Economic Benefits of Fishery Improvements Associated with Lake Destratification

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Abstract: Lake destratification was conducted from 1987 to 1989 at Beech Fork Lake, a 720-acre lake in West Virginia, to improve the fishery habitat. Improvements in the habitat was associated with increases in standing crop, harvest, catch, and recreational use. The economic benefits of the improvements were evaluated and compared to the cost of the destratification program. On an annual basis, the fishery benefits ranged from $5,676 for the harvest valuation method, to $30,000 for the catch valuation method, $100,282 for the fishermen use valuation method, and $726,660 for the standing crop valuation method. The benefit crop ratio ranged from 1 to 127 times the annual cost depending on the evaluation technique.

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As lake surface waters are warmed during spring and summer months, thermal-density stratification develops and hinders lake circulation. Typically, lakes form 3 distinct layers. The epilimnion, or upper layer, is characterized by warm temperatures, sufficient dissolved oxygen (DO), and good quality water. The hypolimnion, or bottom layer, is characterized by cold temperatures, low or depleted DO, and poor water quality. The thermocline, or metalimnion, is the layer between the epilimnion and hypolimnion, and is characterized by a temperature gradient. The hypolimnion comprises a large proportion of the water volume and benthic habitat in many North American reservoirs and is unsuited to biological productivity during most of the growing season. Lake destratification by man-made means has been demonstrated to be effective in improving water quality (Ewing 1969; Fast 1966, 1968, 1982; Garton et al. 1976; Garton and Punnett 1980; Hess et al. 1976; Hill 1987; Labaugh 1975, 1979, 1980; Moon et al. 1979; Price and Sneed 1989; Punnett 1978, 1988; Robinson et al. 1982; Steichen et al. 1974; Summerfelt and Cross 1983; Summerfelt and Hover 1969; Van Ray 1968). The economic benefits of fishery improvements associated with lake destratification has received little attention.

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Methods

Lake Destratification

Beech Fork Lake is a 720-acre Corps of Engineers lake near Huntington, West Virginia, in Wayne County. The lake is shallow, averaging only 13 feet in depth (maximum depth 35 feet), and is characterized by an infertile watershed of 78 square miles. The lake was first impounded in 1978. After an initial 3-year bloom, fishery productivity was considered poor while fisherman use was very high, averaging over 100 hours per acre each year. Poor water quality (DO below 2 mg/l) in the hypolimnion occurred during the productive summer months every year. The epilimnion tended to be shallow (<7 feet deep) and the thermocline tended to be both shallow and anoxic rendering most of the water volume and benthic habitat unsuitable for fishery, benthic, or primary production. In 1984 the Corps of Engineers began coordination with the West Virginia Wildlife Resources Division to correct this problem using Corps of Engineers environmental enhancement funds. The lake shape is bifurcated and dendritic (Fig. 1) and therefore not particularly suited for lake destratification by mixing from a single location.

Various methods have been used to improve the DO content in lakes. Mechanical mixing has been used to pump surface water downward to mix with the bottom waters to eliminate thermal stratification. This method has been demonstrated to be effective and economical in shallow lakes. Because of the size and depth of the lake, destratification by mixing using mechanical pumps was selected as the most cost-effective method. Four axial flow pumps were designed to operate in a cluster and installed by the Corps of Engineers near the dam site in spring 1987. The basic components of each pump are a platform, gearbox, motor, shaft, bearings, and propeller. A 6-bladed, 6-foot diameter, variable-pitch propeller was used to pump the water (Fig. 2). The pumping rate was about 75 cubic feet per second (cfs) with an average velocity of about 2.7 feet per second. Although 3.0 horsepower (hp) motors were installed, the power requirement was about 1.1 hp per pump at the blade setting used. An instructional report (Punnett 1991) describes the design criteria and considerations for axial flow pumps.

Fishery Sampling

Cove rotenone samples were obtained during the second week of August annually from 1981 through 1989 at the Pat Hensley Branch cove (Fig. 1) approximately 2.0 miles upstream of the destratification pumps. Additional cove samples during 1985, 1987, 1988, and 1989 were obtained at Dockside Cove (0.3 miles

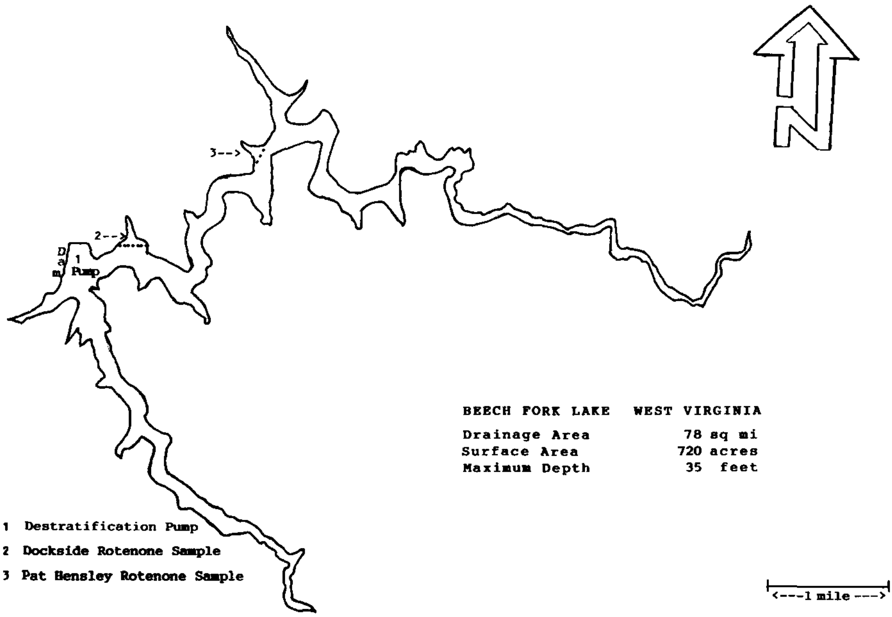

Figure 1. Study sites at Beach Fork Lake, West Virginia.

upstream of the destratification pumps) to supplement the Pat Hensley samples with a site representative of the deeper habitats affected by the pumps. A stratified random creel survey was conducted in April through October annually from 1981 to 1989. One weekday and 1 weekend day (10 hours each) were surveyed every week. Data were stratified by month, weekday, weekend day, boat angler, and shore angler. Pressure counts (1 hour for a complete round trip by boat) were obtained twice each day sampled. Starting times for pressure counts and the days of the week to be surveyed were assigned randomly.

Monetary Valuations

Initial Costs.—The 4 pumps were constructed by B&Q Machine in Leon, West Virginia. The 1987 cost of the 4 pumps was about $24,000. Additional parts (e.g., anchors, cables, fencing, warning signs, electrical supplies) and manpower at $200 per man day added $3,000 to the initial costs. The total expenditure for equipment and installation was about $27,000.

Maintenance and Operational Costs.—The daily operation cost for electric power at 6 cents per kilowatt hour was about $4.50 per day over a 4-month period each year. Pumps were removed for cleaning and repainting every 2 years. After power failures, the main power switch had to be reset. The gearbox oil was checked occasionally. Total operation and maintenance costs averaged about $3,000 per year.

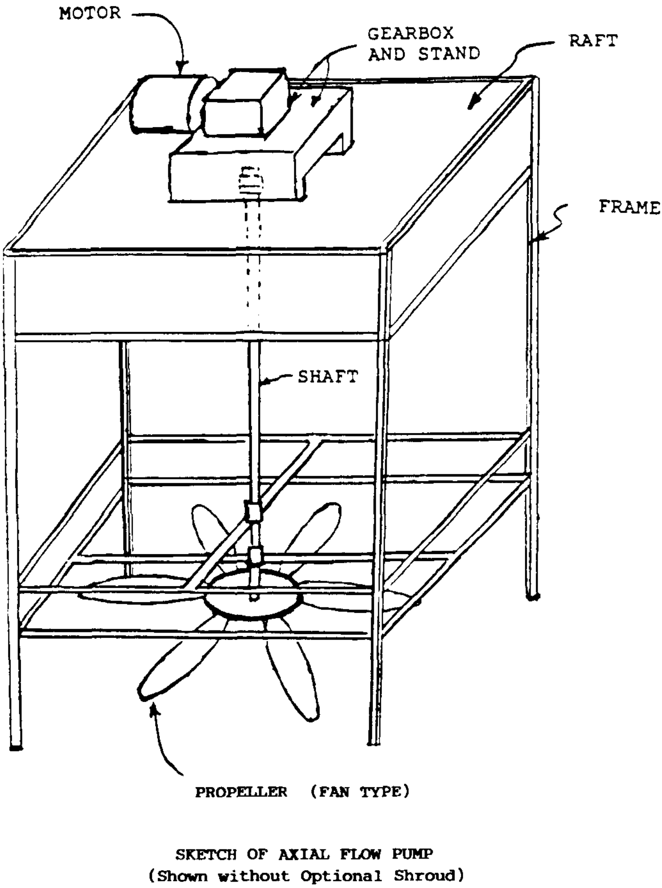

Figure 2. Destratification pump used in Beech Fork Lake, West Virginia.

Total Costs.—Total costs for the 10-year life expectancy of the pumps were estimated to be about $57,000; thus, the average yearly cost was estimated at $5,700.

Value of Fish.—The value of each fish in the standing crop (rotenone samples) and the harvest (creel survey) was assigned a value according to the Monetary Values of Freshwater Fish Committee (Am. Fish. Soc. 1982). Total values were corrected for inflation to reflect dollar equivalents in 1990.

Value of a Fisherman Day.—The value assigned to a fisherman day ($14.00) was derived from the 1985 National Hunting and Fishing Survey conducted by the United States Fish and Wildlife Service (U.S. Fish and Wildl. Serv. 1986). The values were reported for a warm water fishing day in West Virginia.

Value of the Catch.—No established guidelines or precedents were available for determining the monetary value of catching a fish. The value of a catch was assigned an arbitrary value of $1.00 each.

Results

Tarter et al. (1988) investigated water quality, primary production, and benthic production before and after destratification. Their studies revealed dramatic improvements in all conditions after destratification. Wildlife Resources Division studies revealed correlating improvements in the fishery, fishermen use, catch, and harvest (Hoeft 1988, 1989, 1990).

Rotenone samples at 2 coves revealed that in the overall standing crop of fish at Beech Fork Lake increased from 150 lbs/acre (A) to over 300 lbs/A during the first 3 years of destratification (Tables 1a, 1b). This is in contrast to the state wide average of all other reservoirs which dropped from 116 to 93 lbs/A during the same time periods. Standing crops of piscivorous species, sunfish, and rough and forage species all were approximately double previous levels. The percent composition by weight of rough and forage species remained relatively stable at about 75% of the total standing crop. Increases of the standing crop in each of the various size groups (fingerling, intermediate, and harvestable) of fish were also relatively uniform. These type of evenly distributed increases are consistent with what would be expected by an overall increase in the carrying capacity of the reservoir as suggested by the Marshall University studies (Tarter et al. 1988).

Increases in fishermen use (Table 2), catch (Table 3), number harvested (Table 3), and weight harvested (Table 3) accompanied the increases in the available fish for the fishermen. These increases were also evident when comparing the number of fish caught per acre and per hour, the number of fish harvested per acre and per hour, and the weight of fish harvested per acre and per hour.

The mean value of the harvest per year after destratification exceeded the mean value of the harvest per year before destratification by approximately $5,676. This benefit per year for the harvest valuation method was about the same as the cost per year for destratification ($5,700).

The mean value of the catch per year after destratification exceeded the mean value of the catch before destratification by about $30,000. This annual benefit valuation was >5 times the annual cost of destratification.

The mean total annual value of increased fishermen use (at $14.00 per day) after destratification greatly exceeded the mean value before destratification. The annual benefit of $100,282 yielded a benefit cost ratio of approximately 18 to 1.

The value of fish according to Monetary Values of Fish Publication (Monetary Values of Freshwater Fish Committee 1982) in Beech Fork Lake increased by approximately $726,660 after destratification. This annual benefit yielded a benefit cost ratio of approximately 127 to 1.

Discussion

The 4 different valuation methods used to identify the economic benefits of fishery improvements associated with destratification yielded very different results in benefit cost ratios from 1 for the increased value of the harvest to 127 for the

Table 1. Summary of Beech Fork rotenone survey data per acre before (7 samples) and after (6 samples) destratification (N = number of fish, Wgt − weight in pounds).

Species	Fish Mean Before	1990[a] Dollar Values	Fish Mean After	1990[a] Dollar Values	CL[b]	F[b] Factor	Net[a] Benefit
Largemouth bass							
Fingerlings-*N*	34.00	24.22	65.33	46.54	88.34	0.12	22.32
Fingerlings-Wgt	0.21		1.07		99.95	0.00	
Intermediates-*N*	5.14	8.64	14.00	23.52	95.86	0.04	14.88
Intermediates-Wgt	0.51		1.41		95.65	0.04	
Harvestables-*N*	4.00	16.18	5.83	23.60	48.74	0.51	7.42
Harvestables-Wgt	3.09		5.57		65.41	0.35	
Total *N*	43.14	49.05	85.17	93.67	94.52	0.05	44.62
Total Wgt	3.81		8.05		88.14	0.12	
Spotted bass							
Fingerlings-*N*	26.86	19.13	78.33	55.80	96.93	0.03	36.67
Fingerlings-Wgt	0.14		0.77		99.68	0.00	
Intermediates-*N*	3.14	5.28	12.00	20.16	96.74	0.03	14.88
Intermediates-Wgt	0.27		1.14		94.11	0.06	
Harvestables-*N*	0.71	2.89	4.17	16.86	99.33	0.01	13.97
Harvestables-Wgt	0.31		1.76		97.42	0.03	
Total *N*	30.71	27.30	94.50	92.83	98.41	0.02	65.53
Total Wgt	0.72		3.67		98.95	0.01	
Channel catfish							
Fingerlings-*N*	1.71	0.18	0.67	0.07	53.93	0.46	−0.11
Fingerlings-Wgt	0.03		0.02		21.62	0.78	
Intermediates-*N*	20.86	9.53	27.17	12.42	54.49	0.46	2.89
Intermediates-Wgt	1.92		3.26		97.34	0.03	
Harvestables-*N*	3.00	3.83	11.33	14.47	97.89	0.02	10.64
Harvestables-Wgt	2.38		12.54		99.05	0.01	
Total *N*	25.57	13.55	39.17	26.96	83.70	0.16	13.41
Total Wgt	4.33		15.81		99.16	0.01	
Crappie							
Fingerlings-*N*	5.71	2.84	246.50	122.59	99.75	0.00	119.75
Fingerlings-Wgt	0.07		1.08		98.41	0.02	
Intermediates-*N*	33.86	33.22	78.67	77.19	78.66	0.21	43.97
Intermediates-Wgt	2.44		7.01		91.83	0.08	
Harvestables-*N*	0.86	1.77	22.83	47.27	99.67	0.00	45.50
Harvestables-Wgt	0.18		4.70		99.47	0.01	
Total *N*	40.43	37.84	348.00	247.05	99.61	0.00	209.21
Total Wgt	2.70		12.79		97.89	0.02	
Total piscivorus[c]							
Fingerlings-*N*	73.57	50.82	391.17	225.81	99.83	0.00	174.99
Fingerlings-Wgt	0.55		2.99		99.61	0.00	
Intermediates-*N*	86.86	110.48	134.67	139.00	79.09	0.21	28.52
Intermediates-Wgt	7.82		13.02		87.86	0.12	
Harvestables-*N*	10.43	11.34	44.50	149.66	99.68	0.00	138.32
Harvestables-Wgt	6.75		27.82		99.51	0.00	
Total *N*	170.86	194.83	570.33	514.47	99.82	0.00	319.64
Total Wgt	15.12		43.83		99.65	0.00	

(*continued*)

Table 1. Continued.

Species	Fish Mean Before	1990[a] Dollar Values	Fish Mean After	1990[a] Dollar Values	CL[b]	F[b] Factor	Net[a] Benefit
Sunfish (BG+others)							
Fingerlings-*N*	591.86	238.66	649.17	261.77	21.15	0.79	23.11
Fingerlings-Wgt	3.92		2.58		59.79	0.40	
Intermediates-*N*	360.86	281.33	361.33	281.70	81.80	0.18	0.37
Intermediates-Wgt	11.29		13.89		67.99	0.32	
Harvestables-*N*	15.57	25.12	40.00	64.52	97.63	0.02	39.40
Harvestables-Wgt	1.77		6.28		98.36	0.02	
Total *N*	968.29	545.11	1050.50	607.99	30.20	0.70	62.88
Total Wgt	16.97		22.75		86.89	0.13	
Total Panfish[d]							
Fingerlings-*N*	595.71	238.97	653.50	262.30	21.37	0.79	23.33
Fingerlings-Wgt	3.94		2.63		58.36	0.42	
Intermediates-*N*	364.00	282.34	363.50	282.63	80.93	0.19	0.29
Intermediates-Wgt	11.61		14.11		66.55	0.33	
Harvestables-*N*	15.86	25.26	40.33	64.42	97.46	0.03	39.16
Harvestables-Wgt	1.85		6.42		98.11	0.02	
Total *N*	975.57	546.57	1057.33	609.35	30.08	0.70	62.78
Total Wgt	17.40		23.16		86.56	0.13	
Gizzard shad							
Fingerlings-*N*	354.86	28.62	777.17	62.68	52.34	0.48	34.06
Fingerlings-Wgt	3.19		8.45		62.53	0.37	
Intermediates-*N*	1367.43	312.47	2903.83	663.54	97.12	0.03	351.07
Intermediates-Wgt	85.66		188.17		99.22	0.01	
Harvestables-*N*	44.86	13.87	9.50	2.94	94.85	0.05	−10.93
Harvestables-Wgt	10.78		2.57		98.78	0.01	
Total *N*	1767.14	354.96	3690.50	729.16	97.48	0.03	374.20
Total Wgt	99.63		199.19		99.14	0.01	
Rough & forage fish[e]							
Fingerlings-*N*	404.14	32.59	836.83	67.49	53.34	0.47	34.90
Fingerlings-Wgt	3.46		8.81		63.29	0.37	
Intermediates-*N*	1472.00	335.06	2927.17	666.05	97.13	0.03	330.99
Intermediates-Wgt	98.97		192.19		99.29	0.01	
Harvestables-*N*	63.71	23.14	29.17	10.08	85.00	0.15	−13.06
Harvestables-Wgt	21.98		26.96		39.97	0.60	
Total *N*	1939.86	390.80	3793.17	743.62	97.69	0.02	352.82
Total Wgt	124.41		227.96		99.81	0.00	
% total *N*	60.01		67.98		61.93	0.39	
% total Wgt	77.79		77.27		9.93	0.90	
Grand Total *N*[f]	3086.29	1132.20	5420.83	1867.43	99.42	0.01	735.23
Grand Total Wgt[f]	156.93		294.95		99.98	0.00	

[a]Monetary values of freshwater fish converted to 1990 dollars (Anon. 1982).
[b]Analysis of Variance derived confidence level that a statistically significant change in number or weight has occurred.
[c]Piscivorous species include largemouth and spotted bass, tiger musky, channel catfish, crappie, and hybrid striped bass.
[d]Panfish species include bluegill, longear sunfish, hybrid sunfish, bullhead sp., and warmouth.
[e]Rough and forage species include gizzard shad, carp, suckers, minnows, and darters.
[f]Grand total includes piscivorous, panfish, and rough and forage.

Table 2. Summary of Beech Fork Lake angler use data before and after destratification.

	Before Mean 1981–86	After Mean 1987–89	CI[a]
Total hours fishing pressure	65,249	84,469	91.99
N angler hours per acre	91	117	91.99
Total *N* angler days	16,085	23,248	96.97
N angler days per acre	22	32	96.97
Average length of completed trip (hours)	4.1	3.6	96.17

[a]Analysis of variance derived confidence level that a statistically significant change has occurred.

increased value of the standing crop. Both methods relied on the same monetary values of fish. The lower value of benefits using the harvest valuation reflects the increasing tendency of anglers to practice catch and release fishing. Although both the mean catch of fish and the mean harvest of fish approximately doubled after destratification, Beech Fork Lake anglers keep only 1 of every 7 to 10 fish caught. Although the mean annual catch increased by 29,943 the mean annual harvest increased by only 5,840. Many fishermen at Beech Fork would be characterized as family group fishermen who fish for the pure pleasure of catching a fish with no intention of harvesting what they catch.

Determining an inherent value for catching a fish is difficult and establishment of a rational for assigning a definite monetary value has not been accomplished. Obviously, the value of each fish caught assumed in this paper ($1.00) is far less than the average value of the fish if each fish was assigned a value according to the Monetary Values of Fish Publication (Am. Fish. Soc. 1982). Most of these fish are returned to the fishery so it would not be logical to assign the full replacement value of the caught and released fish. The arbitrarily assigned value of $1.00 per fish is also far less than what would be expected if the value of a fishermen day ($14.00) was proportionally distributed across the 3 to 5 fish the average fishermen catches during a day of fishing at Beech Fork Lake. The value of a caught fish to a fishermen would vary according to the species, size, and number of fish caught. Presumably the value of the first fish caught would be far higher than the tenth fish caught during 1 day of fishing. Bass would be more valuable to bass fishermen and catfish would be more valuable to catfish fishermen. The experience of catching a large or trophy fish would be far more valuable to most fishermen than catching a small or average size fish.

However, destratification is valued, it obviously provides increased fishery productivity in a limited natural resource. Fishery improvements were especially noteworthy for crappie, channel catfish, sunfish, largemouth bass, and gizzard shad (Tables 1a, 1b). A $5,700 investment per year in a 720. acre lake increased the value of the fish in Beech Fork Lake by $726,660. The increased economic benefits associated with these fishery improvements accrue to the surrounding community in terms of increased purchases of food, lodging, gas, and other travel costs, and to

Table 3. Summary of Beech Fork creel survey data before and after destratification.

	Reservoir totals								
	N caught			*N* harvested			Pounds harvested		
Species	Before Mean 1981–86	After Mean 1987–89	CL[a]	Before Mean 1981–86	After Mean 1987–89	CL[a]	Before Mean 1981–86	After Mean 1987–89	CL[a]
Largemouth bass	4498	6236	66.98	1053	501	83.30	2059	1134	76.67
Spotted bass	296	648	94.87	80	62	24.83	122	104	18.08
Crappie	2496	8953	97.78	315	1432	92.60	81	504	94.49
Bluegill	29839	47367	94.42	2473	6617	93.19	412	1037	85.61
Channel catfish	1396	5265	99.69	377	1527	97.50	599	2277	95.04
Totals	38525	68468	96.91	4298	10138	92.49	3273	5055	72.49

	Totals per acre								
	N caught			*N* harvested			Pounds harvested		
Species	Before Mean 1981–86	After Mean 1987–89	CL[a]	Before Mean 1981–86	After Mean 1987–89	CL[a]	Before Mean 1981–86	After Mean 1987–89	CL[a]
Largemouth bass	6.3	8.7	66.81	1.5	0.7	82.19	2.9	1.6	74.19
Spotted bass	0.4	0.9	95.69	0.1	0.1	40.81	0.2	0.2	30.86
Crappie	3.5	12.5	97.86	0.4	2.0	93.05	0.1	0.7	94.43
Bluegill	41.5	65.8	94.37	3.4	9.2	93.13	0.6	1.9	95.58
Channel catfish	2.0	7.3	99.67	0.6	2.1	97.27	0.8	3.2	94.94
Totals	53.5	95.1	96.91	6.1	14.1	92.53	4.6	7.6	77.90

	Totals per hour								
	N caught			*N* harvested			Pounds harvested		
Species	Before Mean 1981–86	After Mean 1987–89	CL[a]	Before Mean 1981–86	After Mean 1987–89	CL[a]	Before Mean 1981–86	After Mean 1987–89	CL[a]
Largemouth bass	0.0687	0.0713	10.58	0.0158	0.0057	93.47	0.0312	0.0130	89.98
Spotted bass	0.0042	0.0073	90.58	0.0015	0.0010	55.90	0.0017	0.0025	25.19
Crappie	0.0387	0.1013	96.70	0.0045	0.0153	90.35	0.0013	0.0420	84.46
Bluegill	0.4550	0.5577	72.98	0.0367	0.0750	86.67	0.0062	0.0157	93.61
Channel catfish	0.0207	0.0617	99.83	0.0055	0.0170	97.76	0.0087	0.0253	94.34
Totals	0.5872	0.7993	90.01	0.0640	0.1140	84.36	0.0490	0.0985	79.97

[a]Analysis of variance derived confidence level that a statistically significant change has occurred.

the resource in terms of the increased revenues derived from taxes on increased sales of tackle, boats, and fuel. An improved fishery also provides a benefit we can not value monetarily, increased fishermen satisfaction. The main benefit of destratification may be what we want to see more of in all our states—happier fishermen.

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Table 4. Summary of destratification benefit evaluations for the Beech Fork creel survey and rotenone samples from 1981 to 1989.

Species	Dollar value of the catch[a]		
	Before Mean 1981–86	After Mean 1987–89	Net Benefits
Largemouth bass	$ 4,498	$ 6,236	$ 1,738
Spotted bass	296	648	352
Crappie	2,496	8.953	6,457
Bluegill	29,839	47,367	17,528
Channel catfish	1,396	5,265	3,869
Totals	$38,525	$68,468	$29,943

Species	Values of the harvest[b]		
	Before Mean 1981–86	After Mean 1987–89	Net Benefits
Largemouth bass	$11,192	$ 6,235	$−4,957
Spotted bass	656	566	−90
Crappie	396	2,496	2,099
Bluegill	3,186	8,926	5,740
Channel catfish	1,010	3,893	2,883
Totals	$16,440	$22,116	$ 5,676

Units	Value of fishermen days[c]		
	Before Mean 1981–86	After Mean 1987–89	Net Benefits
Fishermen days	16,085	23,248	7,163
FWS value @ $14/day	$225,190	$325,472	$100,282

Species	Values of the standing crop[a]		
	Before Mean 1981–86	After Mean 1987–89	Net Benefits
Total piscivorous	$140,278	$ 370,418	$230,141
Total panfish	393,530	438,732	45,202
Total rough & forage	281,376	535,406	254,030
Grand total	$815,184	$1,344,557	$529,373

[a]Using $1.00 per fish caught.
[b]According to monetary values of freshwater fish converted to 1990 dollars (Anon. 1982).
[c]According to the 1985 national hunting and fishing survey (U.S. Fish and Wildl. Serv. 1986).

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