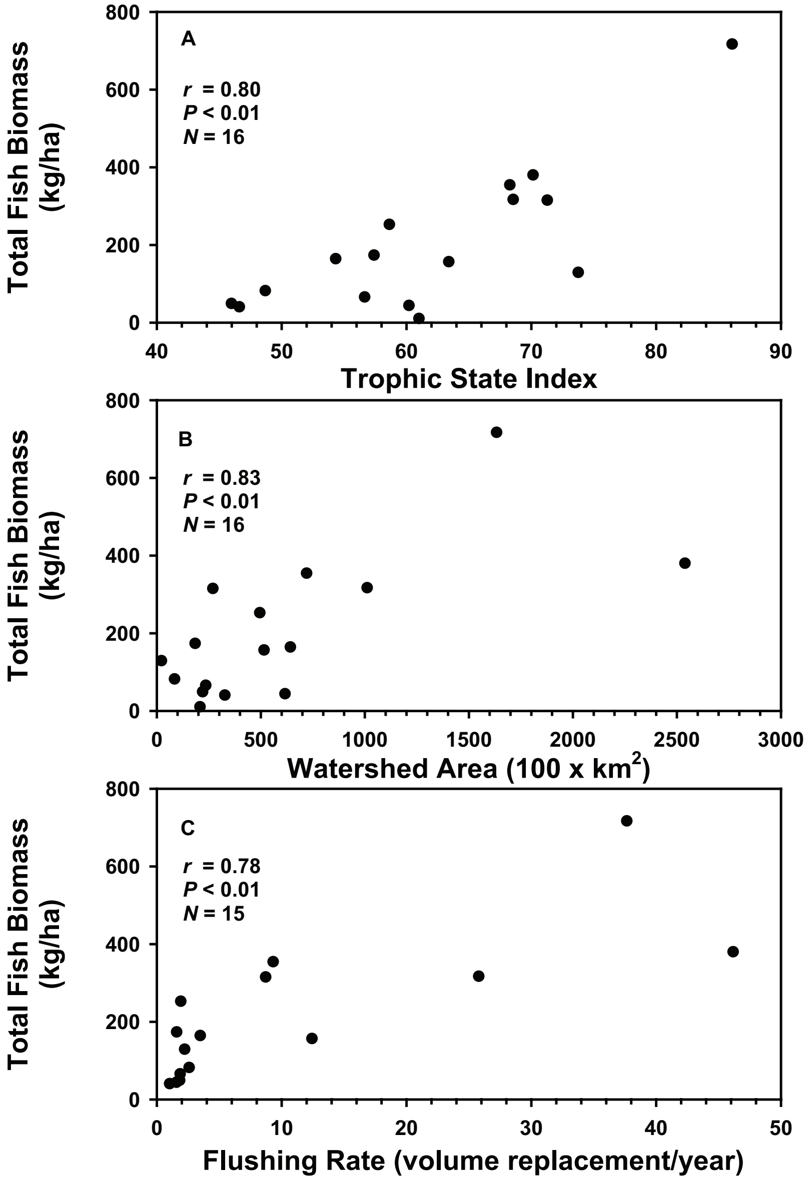

Figure 4. Correlations between acoustic estimates of fish biomass with trophic state index (panel A), watershed size (panel B), and hydraulic flushing rate (panel C) in 16 Ohio reservoirs surveyed during 1999–2006.

lengths for consideration with acoustic survey results. In addition to gizzard shad, 27 species or general fish groups were sampled. Gizzard shad contributed more than half of the catch in most surveys (mean = 67%, median = 63%, range = 36–94%) and in eight surveys exceeded 80% of the catch (Table 5). White crappie *Pomoxis annularis* (mean = 9%, median = 6%, range 0–40%), channel catfish *Ictalurus punctatus* (mean = 9%, median = 8%, range = 0–23%), and white bass *Morone chrysops* (mean = 5%, median = 2%,

Table 4. Ranking of models used to explain variation in mean fish biomass using reservoir characteristics in 16 Ohio reservoirs surveyed during 1999–2006. Variable suite 1 includes the independent variables watershed area (*W*), Carlson Trophic State Index (TSI), reservoir area (*A*), reservoir volume (*V*), and mean depth (MD). Variable suite 2 includes the independent variables hydraulic flushing rate (FR), reservoir area (*A*), reservoir volume (*V*), and mean depth (MD). Results include *K* (number of parameters), σ^2 (residual sum of squares/*N*), AIC_c (Akaike's Information Criteria score), Δ_i (difference between model AICc and minimum AIC_c), r^2 and w_i (model weight) as a measure of importance within the top-ranked models.

Independent variables	*K*	σ^2	AIC_c	Δ_i	r^2	w_i
Suite 1: *W*, TSI, *A*, *V*, MD						
W, TSI, *A*, *V*	4	4,837	137.26		0.84	0.34
W, TSI, *A*, *V*, MD	5	4,514	138.22	0.96	0.85	0.21
W, TSI	2	7,215	139.26	2.00	0.77	0.13
W, TSI, *A*, MD	4	5,779	139.93	2.67	0.81	0.09
TSI, *A*, *V*, MD	4	5,892	140.22	2.96	0.81	0.08
W, TSI, MD	3	6,799	140.37	3.11	0.78	0.07
TSI, *A*, *V*	3	6,805	140.38	3.12	0.78	0.07
Suite 2: FR, *A*, *V*, MD						
FR	1	11,951	144.83		0.61	0.32
FR, MD	2	11,227	145.89	1.06	0.64	0.19
FR, *V*	2	11,600	146.38	1.55	0.62	0.15
FR, *A*	2	11,904	146.77	1.94	0.61	0.12
FR, *A*, MD	3	11,080	147.69	2.86	0.64	0.08
FR, *V*, MD	3	11,081	147.69	2.86	0.64	0.08
FR, *A*, *V*	3	11,333	148.03	3.20	0.63	0.06

range = 0–26%) were the most common species after gizzard shad.

Gizzard shad smaller than 15 cm represented 62% of the gizzard shad catch from gill nets in all reservoirs. Mean lengths of age-0 shad from gill nets and mean lengths of fish from acoustic surveys were distributed around a 1:1 relation (Figure 6), although results were not correlated (r = 0.49, P = 0.05, N = 16). Gill-net catches also confirmed that that few gizzard shad were larger than 35 cm (0.03%), with the catch dominated by gizzard shad smaller than 15 cm (mean = 12.8 cm, median = 13.6 cm, N = 7,578). Nearshore and offshore size distributions of gill-net catches revealed minor differences in size structure among habitats (habitat data available from 22 of 25 surveys). Gizzard shad ≤ 15 cm represented 70% of offshore catches compared to 55% of nearshore catches (Figure 7).

Length distributions of fish from 25 acoustic surveys during 2004–2006 were consistently smaller than those from gill-netting surveys, with 92% of individual acoustic targets providing lengths that were less than 10 cm (mean = 5.1 cm, median = 3.6 cm, N = 171,133). During some years and in some reservoirs, such as Berlin in 2006, Delaware in 2004, and Kiser in 2004, a greater percentage of larger fish appeared in acoustic surveys, but the pattern of small fish dominating habitats surveyed by acoustics was generally consistent among reservoirs and years. Mean length of fish from each survey (used to scale echo integration)

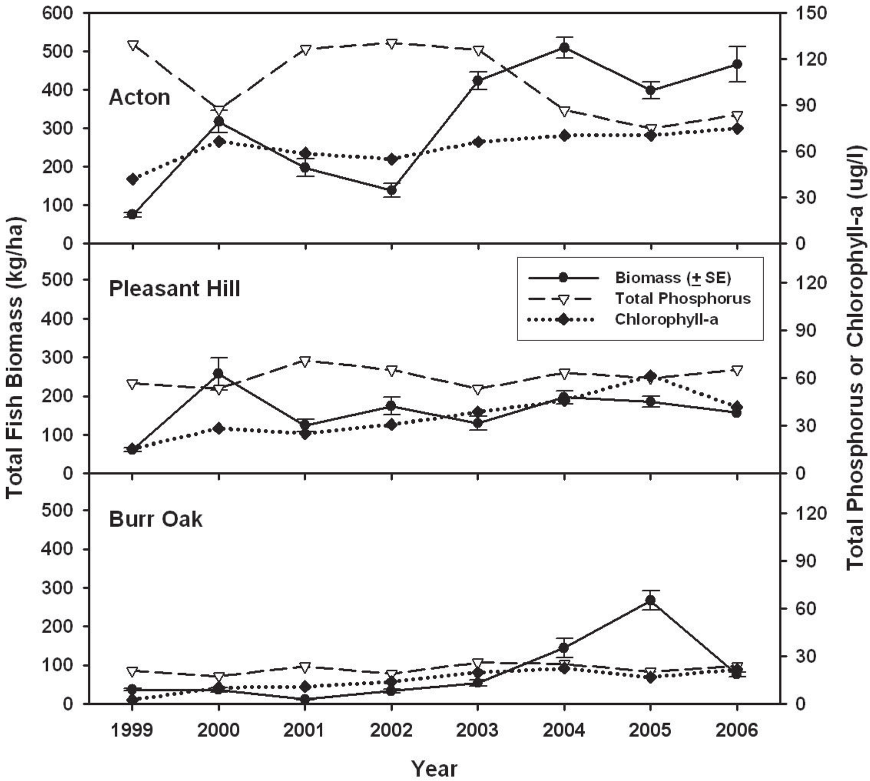

Figure 5. Annual estimates of reservoir fish biomass, total phosphorus, and chlorophyll *a* in Acton, Pleasant Hill, and Burr Oak reservoirs, Ohio, 1999–2006.

Table 5. Number of fish caught and percent of gizzard shad in 25 surveys using experimental gill nets (10-, 13-, 16-, 19-, 25-, 32-, 38-mm mesh) concurrent with acoustic surveys in 11 Ohio reservoirs, 2004–2006.

	Gizzard shad catch					
	2004		2005		2006	
Reservoir	*N*	%	*N*	%	*N*	%
Acton	1,127	90	1,046	84	366	57
Alum Creek					91	36
Berlin	70	69	157	74	177	56
Burr Oak	459	84	43	42	393	88
Deer Creek					297	59
Delaware	338	77	235	52	562	63
Dillon			514	88	474	81
Hoover			451	42	448	57
Kiser	602	82				
Pleasant Hill	636	94	535	56	160	52
Tappan	294	57	454	69	223	59

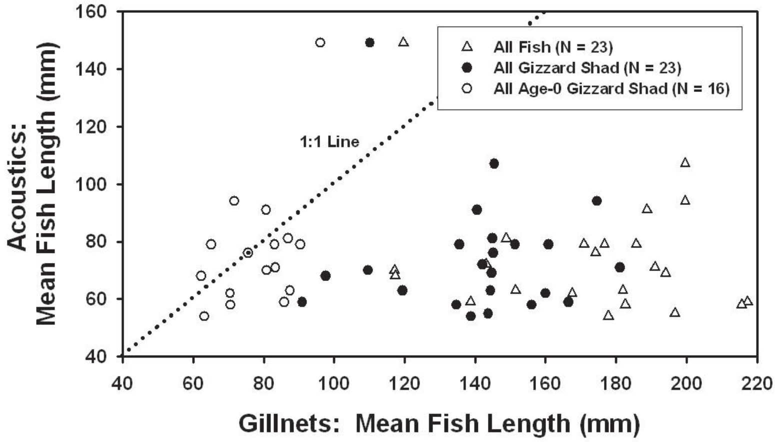

Figure 6. Comparisons of mean length of fish estimated with acoustic surveys and mean lengths quantified from gill-net catches in 11 Ohio reservoirs, 2004–2006; all fish (open triangles), all gizzard shad (closed circles), and age-0 gizzard shad (open circles) in reservoirs.

plotted against the percentage of individual fish targets ≤ 150 mm further demonstrated the preponderance of fish within each survey that were available as prey for age-1 and older saugeyes and many other piscivores (Figure 8). Individual surveys results often revealed that 95% or more of fish targets were available as prey based on our 150-mm criteria. In 20 of 53 surveys, more than 90% of fish were available prey and in 42 of 53 surveys, more than 80% of fish were available prey.

Condition of saugeyes and walleyes in Ohio reservoirs increased with fish biomass, but neither *Sander* spp. growth nor recruitment was related to fish biomass (Figure 9). Relative weight of 23–34-cm *Sander* spp. was positively correlated with fish biomass ($r = 0.53$, $N = 24$, $P < 0.01$) as was condition of 35–46-cm *Sander* spp. ($r = 0.61$, $N = 23$, P

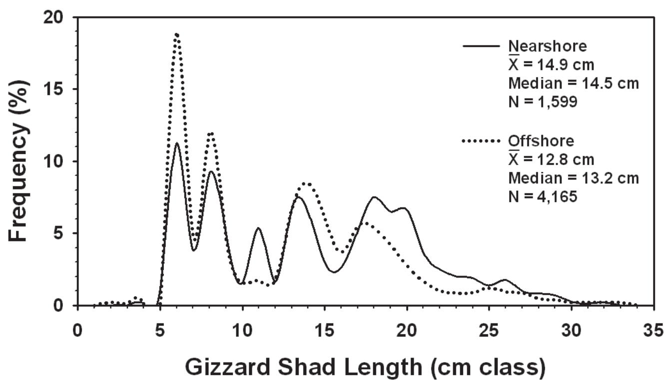

Figure 7. Length–frequency distributions of gizzard shad sampled nearshore and offshore in 22 gill-net surveys conducted in habitats where acoustic data were collected in Ohio reservoirs, 2004–2006.

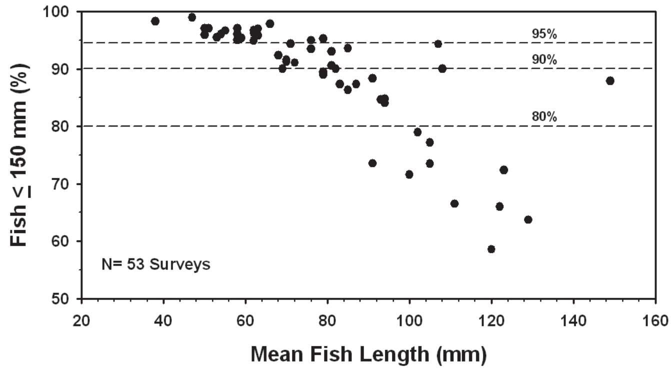

Figure 8. Mean length of acoustic fish targets (millimeters) and the percentage of acoustic fish targets less than the equivalent of ≤ 150 mm (i.e., sizes considered available prey) from 53 acoustic surveys in Ohio reservoirs, 1999–2006.

< 0.01). However, although growth of *Sander* spp. was rapid, indicated by mean length at age during autumn, it was not correlated with fish biomass at ages 0–3 (age 0: $r = 0.05$, $N = 30$, $P = 0.78$; age 1: $r = 0.08$, $N = 18$, $P = 0.77$; age 2: $r = 0.27$, $N = 16$, $P = 0.41$; age 3: $r = 0.11$, $N = 15$, $P = 0.69$). Also, *Sander* spp. recruitment, estimated from catch per effort of age-0 *Sander* spp. from shoreline electrofishing during autumn was not correlated with fish biomass ($r = 0.11$, $N = 28$, $P = 0.58$).

Stocking rates and recruitment success of *Sander* spp. differed substantially among study reservoirs, and neither was consistently related to fish biomass. Five-year stocking averages reflected current fisheries programs in most reservoirs, except Burr Oak and Dillon, where saugeye stocking was recently discontinued, and Acton, with only the 2006 rate reported because experimental stocking rates were used during 2004–2005 when stocking began. Stocking rates ranged from 119 to 627 fingerlings/ha and were often greater in reservoirs with presumably fewer prey resources (Figure 10 A). High stocking rates occurred at Alum Creek, C.J. Brown, Caesar Creek, and Piedmont, all with prey biomass less than 66 kg/ha, whereas lower stocking rates occurred at Dillon, Delaware, and O'Shaughnessy, all with prey biomass greater than 315 kg/ha; therefore, stocking rates were not correlated with fish biomass ($r = –0.45$, $N = 14$, $P = 0.11$). Reservoirs with the greatest flushing rates were among those with the greatest fish biomass; yet, these same reservoirs often had low or variable recruitment (Figure 10B, C). Recruitment success of stocked *Sander* spp., expressed as an index, was not consistently strong or weak among reservoirs depending upon fish biomass. Recruitment was high but extremely variable in Deer Creek and Piedmont at or above the statewide medians (saugeye = 3.7; walleye = 5.6; Ohio Department of Natural Resources, unpublished data) at 10 of 14 stocked study reservoirs and below the median in O'Shaughnessy, Acton, Hoover, and Burr Oak.

Creel surveys conducted during 2004–2006 provided a means to compare angler success and their level of motivation to fish for *Sander* spp. Median angler catch per effort among 35 Ohio reservoirs was 0.24 *Sander* spp./h (saugeye = 0.25, $N = 23$; walleye = 0.21, $N = 12$) and catch rates were particularly high at C.J. Brown (0.45 fish/h), Piedmont (0.41 fish/h), Pleasant Hill (0.43 ±0.14 fish/h), and Tappan (0.44

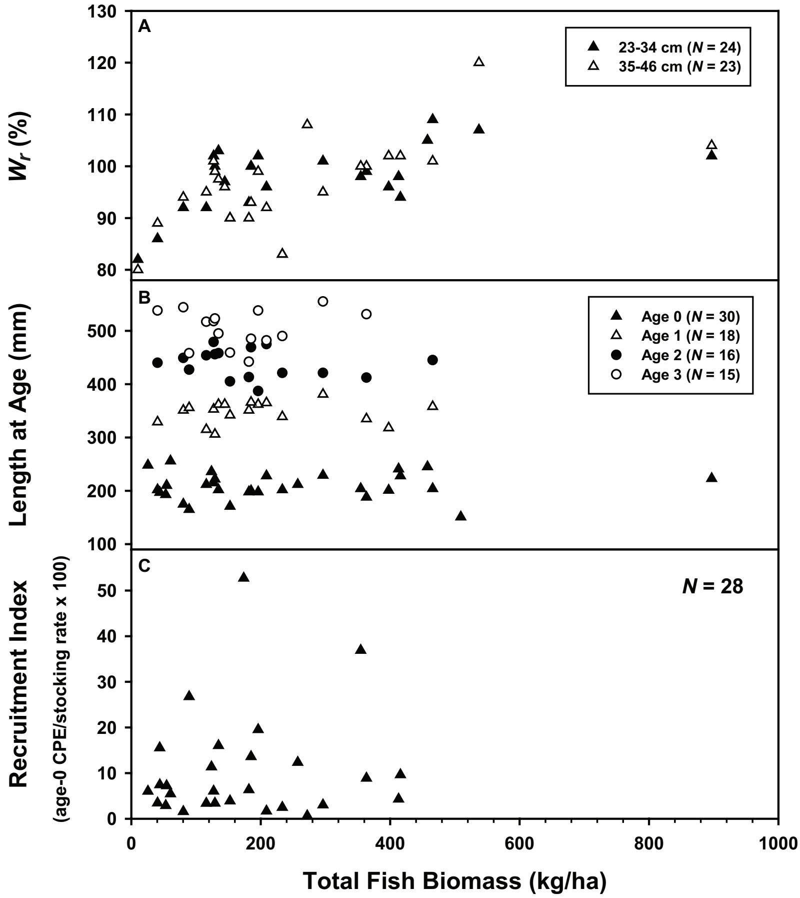

Figure 9. Relative weight (W_r) (panel A), mean length at age (panel B), and recruitment (expressed as an index calculated as electrofishing catch per effort of age-0 *Sander* spp./stocking rate × 100, panel C) of saugeyes and walleyes in relation to fish biomass measured with acoustics in Ohio reservoirs, 1999–2006.

± 0.22 fish/h) reservoirs. The percentage of anglers seeking *Sander* spp. (i.e., percent of trips for *Sander* spp.) significantly increased with directed angler catch rates (Figure 11). Very few anglers fished for saugeyes within the reservoir in Deer Creek, Delaware, or Dillon, where few or no catches were reported.

Discussion

Optimizing stocking rates by determining the capacity of reservoirs to support stocked predators is a difficult process. Quantifying prey supply by estimating fish biomass available as prey is difficult due to gear selectivity and problems associated with prey spatial distribution and size (Noble 1981; Ney 1990; Van Den Avyle et al. 1995). We addressed these issues by using acoustic survey data to quantify fish biomass across reservoirs, discerning that fish biomass was largely available as prey to age-1 and older *Sander* spp., and applied acoustic and gill-net data to conclude that gizzard shad dominate fish biomass in Ohio reservoirs. We did not address

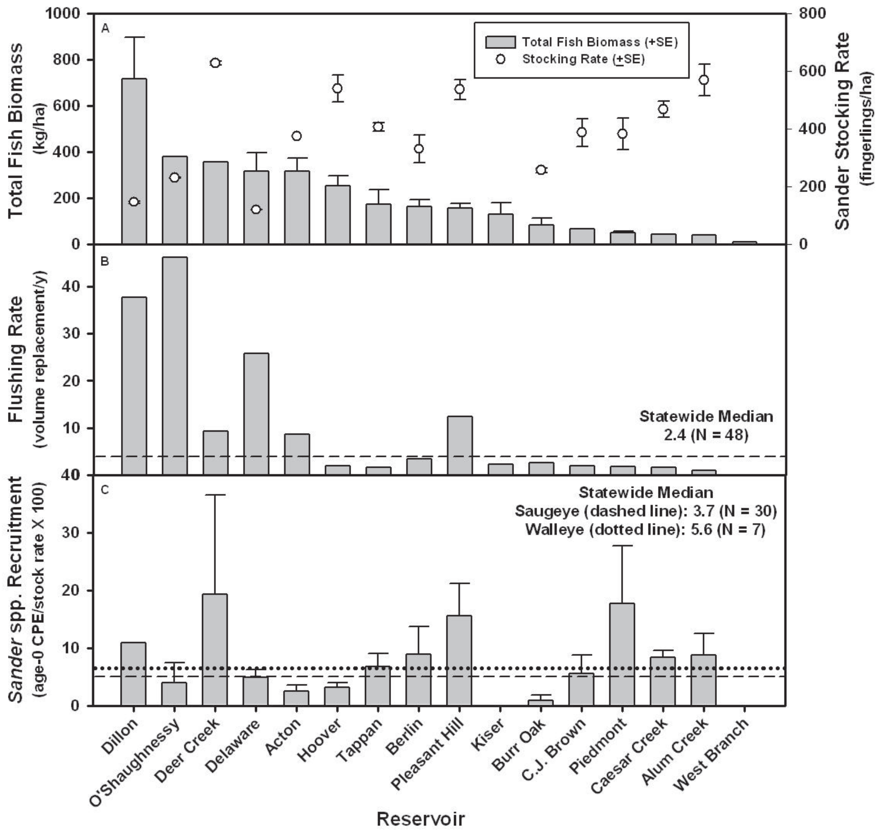

Figure 10. Factors potentially influencing saugeye and walleye success in study reservoirs, including prey availability (prey biomass, panel A), emigration (reservoir residence time, panel B), and *Sander* spp. recruitment success (recruitment index, panel C). Stocking rates in each reservoir represent mean rates for each year fish were stocked during 2002–2006 except Acton, where only the current programmatic rate is reported, and Burr Oak, where 2002–2004 rates are used, and Dillon, where 2002–2005 rates are used. Saugeye stocking was discontinued in Burr Oak in 2005 and Dillon in 2006. All means include SE except where $N = 1$.

predator demand. Matching prey supply and predator demand is difficult, due in part to challenges inherent in estimating consumptive demand (Ney 1990, 1993; Bajer et al. 2003) and asynchrony between prey supply and predator demand (Ney 1990).

Currently, *Sander* spp. stockings in Ohio reservoirs did not appear related to reservoir fish biomass, countering our goal of optimizing sport fish biomass. However, recruitment of *Sander* spp. was unrelated to fish biomass, thereby identifying a major challenge for fisheries managers attempting to stock based solely on prey resources. Reservoirs with greatest fish biomass, but poor or highly variable saugeye recruitment, included Deer Creek, Delaware, Dillon, and O'Shaughnessy. Although each had extensive prey resources, they also had high flushing rates, which led fisheries managers to stock at lower rates, owing to the high likelihood of downstream emigration to the tailwaters, creating fisheries there instead of within reservoirs. Greater stocking rates at Deer Creek

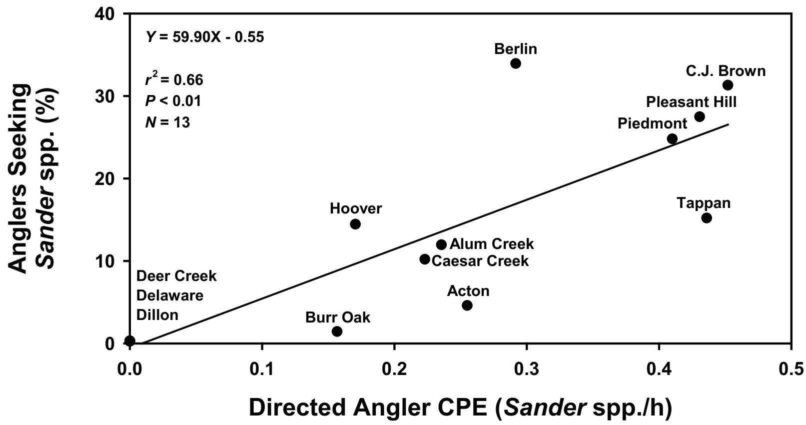

Figure 11. Directed catch per effort of *Sander* spp. and the percent of trips taken for *Sander* spp. from creel surveys conducted in study reservoirs during 2004–2006. Creel surveys were not conducted in Kiser and O'Shaughnessy during these years. Reservoir years of data vary from 1–3 years.

were an exception; yet, the strategy was the same. Saugeye recruitment is highly variable within this reservoir, and an extremely successful tailwater fishery has established (Silk 2001). Although high fidelity of emigrated saugeyes to tailwaters creates an exceptional fishery at Deer Creek (Spoelstra 2001), few saugeyes persist within the reservoir to capitalize on abundant prey. In such cases, the potential of these reservoirs to produce prey is trumped by poor within-reservoir recruitment via flushing rate, the same attribute positively related to fish biomass.

Recruitment success of *Sander* spp. also can be influenced by timing of stocking and predation. Saugeyes stocked in Ohio reservoirs reach greater lengths by fall when stocked prior to peak densities of gizzard shad ichthyoplankton but exhibit greater survival to fall when stocked after these peaks (Donovan et al. 1997). Similarly, early predator and prey (gizzard shad) synchrony influences reproductive success of largemouth bass (Adams and DeAngelis 1987). In the case of walleyes stocked in reservoirs as fry (6 mm), fingerlings (46 mm), or advanced fingerlings (100 mm), abiotic factors, prey abundance, and predation differentially influenced survival (Hoxmeier et al. 2006). Predation by centrarchids has been implicated in poor survival of stocked *Sander* spp. In Acton Lake, an experimental approach of stocking saugeyes at more than 3,300 fingerlings/ha during 2004–2005 resulted in minimal saugeye survival (0.3%/year), likely caused by a dense largemouth bass population (Aman 2007). Although predation has been difficult to confirm, dense largemouth bass populations are associated with poor walleye recruitment in both natural lakes and reservoirs (Santucci and Wahl 1993; Nate et al. 2003; Fayram et al. 2005; Hoxmeier et al. 2006).

Opportunities to increase stocking rates likely exist where *Sander* spp. recruitment is above average and stable and prey fishes are abundant. In Ohio reservoirs, *Sander* spp. condition increased with fish biomass and presumably prey, and W_r routinely exceeded 90%, suggesting that adequate prey are available. Although length at age was not correlated with *Sander* spp. growth in these reservoirs, sport fish growth commonly is related to availability of gizzard shad prey (Michaletz 1998a, 1998b), the dominant prey of Ohio *Sander* spp. (Johnson et al. 1988b; Sieber Denlinger et al. 2006; Aman 2007). Because saugeyes will readily consume nonshad prey (Horton and Gilliland 1992; Sieber Denlinger et al. 2006), acoustic estimates may adequately depict available prey when gizzard shad are less abundant relative to other fishes. Ohio reservoirs with strong and consistent *Sander* spp. recruitment and moderate-to-high prey biomass have the potential for increased predator capacity (Sieber Denlinger et al. 2006). Examples include Tappan, Berlin, and Pleasant Hill reservoirs, where *Sander* spp. recruitment was at or above statewide medians and fish biomass was intermediate. By contrast, stocking may be discontinued or reduced in reservoirs with poor *Sander* spp. recruitment or less prey, allowing managers to allocate fish elsewhere.

Central to refining saugeye stocking rates to match predator demand with prey supply are improvements in modeling saugeye growth and consumptive demand. Lacking a saugeye bioenergetics model, Ohio saugeye research has relied on the Wisconsin bioengergitics model for walleyes (Kitchell et al. 1977; Hanson et al. 1997), which has recently been found to underestimate consumptive demand of Ohio saugeyes (R. Zweifel, Ohio Department of Natural Resources, personal communication). Correcting the existing walleye model (per Whitledge et al. 2006) or developing of a bioenergetic model for saugeyes will improve our estimates of predator demand. Coupling predator demand with insight into prey availability from acoustic surveys will advance this process. In addition, our approach can be generalized by applying acoustic survey results from study reservoirs to predict fish biomass, and prey resources, in other Ohio reservoirs, based on reservoir attributes.

Though acoustic surveys revealed that fish biomass varies substantially among Ohio reservoirs, watershed and reservoir attributes explain most of that variability. Trophic state, watershed area, reservoir area, and reservoir volume explained 84% of variation in fish biomass; in turn, reservoir hydrology, land use, and land management serve to increase our knowledge of how fish biomass is expressed by setting the stage for food–web interactions (Stein et al. 1995; Vanni et al. 2005). As hybrids between rivers and lakes, reservoirs receive nutrients primarily from watersheds via external loading (Kennedy and Walker 1990). In previous work on 12 Ohio reservoirs, watershed area to reservoir volume explained 56% of the variation in total phosphorus and watershed area to reservoir volume, percent agricultural land use, and ratio of cropland to agricultural animals explained 42% of variation in primary production (Knoll et al. 2003). Clearly, reservoir fish biomass is linked to nutrient input, as indicated by declines in fish biomass when total phosphorus, in particular, decreases (Kimmel and Groeger 1986; Yurk and Ney 1989; Ney 1996). However, as nutrient input from watersheds increases, nutrient cycling by detritivorous gizzard shad increases as well (Vanni et al. 2006). Additional data regarding land use, land management, nutrients, and fish biomass are likely to further indicate how watershed characteristics explain variation in fish biomass across a productivity gradient.

In our surveys, we did not parse fish biomass by species because acoustic data could not be used to differentiate species. Indeed, based on our comparison of acoustic and gill-net surveys, gill nets underrepresented small fish. However, in 80% of acoustic surveys, 80% or more of fishes were less than 150 mm, sizes consumed by *Sander* spp. (Johnson et al. 1988b; Sieber Denlinger et al. 2006). More than 50% of the fish captured in more than 90% of gill-net surveys were gizzard shad, and age-0 gizzard shad closely approximated sizes of resultant acoustic targets. Gizzard shad dominance is not uncommon in reservoirs where these fish are established. Among reservoirs in the southeast United States, nearshore, shad *Dorosoma* spp. represent the greatest biomass in cove-rotenone surveys (Jenkins and Morais 1978); offshore trawling and acoustic surveys similarly verify their abundance. Acoustic and trawl surveys in 13 Tennessee Valley Authority reservoirs determined that either threadfin shad *D. petenense* or gizzard shad dominated upstream, mid-reservoir, and downstream habitats of all but one reservoir (Wilson 1991). Acoustic targets similarly were verified at Lake Texoma, where 99% of fish collected with Tucker or frame trawls were either threadfin shad or gizzard shad (Michaletz et al. 1995). Dominance by small fishes in acoustic surveys and saugeye propensity to consume fish prey other than gizzard shad when gizzard shad are less available (Sieber Denlinger et al. 2006) support the conclusion that our estimates of reservoir fish biomass strongly reflect prey supply. Likewise, substantial representation of gizzard shad in these surveys supports our contention that fish biomass in Ohio reservoirs is dominated by gizzard shad, most of which is available as prey to age-1 and older *Sander* spp.

If small fishes, and particularly gizzard shad, dominate Ohio reservoirs, we hope to capitalize on relations between fish biomass and reservoir attributes to characterize prey resources beyond our study reservoirs. In our view, fish biomass quantified through acoustic surveys provides reasonable upper limits of available prey biomass. The proportion of fish biomass truly available as prey can be better ascertained as data increase and complementary sampling gear improve. Given the current impracticality of estimating fish biomass in all reservoirs, accurately predicting fish biomass based on characteristics such as watershed size and trophic state, for example, may allow us to generate coarse, yet functional predictions of prey supply.

Annual variation in fish biomass revealed by 8 years of data from Acton, Pleasant Hill, and Burr Oak reservoirs argues for viewing mean or median estimates of fish biomass as conservative upper limits of prey availability. Difficulties addressing a temporal mismatch in supply and demand, which may result from demand being one or more years out of phase with supply, may be minimized when biomass of prey fishes can be reasonably predicted and growth rates of predators are rapid (Ney and Orth 1986). Therefore, we concur with Raborn et al. (2007), who suggest that due to the expense of monitoring of supply and demand, capitalizing on routinely collected data and adjusting predator demand to median or mean values of prey supply could improve stocking strategies. In Ohio reservoirs, rapid growth of *Sander* spp. also would allow fisheries managers to quickly adjust stocking practices based on routine, yet less detailed, analysis of prey supply and demand.

Hatchery production of saugeyes is at full capacity in Ohio, but reprioritization of stocking is warranted based on fish biomass estimates. Improving our understanding of saugeye stocking success has long been recognized as critical to setting and achieving fisheries management goals and objectives (Noble 1986). In Ohio, routinely collected fish biomass estimates, in concert with other information, have led to experimental high-density stocking of saugeyes at Acton Lake (Aman 2007) and termination of stocking at Burr Oak Lake. Biomass estimates also will allow us to expand hybrid striped bass stocking, which we anticipate will mirror the saugeye program expansion of the late 1980s. Identifying reservoirs by their attributes, among which is potential for fish biomass production, will allow fisheries to be managed by reservoir potential for sport fish capacity. However, quantifying reservoir potential for stocked piscivores and refining a supply and demand approach will require continual progress in understanding reservoir ecosystems and their watersheds.

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