North American Journal of Aquaculture 63:179–190, 2001

Reservoir Ranching of Paddlefish

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Abstract.—Paddlefish *Polyodon spathula* (30–67 cm total length, TL) were stocked in six flood control reservoirs (<41 ha) in western Kentucky in January 1995 at a target stocking density of 10 fish/ha. Fish growth was monitored quarterly beginning in July 1995. The fish were implanted intraperitoneally with passive integrated transponder (PIT) tags. Chemical and physical variables and zooplankton biomass were measured monthly. Three reservoirs that had not been stocked were sampled monthly as controls. Of the 1,440 paddlefish stocked, 353 were recovered at harvest in the fall of 1996, and only two tags were found. Anecdotal evidence indicated some loss to predation by largemouth bass *Micropterus salmoides* and some to escapes through mechanical spillways. The total gross yield was 1,715 kg or 13.7 kg/ha; it ranged from 0.6 to 28.8 kg/ha. Gill nets of 102-mm-bar mesh were optimum for harvest. Mean harvest weights were significantly different among reservoirs. A positive correlation was found between relative growth and mean total alkalinity measured during the April–October growth season. Relative growth was also positively correlated with mean sample site depth and conductivity measured during the growth season. The mean harvest weight was negatively correlated with photic zone depth. Paddlefish growth was lower in reservoirs infested with macrophytes during the growth season, and condition factors at harvest were significantly different among some reservoirs. Our results indicated that reservoir ranching is a viable method for producing market-size paddlefish within the limits set by reservoir fertility. We conclude that PIT tags are not suitable for paddlefish when implanted in the body cavity. There was no evidence that paddlefish grazing at the densities that were realized adversely affected existing reservoir ecosystems.

Reservoir ranching (Welcomme 1992) is an extensive culture method in which hatchery-reared juvenile fish are stocked into artificial reservoirs or natural lakes for grow-out based on the natural productivity of the system. Stock–recapture fisheries are used around the world for food fish production, most notably in China (Desilva et al. 1991), Eastern Europe (Jory 1994), and Africa (Kapetsky 1986). In China, reservoir ranching has been practiced since the early 1950s. Yearly fish yields have varied with primary productivity, ranging from 20 to more than 10,000 kg/ha (Lu 1992).

The paddlefish *Polyodon spathula* is an ancient chondrostean originally common in the river systems of the Gulf of Mexico drainage of North America. It is a filter-feeding zooplanktivore and exhibits rapid growth, especially in the first 3 years of life (Adams 1942; Ruelle and Hudson 1977; Pasch et al. 1980). It will not reproduce in lentic systems but can be artificially propagated (Russell 1973; Graham et al. 1986), and methods for producing fingerlings have been developed (Kurten et al. 1992; Mims et al. 1993; Mims and Shelton 1998). Paddlefish are easily harvested using seines or gill nets, and they yield boneless fillets that are white and firmly textured.

At the beginning of the 20th century, the paddlefish was an important commercial species. In 1899, the wild harvest was reported to be 1.1×10^6 kg (Coker 1930). Stockard (1907) noted that smoked paddlefish meat was sold as sturgeon and the roe was mixed with sturgeon roe in caviar processing. Wild populations of paddlefish have declined substantially in the past 100 years, and the species has been extirpated from some of its former range. Continued loss of spawning habitat by

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Received December 20, 1999; accepted December 2, 2000

dam construction, siltation, and overharvesting are reasons given for the decline (Pearson and Pearson 1989). Of additional concern is the detection of organochlorines in paddlefish roe (Gundersen and Pearson 1993). Many states with paddlefish populations have closed the commercial harvest (Williams et al. 1989); however, the paddlefish could again become commercially important through aquaculture.

No prior studies on reservoir ranching of the paddlefish for food fish production have been published. Graham (1986) and Semmens and Shelton (1986) described efforts by the Missouri Department of Conservation to establish a stock-recapture sport fishery for paddlefish in Table Rock Reservoir. Semmens and Shelton (1986) also described the commercial harvest of wild paddlefish from Cherokee Reservoir in Tennessee through the sale of harvest rights to fishers by the Tennessee Wildlife Resources Agency. These authors then proposed that paddlefish reservoir ranching would combine the main elements of these two fisheries. Data on potential production has been limited to the natural production of paddlefish populations in reservoirs (Alexander and Peterson 1982; Combs 1982) or to that of other zooplanktivorous fish (Yang 1970).

Paddlefish reservoir ranching was investigated in this study using small (<41 ha) flood control reservoirs. The main objective was to quantify paddlefish yield, survival, growth rates, and catch per unit of effort at harvest in the study reservoirs. The secondary objective was to measure the impact of paddlefish grazing on the reservoir ecosystems from limnological data collected during the study.

Methods

Study sites.—Nine reservoirs located in the southwestern Kentucky counties of Christian and Todd were used for this study. The reservoirs were constructed on private land during the 1960s and 1970s for flood control and sediment retention. The area was rural and had infertile soils with high clay content underlain by sandstone deposits. Each reservoir was formed behind an earthen dike across a second-order or third-order stream with principal (mechanical) and emergency spillways. The principal spillways were equipped with trash racks but not screens. Drain valves were nonfunctional. The reservoirs had received substantial silt deposits since construction. Landowner reports indicated the loss of from one-third to one-half of the original depth in the dam forebay areas due to siltation, which had created wetlands in stream inflow areas. Typically, shallow water areas (<1 m) became filled with macrophytes during the summer. All of the reservoirs were used for sportfishing, but none had existing paddlefish populations.

Stocking of fish.—Paddlefish for this study were obtained from two sources. First, broodstock from Lake Cumberland, Kentucky, were artificially propagated as reported by Graham et al. (1986) during the spring of 1994 at the Kentucky State University Aquaculture Research Center (ARC) at Frankfort. Fingerlings were reared in earthen ponds according to fertilization regimes established by Mims et al. (1993) and later with a prepared diet (Tidwell et al. 1991). A target minimum total length (TL) of 30 cm was set for fingerlings in order to minimize predation after stocking (Graham 1986). The second source for fingerlings was a commercial hatchery, Osage Catfisheries, Inc., Osage Beach, Missouri. The broodstock source for these fish is unknown. Four hundred fingerlings from this source were subsequently mixed and randomized with the 1,040 fish reared at Kentucky State University.

In the fall of 1994, all fish to be stocked were implanted intraperitoneally with passive integrated transponder (PIT) tags. The tags were glass enclosed microchips (1 mm in diameter $\times$ 11 mm long) programmed with a unique identification code. The code was read with a battery-powered scanner (Destron/IDI, Inc., St. Paul, Minnesota). The tags were implanted through a 3–5-mm incision in the abdominal wall located on a line between the anterior ends of the symphyses of the pelvic fins and midlateral to the ventral midline. The fish were held after tagging for observation in circular tanks supplied with flow-through reservoir water for 24 h and then returned to earthen holding ponds.

Six of the nine reservoirs used in the study were stocked with paddlefish, while the other three were used as controls. Prior to stocking, all fish were randomly divided into groups for stocking according to reservoir surface area and the study stocking density of 10 paddlefish/ha. All fish were scanned to ensure that tags were present, and the weight, TL, and PIT tag number for each fish were recorded. Stocking took place on January 13, 1995. The fish were transported in aerated insulated tanks filled with reservoir water and supplied with oxygen. Sodium chloride was added to the transport water at the rate of 1 g/L. Travel time to the first reservoir was 3 h, and stocking of all reservoirs was completed within 10 h. Access to the reservoirs was off-road, requiring transfer of fish from the hauling truck to a tank mounted on a truck with four wheel drive at each site. This tank was equipped with aerators and oxygen. At the reservoir bank, the paddlefish were transported to the water in baskets and released in water at least 1 m deep.

Sampling: water quality and zooplankton.—Beginning in January 1995 and continuing through August 1996, all reservoirs were sampled monthly for various physical and chemical properties and for zooplankton biomass. Inclement weather prevented sampling in May and December 1995. Four sites were sampled in January 1996, and five in February 1996, which were combined to form a ‘‘winter’’ sample. A sampling site for each reservoir was established in the deepest water available.

Depth and Secchi disk visibility were measured at each sample site. Photic zone depth (Lind 1985) was measured using a submarine photometer (Li-Cor model LI-189, Li-Cor, Inc., Lincoln, Nebraska). Dissolved oxygen and temperature profiles were measured through the water column to 2.5 m using a YSI model 59 dissolved oxygen meter (YSI, Inc., Yellow Springs, Ohio). A Hach One portable meter (Hach Co., Loveland, Colorado) was used to measure pH.

A pump was lowered through the photic zone to collect composite samples for chlorophyll-*a* and zooplankton biomass determination. Zooplankton samples were collected by pumping water through a No.-25 Wisconsin plankton net (Wildlife Supply Co., Saginaw, Michigan) until 40 L had passed through the net (Lind 1985). Zooplankton samples were field preserved as reported by Haney and Hall (1973). Additional composite water samples were collected at each site for chemical analysis. All samples were held on ice, with minimal exposure to light while in the field.

Sampling: paddlefish growth.—Sampling to measure paddlefish growth began in July 1995 and was repeated in October 1995, January–February 1996, April 1996, and July 1996. All sampling was done during daylight hours. Floating gill nets of 64, 76, 102 and 127 mm-bar mesh were used to capture paddlefish from each reservoir. Sampling at each reservoir was limited by time constraints. Nets were set for the available time and removed when the time had expired regardless of fishing success. Typical times for net sets were from 4 to 6 h.

Scanning to read PIT tags was performed in July and August 1995, but tags were not found and scanning was discontinued until harvest. All captured fish were weighed using a tubular spring scale (Chatillon 12.5 kg ×100 g, Forestry Suppliers, Inc., Jackson, Mississippi). After sampling, live paddlefish were returned to the water.

Water analysis.—Water samples were analyzed for chlorophyll-*a* concentration as described by Boyd (1979). A Hach model 44600 meter was used to measure conductivity. Turbidity was measured using a Hach model 2100 nephelometer. Total solids dried at 105°C and total dissolved solids dried at 180°C were measured according to the methods detailed in APHA (1985).

Total alkalinity, phenolphthalein alkalinity, total hardness, and chloride were measured by titration. Ammonia–nitrogen was measured by the ion-selective-electrode method with a detection limit of 0.01 mg/L. Nitrate concentration was determined by the cadmium reduction method, while nitrite levels were measured by the diazotization method. Total phosphorus and soluble reactive phosphorus were measured by the acid persulfate digestion and ascorbic acid methods, respectively. All methods applied were from APHA (1985). The Kentucky Division of Water laboratory at Frankfort performed total organic carbon measurements.

Zooplankton analysis.—Zooplankton samples were examined to determine the number of copepods and cladocerans present. Copepods were identified to suborder and cladocerans to species using the taxonomic keys in Pennak (1978). Copepod nauplii and rotifers are not filtered by paddlefish (Rosen and Hales 1981) and therefore were not counted.

When possible, all copepods and cladocerans present in the sample were counted. Animals of interest in each sample were counted at least twice. If the two counts were not similar, a third count was done. The average number of plankters was computed from the counts for each taxon found in the sample. When the number of animals in a sample was too large to count at one time, they were subsampled using a Folsom plankton splitter (Longhurst and Seibert 1967; APHA 1985).

After counting, representative plankters from each taxon found in the sample were measured (total body length) as defined and illustrated by Lawrence et al. (1987). The number of plankters measured was based on their frequency of occurrence in the sample and ranged from 3 to 10. Mean total body lengths were computed for each taxon.

The regression equations derived by Dumont et al. (1975) were used to calculate dry weight biomass per individual from mean total body lengths.

This value was multiplied by the number of individuals from each taxon in the sample, summed to determine total zooplankton biomass, and divided by the volume of water filtered (40 L) to arrive at zooplankton biomass per liter.

Harvest.—The paddlefish were harvested during September and October 1996. Gill nets were set so that paddlefish feeding parallel to the shoreline would be likely to encounter a net. The size and time of set was recorded for each net. Fish activity was increased by striking the bottom of the harvest boat while it was under way. The nets were tended continuously, and the time of removal from the net for each paddlefish caught was recorded. All fish were weighed, measured (TL), scanned for PIT tags, and visually examined for tags during tissue processing.

Fishing time was determined by the catch rate and time constraints. Fishing was done during both daylight and dark hours. All reservoirs were fished for at least one dusk-to-dawn period. The nets were removed when fish were no longer regularly caught, and the time of removal was recorded for each net. Typically, this was 24–36 h after fishing began.

Data analysis.—Carlson's trophic state index (TSI) was calculated for each reservoir from the mean growth season chlorophyll-*a* concentrations (Carlson 1977). The growth season was defined as the April–October period (Kentucky Division of Water 1992). The TSI was used to quantify reservoir fertility. The regression method of Delury (1947) was applied to catch data collected at harvest to estimate survival. This method is based on the premise that for a given fish population and constant fishing effort, the decrease in catch per unit of effort is directly related to the extent of depletion of the population (Seber and Le Cren 1967; Seber 1982).

Reservoir fertility, zooplankton biomass, paddlefish growth, and condition factor data were analyzed by analysis of variance (ANOVA) using the general linear model procedure of the Statistical Analysis Software system (SAS 1988). The models included reservoir and weed status. Reservoirs were classified as weedy if floating-leafed and emergent macrophytes became dense in available habitat during the growing season. In nonweedy reservoirs, macrophytes were present but did not noticeably fill the water column. The Student–Newman–Keuls method of multiple comparisons was used to compare means of interest. Mean weights at the time of sampling and harvest and relative growth over the study period (i.e., [mean final weight–mean initial weight]/mean initial weight) (Everhart and Youngs 1981) were used to define paddlefish growth. Market-size was defined as more than 4.5 kg, and condition factor (*k*) was defined as $10^5 \times$ weight (g)/TL (mm)^3 (Everhart and Youngs 1981). Pearson's correlation coefficient (*r*) was used to identify linear relationships between paddlefish growth and the measured variables (Rosner 1995).

TABLE 1.—Yield and recovery of paddlefish from extensive culture in western Kentucky reservoirs.

Reservoir[a]	Surface area (ha)	Number Stocked	Number Harvested	Recovery (%)	Total weight (kg)	Yield (kg/ha)
4	40.1	340	97	28.5	577.6	14.4
5	17.8	196	56	28.6	285.9	15.9
6	20.4	184	2	1.1	14.0	0.6
7	12[b]	324	62	19.1	172.5	14.4
8	14.5	204	91	44.6	417.2	28.8
9	20	192	45	23.4	247.8	12.4
Total	124.8	1,440	353	24.5	1,715.0	13.7

[a] Reservoirs 1–3 were controls that did not contain paddlefish.
[b] Adjusted from 23.9 ha to compensate for coverage by American lotus *Nelumbo lutea.*

Grazing effects on nutrient levels and primary and secondary productivity were examined by plotting growth season changes in related estimators over time and comparing the observed trends in two control reservoirs with those in two stocked reservoirs. Reservoirs 1 and 2 were selected as the controls because the TSI in these reservoirs was closest to that of the stocked reservoirs. Reservoirs 7 and 8 were selected for comparison with the controls because paddlefish densities were probably highest in these reservoirs and because reservoir 7 was a weedy reservoir. Mean sample values were averaged for the two control and two stocked reservoirs and the averages were plotted to show trends. Chlorophyll-*a* concentration was examined for trends in primary productivity. Zooplankton biomass was examined for trends in secondary productivity. Conductivity was examined as a measurement of available nutrients.

Results

Paddlefish Yield

Of the 1,440 paddlefish stocked in the six reservoirs, 353 (24.5%) were captured at harvest (Table 1). After stocking, we found that the surface areas used to calculate the number of fish stocked in each reservoir did not agree with those reported in the original specifications, which were not avail-

TABLE 2.—Regression estimates of survival from stocking to harvest and density at harvest for paddlefish stocked in western Kentucky reservoirs.

Reservoir[a]	Number harvested	Population estimate	Percent harvested	Survival (%)	Density (fish/ha)
4	97	148	65.5	43.5	3.69
5	56	102	54.9	52.0	5.73
6	2		100.0	1.1	0.10
7	62	67	92.5	20.7	5.58
8	91	90	100.0	44.6[b]	6.28
9	45	38	100.0	23.4[b]	2.25

[a] Reservoirs 1–3 were controls that did not contain paddlefish.
[b] Survival estimates based on the number actually harvested.

TABLE 3.—Catch per unit effort during paddlefish harvest ($\times 10^{-4}$) for different sizes of gill net. Units are catch/net meter·ha·h; the number of nets of each size that were set is included in parentheses.

Reservoir[a]	Net size (bar mesh) 76 mm	102 mm	127 mm
4	2.4 (2)	9.0 (5)	2.4 (2)
5	2.9 (2)	12.8 (2)	5.0 (2)
6	0 (2)	0.8 (3)	0 (1)
7	4.1 (2)	7.5 (3)	
8	5.9 (2)	21.0 (3)	2.2 (1)
9	2.4 (2)	3.1 (2)	0.9 (2)

[a] Reservoirs 1–3 were controls that did not contain paddlefish.

able before stocking. These differences placed doubt on the equality of initial stocking densities; however, the discrepancy was moot because density was not constant throughout the study. The yield data reported in Table 1 are based on surface areas at the principal spillway crests as reported in the original specifications. The mean paddlefish weight at harvest was 4.86 kg, with a range of 1.73–9.69 kg. Total gross yield was 1,715 kg (13.7 kg/ha). The yield data in Table 1 do not include sampling mortalities, of which there were seven from reservoir 4 (26.4 kg), one from reservoir 7 (2.6 kg), four from reservoir 8 (7.9 kg), and one from reservoir 9 (5.8 kg). The open-water area of reservoir 7 was reduced to approximately 12 ha by the growth of American lotus during the two growth seasons of the study. Thus, the yield for reservoir 7 was based on a surface area of 12 ha.

Survival

Regression estimates of survival to harvest ranged from 1.1% to 52% (Table 2). Since only two paddlefish were captured from reservoir 6 after fishing six nets for 12 h, it was assumed that these were the only fish surviving to harvest. This was consistent with catches during sampling, which never exceeded three fish in this reservoir.

The estimates indicated that virtually all surviving paddlefish were harvested in reservoirs 7, 8, and 9. However, the owner of reservoir 8 reported that about 30 paddlefish were recovered when this reservoir was drained in 1999. In reservoir 4, the estimate showed that 65.5% of the surviving population was harvested. Anecdotal evidence of an incomplete harvest in this reservoir was given by a landowner who reported observing paddlefish in the outflow pool in March 1997, 5 months after harvest; this report followed a severe storm event that resulted in heavy flows through the emergency spillway. In reservoir 5, the estimate indicated a harvest of 54.9% of the surviving population. However, this estimate was increased to well above the actual harvest by an unexpected increase in the catch rate near the end of the harvest period.

Some paddlefish escaped through the mechanical spillway before harvest. One month prior to harvest, a landowner reported capturing a paddlefish weighing 3.6 kg in an isolated pool 0.2 km below the dam of reservoir 4.

Tag Loss

Loss of PIT tags was first observed during the July 1995 sampling, when only one tag was detected in the 31 fish that were captured. Tag loss was confirmed by dissection of three fish from reservoir 8 that were sampling mortalities. During the October 1995 sampling, no tags were detected in 36 fish. Tag loss was confirmed by dissection of five fish from reservoir 4 and one from reservoir 9, also sampling mortalities. Scanning for tags was discontinued after the October 1995 sampling. At harvest, only two tags were recovered.

Catch per Unit Effort

Gill nets of 102-mm-bar mesh consistently captured the greatest number of paddlefish in all reservoirs (Table 3), ranging from 0.8 to 21.0 paddlefish/(net-meter·ha·h). For 76-mm-bar mesh nets, the catch rate ranged from 0 to 5.9 paddlefish, and for 127-mm-bar mesh nets it ranged from 0 to 5.0 paddlefish. Gill nets of 127-mm-bar mesh were not set in reservoir 7 due to the small size of the fish captured in this reservoir during sampling.

Growth

Mean stocking weights ranged from 0.17 kg in reservoir 5 to 0.33 kg in reservoir 9 and were

TABLE 4.—Selected paddlefish growth features and reservoir productivity estimates. Mean values along a row sharing the same letter are not significantly different.

Variable	Reservoir[a] 4	5	6	7	8	9
Mean stocking weight (kg; ± SD)	0.21 ± 0.16 z	0.17 ± 0.09 z	0.20 ± 0.15 z	0.23 ± 0.15 zy	0.30 ± 0.18 y	0.33 ± 0.18 y
Mean harvest weight (kg; ± SD)	5.96 ± 1.26 z	5.11 ± 1.00 y	7.01 ± 0.77 z	2.78 ± 0.72 x	4.59 ± 0.82 w	5.51 ± 1.16 z
Relative growth	27.9	29.4	34.4	11.1	14.3	15.5
Trophic state index	73.0	77.5	73.5	72.6	75.4	78.6
Mean zooplankton biomass (μg/L; ± SD)[b]	171 ± 145 z	80 ± 74 y	31 ± 39 y	26 ± 28 y	29 ± 29 y	75 ± 128 y
Mean condition factor at harvest	0.51 zy	0.43 x	0.49 yx	0.33 w	0.47 yx	0.44 x

[a] Reservoirs 1–3 were controls that did not contain paddlefish.
[b] Measured during the April–October growth season.

significantly different ($P < 0.05$) among some reservoirs (Table 4). The effects of these conditions on mean harvest weights are unknown, as PIT tag loss prevented the tracking of individual fish and the distribution of the stocking size of fish surviving to harvest could not be determined. However, there was no pattern that would indicate that reservoirs with fish of low mean stocking weight produced fish of low mean harvest weight or that reservoirs with fish of higher mean stocking weight produced fish of higher mean harvest weight.

Mean weights at harvest were significantly different ($P < 0.05$) and ranged from 2.8 kg in reservoir 7 to 7.0 kg in reservoir 6 (Table 4). Paddlefish reaching the target market-size of 4.5 kg were harvested in five of the six reservoirs. Except for the two fish from reservoir 6, reservoir 4 produced the greatest percentage of market-size fish; no fish of market size were produced in reservoir 7. Reservoir 4 also produced the largest fish (9.69 kg), while the smallest fish (1.73 kg) came from reservoir 7. Relative growth (increase in weight) ranged from 11.1 in reservoir 7 to 34.4 in reservoir 6 (Table 4) and followed a trend similar to that of mean harvest weight.

No correlations existed ($P > 0.05$) between reservoir surface area and the measures of growth. A significant correlation ($r = 0.88$, $P < 0.05$) was found between relative growth and mean total alkalinity during the April–October growth season. Significant correlations also occurred between relative growth and two abiotic factors, conductivity ($r = 0.88$, $P < 0.05$) and mean sample site depth ($r = 0.90$, $P < 0.05$). A significant negative correlation existed ($r = -0.94$, $P < 0.05$) between mean harvest weight and photic zone depth. No correlations existed ($P > 0.05$) between mean harvest weight or relative growth and density (paddlefish/ha) at harvest.

Calculation of TSI for each study reservoir from the chlorophyll-*a* concentrations for April−October indicated little variation in reservoir fertility (Table 4). When TSI was calculated for each sample period, no significant differences were found based on ANOVA ($P > 0.05$). As expected, no significant correlations were found between TSI and the measures of growth.

Wide variability in the zooplankton biomass data prevented determination of statistical differences among reservoirs (Table 4), with the exception of reservoir 4. This reservoir was significantly higher in zooplankton biomass than the other reservoirs during the growth season ($P < 0.05$). No significant correlations were found between zooplankton biomass and the measures of growth ($P > 0.05$).

Mean weight at harvest was significantly higher in the nonweedy reservoirs (4, 5, 8, and 9) than in the weedy reservoirs (6 and 7; $P < 0.05$). The seasonal increase in mean fish weight was also higher in nonweedy reservoirs (Figure 1). Additionally, we found that zooplankton biomass, conductivity, and total organic carbon during the growth season were significantly lower ($P < 0.05$) in weedy reservoirs.

There were significant differences ($P < 0.05$) in the mean condition factor at harvest among some reservoirs (Table 4). Paddlefish from reservoir 4 had the highest condition factor, while those from reservoir 7 had the lowest. Correlations were not found between the condition factors and the measures of growth or other variables ($P > 0.05$).

Grazing Effects

Chlorophyll-*a* trends were similar, with the exception that the levels in the stocked reservoirs did

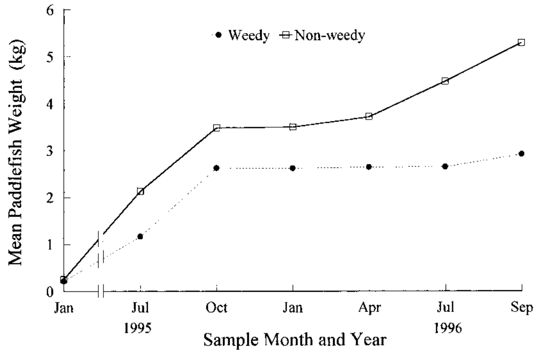

FIGURE 1.—Absolute growth of paddlefish in weedy versus nonweedy reservoirs.

not fall as rapidly as those in the controls in August 1996 (Figure 2). Little difference was apparent in the zooplankton biomass trends (Figure 3). Conductivity levels were consistently higher in the control reservoirs throughout the study compared with the average of reservoirs 7 and 8 (Figure 4); however, the trends were similar and no significant fluctuations were observed.

Discussion

The overall gross yield of 13.7 kg/ha in this study is similar to other published values. Studies by Alexander and Peterson (1982) and Combs (1982) found that the yield of paddlefish from natural production in reservoirs ranged from 11 to 22 kg/ha. Similarly, the yield from extensive culture of the zooplanktivorous bighead carp *Hypophthalmichthys nobilis* was reported to be approximately 22 kg/ha (Yang 1970). The wide range of yield values for individual reservoirs in this study indicates that it is possible to expect yields exceeding those reported in the literature if survival can be maximized.

Survival was lowest in reservoirs containing populations of largemouth bass *Micropterus salmoides,* with size distributions appearing to be skewed towards large individuals. This was particularly evident in reservoir 6 (which is weedy), where largemouth bass up to 2.7 kg were regularly caught during sampling and at harvest. Similar-sized largemouth bass were also caught regularly during sampling in reservoir 7 and during harvest in reservoir 9. Largemouth bass were present but were not frequently captured in other reservoirs with higher survival. Young paddlefish are known to be highly susceptible to predation by other fish. Tidwell and Mims (1990) reported zero survival of paddlefish of 9–15 cm TL that had been stocked together with channel catfish *Ictalurus punctatus*

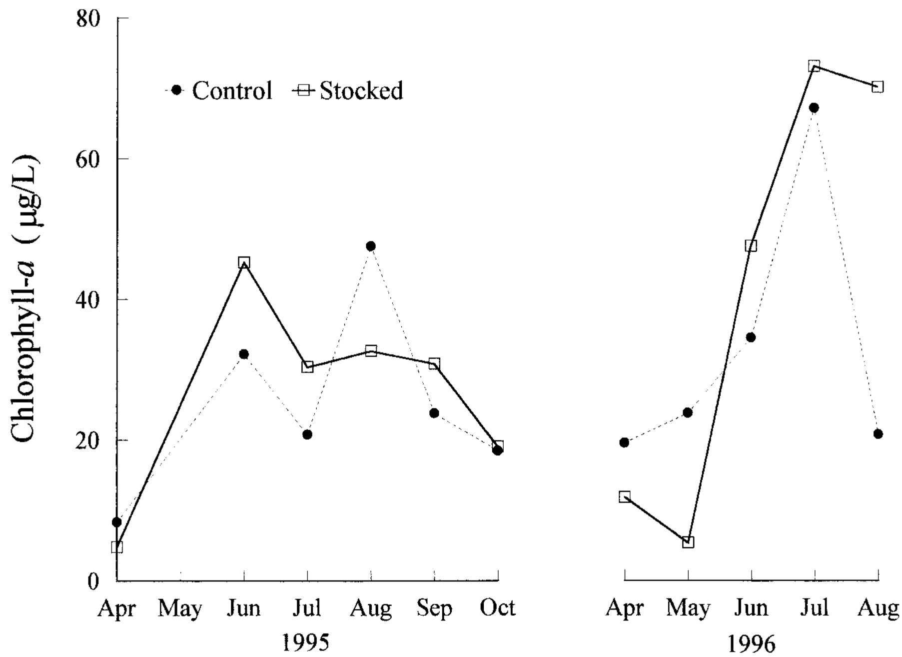

FIGURE 2.—Trends in chlorophyll-*a* concentration during the April–October growth seasons of 1995 and 1996 in reservoirs with and without (control) stocked paddlefish. Weather conditions prevented access to reservoirs in May 1995.

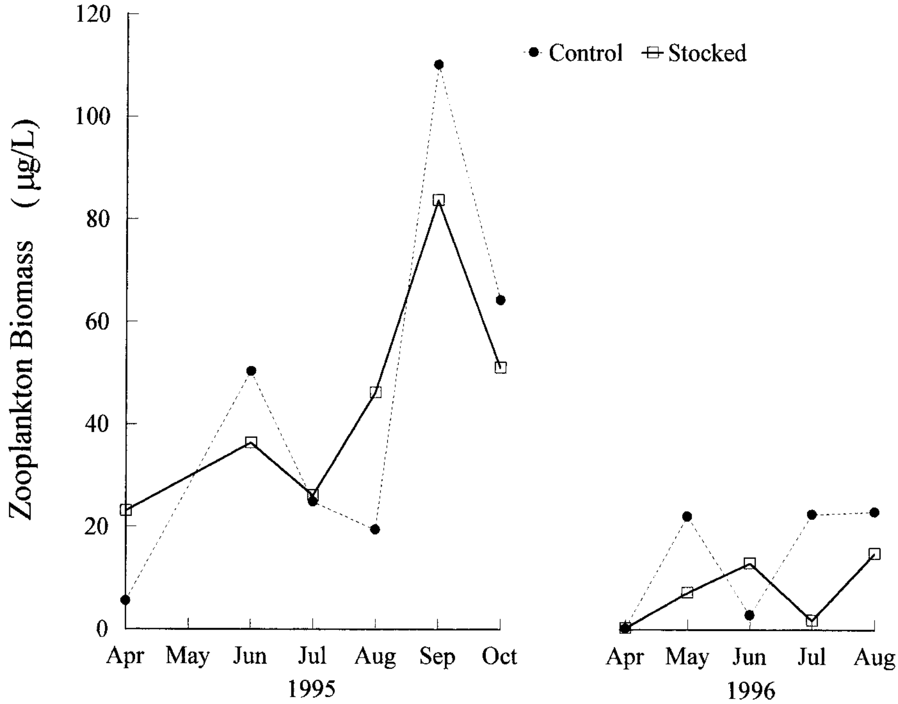

FIGURE 3.—Trends in zooplankton biomass during the April–October growth seasons of 1995 and 1996 in reservoirs with and without (control) stocked paddlefish. Weather conditions prevented access to reservoirs in May 1995.

(TL > 38 cm) in polyculture. Graham (1986) found that a minimum stocking size of 25–30 cm TL was necessary for reasonable survival in large reservoirs. The minimum stocking length in this study was 30 cm, and length ranged up to 67 cm. However, the effect of stocking size on survival could not be determined due to PIT tag loss.

The mortalities that resulted from handling and transport stresses are unknown, but all fish were observed swimming off following release. Barton et al. (1998) reported that paddlefish exhibited lower physiological responses to handling than similarly stressed teleosts such as salmonids. Either paddlefish are not stressed by handling as severely as teleosts, or they are different in their physiological capacity to respond to stress. While we assumed that initial poststocking losses were minimal, the possibility exists that variations in initial survival affected harvest rates. Aside from increasing the stocking size of fish and taking steps to decrease handling stress (such as reducing hauling tank density or transport time), one can reduce losses to predation and handling stress by stocking fish at the beginning of the growth season (April in the study area) instead of in early winter. This would ensure the presence of zooplankton and the energy necessary for recovery from stress. In addition, the onset of rapid growth at this time, as was observed in this study, would reduce the period during which fingerlings would be susceptible to predation. Although not practical for this study, losses through the mechanical spillways of small reservoirs could be controlled by installing screens over the trash racks.

It is possible that PIT tags were shed through the ostium, a one-way valve providing a pathway from the body cavity to the oviduct. This structure is present in both sexes, though it is less developed in males (Hoar 1969). High rates of PIT tag loss have not been experienced with salmonid applications in the body cavity, according to the manufacturer. However, we conclude that PIT tags are not suitable for use with paddlefish when implanted in the body cavity.

Monofilament gill nets were demonstrated to be highly suitable gear for harvest in small reservoirs. For paddlefish of the size harvested in this study, 102-mm-bar mesh was the optimum size. This study indicates that it is possible to capture most

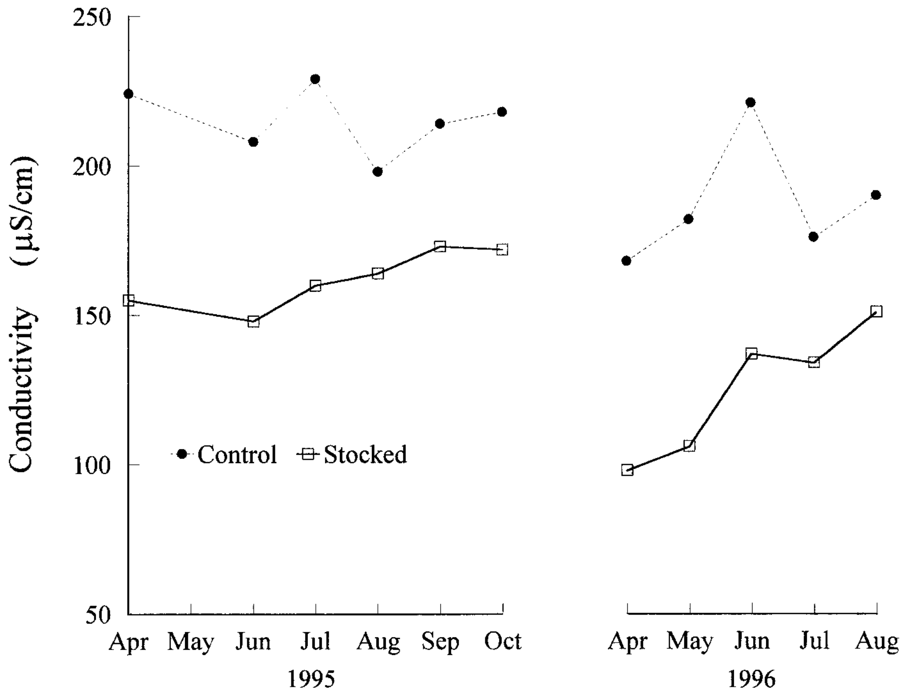

FIGURE 4.—Trends in conductivity during the April–October growth seasons of 1995 and 1996 in reservoirs with and without (control) stocked paddlefish. Weather conditions prevented access to reservoirs in May 1995.

of the harvest-size paddlefish in reservoirs between 14 and 40 ha within 24–36 h.

There was some indication that differences in reservoir fertility existed despite the similarity in trophic status as described by the TSI and that these differences resulted in growth differences among the study fish. For example, the strong positive correlations between both total alkalinity and conductivity and relative growth suggest that the reservoirs differed in their levels of available nutrients and that this affected growth. The strong negative correlation between mean harvest weight and photic zone depth suggests that the reservoirs were also different in their levels of primary productivity, as increased phytoplankton biomass increases turbidity (Boyd 1990). Finally, it is notable that reservoir 4, which had significantly higher zooplankton biomass during the growth season, also had the highest values for total alkalinity and conductivity during this period and produced fish of the highest (excluding reservoir 6) mean harvest weight.

Since only two fish were recovered from reservoir 6, the difference in growth between weedy and nonweedy reservoirs was examined by a comparison between reservoir 7 and reservoirs 4, 5, 8, and 9. As noted previously, infestations of American lotus reduced the open-water areas in reservoir 7 substantially during the growth season. Dobbins and Boyd (1976) reported a negative correlation between gross primary productivity and macrophyte biomass in a pond fertilization study. There were some indications from the data that fertility was lower in reservoir 7 than in the nonweedy reservoirs. Zooplankton biomass was lower as well, suggesting that reduced food resources in reservoir 7 restricted growth. In addition, the mean condition factor at harvest was lower in reservoir 7 than in any other reservoir.

The small sample size in this study restricted significant correlations to those with large positive or negative values for r. For the correlations between growth and density, r was required to be less than -0.81, but the closest value found was -0.77. This might be attributed to error in the regression method used to estimate survival, as the number of paddlefish recovered when reservoir 8 was drained would indicate. However, we do not conclude that paddlefish growth was limited by density.

The correlation between relative growth and mean sample site depth appears to be coincidental, as mean sample site depth was also correlated ($r > 0.90$) with alkalinity and conductivity, both indicators of fertility that were correlated with growth.

Filter-feeding fish are able to cause dramatic changes in planktonic communities and nutrient cycling because of the potential for filtering great volumes of water (Drenner et al. 1982). Intense predation on zooplankton can result in either sharp declines in the biomass of large zooplankton or shifts in the community structure toward dominance by smaller species that are not efficient grazers of phytoplankton (Hrbácek et al. 1961; Brooks and Dodson 1965). The result can thus be increased phytoplankton biomass (Andersson et al. 1978; Lynch and Shapiro 1981). Burke and Bayne (1986) found that paddlefish stocked at 990/ha in polyculture with channel catfish and blue catfish *Ictalurus furcatus* depressed zooplankton densities, with a concurrent increase in the standing crop of phytoplankton and a decrease in nutrient availability. Although their paddlefish stocking rate was excessive, their study illustrates the potential impact of paddlefish grazing on an aquatic community. However, we observed no such effects attributable to paddlefish grazing.

Our results indicate that reservoir ranching is a viable method for producing market-size paddlefish within 20 months of stocking fingerlings. Substantial paddlefish populations were established in five of the six reservoirs stocked, and harvesting was readily accomplished with conventional fishing gear. Yield was similar to the values expected from natural production in reservoirs. At the population densities realized in this study, there was no evidence that existing reservoir ecosystems were adversely affected.

Although the study reservoirs were similar in trophic status, some data indicated that paddlefish growth was correlated with reservoir fertility. Our evidence also suggested that macrophytes negatively impacted growth by reducing available habitat or fertility. Though anecdotal, there was evidence that largemouth bass predators affected survival and that some dispersal losses occurred through reservoir drain structures.

During the 20th century, paddlefish populations were isolated in the rivers altered and reservoirs formed by dam construction in their native range. Many of these populations had previously thrived and supported commercial fisheries (Carlson and Bonislawsky 1981). Most of these fisheries have been closed or severely restricted due to concerns about depleted stocks. Extensive aquaculture could be employed to revitalize this valuable fishery resource.

Acknowledgments

U.S. Department of Agriculture 1890 Capacity Building Grant 94–38814–0473 supported this research. The Kentucky Department of Fish and Wildlife Resources assisted in the stocking of paddlefish, and the Natural Resources Conservation Service arranged landowner and water board contacts. Kenneth Thompson, Miles Lange, David Mahl, Paul Woodall, James Dancy, Forrest Wynne, and William Wurts provided field assistance. Special thanks are due to the landowners who participated in this project, especially Ira Combs, Mark Combs, C. W. Davis, and James Hale.

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