COMMUNITY STRUCTURE AND DIFFERENTIAL IMPINGEMENT OF SAVANNAH RIVER FISHES

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Abstract: the fish communities of the middle Savannah River and 2 cooling water intake canals connected to the river had equal species richness and were equally diverse. However, the relative abundance of functionally similar species groups differed between the localities. Sunfishes were more dominant in the canal communities. Suckers contribued 55% of the biomass in all 3 communities. Impingement was very low and spread over 32 species. Three species of clupeids comprized 32% of the total number of fish impinged. The impingement of a number of species was disproportionate to their relative abundance in the intake canals.

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The fishes of the Savannah River in the vicinity of the Savannah River Plant (SRP), some 60 km downstream from Augusta, Georgia, are relatively well known. They have been sampled by the Academy of Natural Sciences of Philadelphia almost every year since 1951, when the SRP was created by the U.S. Atomic Energy Commission. They have recently been intensively sampled at monthly intervals during a study of entrainment and impingement at the SRP (McFarlane et al. 1978). Seventy species of fish are known to inhabit the Savannah River at this point and 10 additional species have been collected from the tributary streams of the SRP itself (Bennett and McFarlane, in press).

This study compares the relative abundance of fishes in the riverine community to that found in 2 large intake canals constructed to withdraw cooling water for nuclear production reactors and examines several aspects of community structure. It also reports on the differential impingement of those species inhabiting the intake canals during cooling water withdrawal. The study was conducted for the U.S. Department of Energy under contract AT(07-2)-1 to E.I. du Pont de Nemours and Co.

STUDY SITE AND METHODS

The study site is located 252 km upstream from the mouth of the Savannah River and 28.8 above sea level. The river varies from 100 to 150 m in width with a gradient of 0.12 m/km. The mean annual discharge at this point is 316 m^3/sec with a mean current velocity of 0.74 m/sec. Water depth fluctuates more than 4 m annually. Flow, temperature and water quality are effected by release of hypolimnetic water from Clarks Hill Dam and Reservoir 130 km upstrem of the study site.

The Savannah River Plant withdraws water for cooling and industrial purposes from two intake canals. The 1G intake canal is 550 m long with a broad, shallow cross-sectional profile. It varies seasonally from 30 to 70 m in width and from 2 to 10 m in depth. Maximum velocity approaches 0.24 m/sec. The 3G intake canal, 2.8 km further downstream, is of similar depth but shorter and broader, being 410 m long and varying seasonally from 27 to 90 m in width, with maximum velocity of 0.28 m/sec. The pumping

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regime was such that flow averaged 6.72 m^3/sec in the 1G canal and 12.04 m^3/sec in the 3G canal during the study period. Further details regarding the site and water withdrawal are available in McFarlane et al. (1978).

The fishes of the Savannah River and the intake canals were studied from March 1977 through February 1978. Collecting techniques included electrofishing, variable mesh gill nets, trammel nets, beach seines, wire traps and impingement samples. Fishes impinged at the pumping stations were sampled biweekly during the one year period; from March through June the fishes impinged were sampled for several consecutive days biweekly to determine the extent of daily variation. The trash screens generally were washed once daily, thus fishes collected during the washing operation represented a 24 hr. sample. Fishes inhabitating the river and intake canals were sampled monthly by nocturnal electrofishing from April through February. Fish movements were determined by tagging fishes with dart tags implanted in the dorsal muscles or, on smaller fish, fingerling tags tied to the first dorsal spine.

Community structure can be described by a number of measures. The simplest of thse is species richness (S), the number of species found in a given habitat. Since it is rare for a community to have all species equally abundant, a measure of diversity which takes into account the relative abundance of the species is desirable. The Shannon diversity index incorporates relative abundance and the form used here is:

$$H' = -\sum \frac{n_i}{N} \log_2 \frac{n_i}{N}$$

where n_i is the number of individuals of each species and N is the total sample size. This index permits the relative contribution of each species or species group to total diversity to be determined as well. The evenness with which the individuals of a community are apportioned is determined by the ratio of the observed diversity index to the maximum diversity possible (that is, complete evenness) for a given number of species. This evenness index (Pielou 1975) is calculated as:

$$J' = \frac{H'}{\log_2 S} .$$

A maximum evenness index value of 1.00 represents a community where all species are equally abundant and any tendency for one or more species to become dominant decreases the index value toward zero. Communities inhabiting stable, self-maintaining ecosystems typically exhibit evenness of 0.7 - 0.8 (Odum 1975).

Species overlap between communities is calculated as an index of similarity (SI) (Odum 1971):

$$SI = \frac{2C}{A + B}$$

where A and B represent the number of species known from localities A and B, respectively, and C is the number of species common to both.

A chi-square test of homogeneity for contingency tables (Christensen 1977) was used to determine whether the relative proportions of several species groups were equivalent between habitats.

RESULTS

More than 5500 fishes of 59 species were collected by all methods during this study. These species are subjectively categorized by relative abundance in Table 1. Five species were new to the list of SRP riverine fishes. A larval Atlantic sturgeon was collected in an

TABLE 1. The ichthyofauna of the Savannah River at the Savannah River Plant.

ABUNDANT[a]

American eel, *Anguilla rostrata*
Blueback herring, *Alosa aestivalis*
American shad, *Alosa sapidissima*
Silvery minnow, *Hybognathus nuchalis*
Spottail shiner, *Notropis hudsonius*
Spotted sucker, *Minytrema melanops*
Redbreast sunfish, *Lepomis auritus*
Bluegill, *Lepomis macrochirus*

COMMON[b]

Longnose gar, *Lepisosteus osseus*
Bowfin, *Amia calva*
Gizzard shad, *Dorosoma cepedianum*
Redfin pickerel, *Esox americanus*
Chain pickerel, *Esox niger*
Flat bullhead, *Ictalurus platycephalus*
Channel catfish, *Ictalurus punctatus*
Mosquitofish, *Gambusia affinis*
Brook silverside, *Labidesthes sicculus*
Warmouth, *Lepomis gulosus*
Redear sunfish, *Lepomis microlophus*
Largemouth bass, *Micropterus salmoides*
Black crappie, *Pomoxis nigromaculatus*
Yellow Perch, *Perca flavescens*

UNCOMMON[c]

Threadfin shad, *Dorosoma petenense*
Carp, *Cyprinus carpio*
Rosyface chub, *Hybopsis rubrifrons*
Golden shiner, *Notemigonus crysoleucas*
Ohoopee shiner, *Notropis leedsi*
Whitefin shiner, *Notropis niveus*
Coastal shiner, *Notropis petersoni*
Silver redhorse, *Moxostoma anisurum*
White catfish, *Ictalurus catus*
Pirate perch, *Aphredoderus sayanus*
Flier, *Centrarchus macropterus*
Bluespotted sunfish, *Enneacanthus gloriosus*
Pumpkinseed, *Lepomis gibbosus*
Spotted sunfish, *Lepomis punctatus*
Striped mullet, *Mugil cephalus*
Hogchocker, *Trinectes maculatus*

RARE[d]

Florida gar, *Lepisosteus platyrhinchus*
Eastern mudminnow, *Umbra pygmaea*
Ironcolor shiner, *Notropis chalybaeus*
Pugnose minnow, *Notropis emiliae*
Taillight shiner, *Notropis maculatus*
Quillback, *Carpiodes cyprinus*
Creek chubsucker, *Erimyzon oblongus*
Lake chubsucker, *Erimyzon sucetta*
Snail bullhead, *Ictalurus brunneus*
Yellow bullhead, *Ictalurus natalis*
Speckled madtom, *Noturus leptacanthus*
Atlantic needlefish, *Strongylura marina*
Lined topminnow, *Fundulus lineolatus*
White bass, *Morone chrysops*

Mud sunfish, *Acantharchus pomotis*
Dollar sunfish, *Lepomis marginatus*
White crappie, *Pomoxis annularis*
Swamp darter, *Etheostoma fusiforme*
Christmas darter, *Etheostoma hopkinsi*
Tessellated darter, *Etheostoma olmstedi*
Blackbanded darter, *Percina nigrofasciata*

NOT COLLECTED[e]

Atlantic sturgeon, *Acipenser oxyrhynchus*
Hickory shad, *Alosa mediocris*
Blueface chub, *Nocomis leptocephalus*
Dusky shiner, *Notropis cummingsae*
Northern hogsucker, *Hypentelium nigricans*
Brown bullhead, *Ictalurus nebulosus*
Tadpole madtom, *Noturus gyrinus*
Swampfish, *Chologaster cornuta*
Striped bass, *Morone saxatilis*
Banded pygmy sunfish, *Elassoma zonatum*
Green sunfish, *Lepomis cyanellus*

Table 1. (cont.)

[a] = Abundant: very likely to be collected in large numbers every time its habitat is sampled at the proper season.
[b] = Common: may be collected most of the time or in small numbers in the appropriate habitat and season.
[c] = Uncommon: may be collected quite regularly in small numbers in the appropriate habitat and season.
[d] = Rare: selcom encountered at any locality.
[e] = Not collected: reported from the site but assumed rare or accidental.

ichthyoplankton sample; adults have previously been reported by commercial shad fishermen. Striped mullet were repeatedly captured by electrofishing or traps. White bass have been introduced into upstream reservoirs and one specimen was collected in a canal. The mud sunfish and Christmas darter are more characteristic of SRP streams (McFarlane 1976) than the river, but both were impinged during this study.

Ten of the 65 species reported by the Academy of Natural Sciences of Philadelphia were not collected during this study. The blueface chub, dusky shiner, tadpole madtom and banded pygmy sunfish are all more characteristic of SRP streams than the river. The swampfish is rare and unlikely to be collected by the techniques used in this study. A striped bass was observed while electrofishing but eluded capture. The northern hogsucker was first reported in an SRP stream in 1974 (McFarlane 1976) and first collected in the river by the Academy in 1976. The inclusion of green sunfish in the SRP fauna is questionable while the absence of hickory shad and brown bullhead is notable (Bennett and McFarlane, *in press*).

The fishes found in the river were compared with those known to inhabit the intake canals. Single specimens each of the Florida gar, quillback and blackbanded darter were collected in the river but not in the intake canals. Thirteen species were found only in the canals, with all but the threadfin shad represented by 4 or fewer specimens. The swamp and Christmas darters were collected only by impingement. All fishes in the canals must have entered from the river, and this study indicated that virtually all fishes found in the river can be expected to appear in the canals.

The superficial similarity of the 3 fish communities is striking. Table 2 compares the pooled samples of fishes collected by all methods. Species richness, diversity and evenness values for the communities were nearly identical. The communities were categorized into 5 "functional" groups for further analysis. Five species (longnose gar, bowfin, redfin and chain pickerels, and largemouth bass) were considered top carnivores. Nine centrarchid species were combined as sunfishes. Nine cyprinid species (carp excluded) were grouped as minnows. The spotted sucker and silver redhorse formed the sucker category. All other species were combined into a single group.

The relative contribution of the functional groups to overall diversity (Table 2) indicated that the communities were not truly equivalent. Top carnivores contributed equally to diversity (7.1, 9.5, 7.3% of the river, 3G canal and 1G canal diversity, respectively). Sunfishes increased their contribution from river to 3G canal to 1G canal (29.0, 34.1 and 39.0% of diversity, respectively). Minnows contributed less to diversity in the canals (3G, 18.1%; 1G, 19.3%) than in the river (29.8%). Suckers also decreased from river (11.1%) to 3G (7.5%) to 1G (6.1%). Species overlap between the 3 habitats was very similar.

No single collecting technique provides an adequate approximation of an entire fish community but, among the techniques utilized in this study, the samples collected by electrofishing permit the most reasonable comparisions. They do not represent equal effort. The 2 canals were usually sampled on the same night each month in similar fashion (a continuous rectangular fishing pattern) but the canals differed in surface area and

TABLE 2. Characteristics of river and canal fish communities.

	River	3G Canal	1G Canal
Sample Size	1434	1802	2022
Species Richness	48	47	45
Total Diversity (H')	4.195	4.154	3.994
Top Carnivores	0.297	0.393	0.292
Sunfishes	1.216	1.418	1.558
Minnows	1.248	0.750	0.771
Suckers	0.464	0.310	0.242
Others	0.969	1.283	1.130
Evenness (J')	0.751	0.748	0.727
Species Overlap	River-3G	River-1G	3G-1G
Number of Common Species	37	39	41
Similarity Index	0.813	0.848	0.863

amount of floating vegetation. The river was sampled on another night each month at a number of points (submerged trees, sand bars, groins, etc. determined by experience to harbor fishes) rather than linearly. The samples for 7 consecutive months (May through November) are compared herein. The initial samples were omitted due to subsequent equipment modification which improved catch efficiency. The winter samples (December through February) were collected under adverse conditions (high river elevations, floodplain dispersal of fish, low water temperature) and few fish were captured. Certain fishes (e.g., catfishes, carp, mosquitofish) observed or collected by other techniques are known to be underrepresented in the electrofishing samples. However, assuming that the use of pooled (7 consecutive months) samples of 1107, 1174 and 1371 fishes is valid for certain comparisons, community structure can be examined.

Electrofishing samples are characterized in Table 3. Species richness, diversity and evenness of the 3 communities were very similar. The decreasing trend from river to 3G canal to 1G canal, first apparent in Table 2, is again seen. The number of both species and individuals collected in a given monthly sample was highly variable. Correlation analysis revealed that the number of species collected was highly correlated to sample size ($r=0.797$, $p<0.001$) but diversity was not ($r=0.241$). An analysis of variance of the diversity of the monthly samples was performed (Table 4). The null hypothesis that diversity of the 3 communities was equal could not be rejected. The number of fishes collected representing each functional group is shown in Table 5. A chi-square test of homogeneity demonstrated that the proportions of each functional group were not equivalent for the 3 localities ($p<0.005$). Sunfishes increased and suckers decreased in abundance from river to 3G canal to 1G canal.

Table 6 compares the proportion of total individuals to the proportion of total wet weight contributed by each group. Biomass data are less reliable because of the bias which can be contriubted by a few very large fish but several interesting points are apparent. The association between sunfish abundance and slower currents held for both numbers and biomass. Suckers accounted for about 55% of the biomass in all 3 localities. In fact, a single species, the spotted sucker, contributed 40.5, 51.7 and 48.7% of the total biomass of the electrofished sample of the river, 3G canal and 1G canal, respectively. Thus a substantial portion of these communities is supported by detritus and benthic organisms.

TABLE 3. Characteristics of electrofishing samples, May to November.

	River	3G Canal	1G Canal
Combined Sample			
Sample Size	1174	1107	1371
Species Richness	40	36	36
Diversity (H')	3.927	3.756	3.493
Evenness (J')	0.740	0.727	0.692
Monthly			
Number of Samples	7	7	7
Sample Size			
Mean	168.6	172.6	202.4
Range	83-389	86-281	121-324
Species Richness			
Mean	22.1	21.6	18.7
Range	18-27	17-27	12-24
Diversity (H')			
Mean	3,479	3.346	3.083
95% Confidence Limits	0.123	0.213	0.433

TABLE 4. Variation of Shannon diversity index (H') in electrofishing samples from 3 localities. Critical F(0.05, 2, 18) = 3.55, therefore the null hypothesis that diversity at the three localities is equal cannot be rejected.

	River	3G Canal	1G Canal	
May	3.274	3.415	2.755	
June	3.453	3.250	3.310	
July	3.680	3.455	2.932	
Aug	3.527	3.106	3.438	
Sept	3.355	3.476	3.196	
Oct	3.518	3.471	3.670	
Nov	3.546	3.027	2.277	
ANOVA Table Source	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio
Between Localities	3-1	0.5553	0.2776	F = 3.06
Within Localities	3x6	1.6324	0.0907	

TABLE 5. A chi-square test of the homogeneity of functionally similar groups of fishes from 3 localities, using composite samples. The critical chi-square ($P<0.005$, 8 df) = 21.955, therefore the null hypothesis that the numbers in one column are proportionate to the numbers in every other column is rejected.

	Number of Fishes			
	River	3G Canal	1G Canal	Total
Top carnivores	65	74	48	187
Sunfishes	221	353	618	1192
Minnows	556	366	462	1384
Suckers	174	112	80	366
Others	158	202	163	523
Total	1174	1107	1371	3652
Chi-square = 256.625				

TABLE 6. Relative percentage of numbers and biomass contributed by functional groups of fishes at three localities.

	River		3G Canal		1G Canal	
	Number	Biomass	Number	Biomass	Number	Biomass
Top carnivores	5.5	28.4	6.7	23.7	3.5	14.3
Sunfishes	18.8	5.5	31.9	8.6	45.1	16.8
Minnows	47.4	1.0	33.1	0.7	33.7	2.1
Suckers	14.8	54.6	10.1	56.0	5.8	55.4
Others	13.5	10.5	18.2	11.0	11.9	11.5

The top carnivores were dominated by the bowfin, which comprised 21.7, 17.4 and 5.8% of the total electrofished sample biomass in the river, 3G canal and 1G canal, respectively.

Canal fishes were tagged and released throughout this study to determine the extent of fish movement between the study habitats. Seventy of the 680 fishes of 22 species tagged were recovered. Only 2 fish were recaptured in an area other than the tagging locality. A redbreast sunfish tagged in the 3G canal was recaptured in the 1G canal 12 days later. A mullet tagged in the 3G canal was recovered in the river immediately upstream from the canal 42 days later. Fishes were recovered in their original canals at intervals as long as 6 months after tagging. Several fish were recaptured twice. Recapture rates for bluegills, redbreast sunfish, and redear sunfish were 12, 15, and 20%, respectivley.

Fish impingement was very low (Table 7), averaging 6 or fewer fish impinged per day or per million cubic meters of water pumped at each station. Thirty-two species of fish were impinged from the two canals (Table 8). No single species dominated the samples, as the most commonly impinged species, the threadfin shad, comprized only 18.5% of the total. Only 5 species contributed 5% or more of the sample.

DISCUSSION

Nearly all riverine fishes can be expected to enter the intake canals at some time. The sunfishes seemed particularly attracted to them. Sunfish established residence in the canals and also utilized them for spawning, as larval sunfish were more abundant in several canal ichthyoplankton samples than in river samples. While species richness and

TABLE 7. Summary of fish impingement, March 1977 to February 1978.

	1G Canal	3G Canal
Number of Days Sampled	39	44
Sample Days with Fish Impingement		
Number	30	40
Percent	76.9	90.9
Number of Species Impinged	28	30
Number of Fish Impinged	130	258
Weight of Fish Impinged (kg)	13.40	21.15
Maximum Number of Fish		
Per Day	17	28
Per km^3 of Water Pumped	49.4	27.5
Average Number of Fish		
Per Day	3.3	6.1
Per km^3 of Water Pumped	6.0	5.4
Estimated Annual Impingement	1204	2226

TABLE 8. Fishes impinged at canal pumping stations.

		Number	Percent
Threadfin shad		73	18.5
Gizzard shad		34	8.6
Channel catfish		31	7.9
Warmouth		25	6.4
Redbreast sunfish		20	5.1
Less than 5 percent of total sample			
Bowfin	Mud Sunfish		
American shad	Flier		
Redfin Pickerel	Bluespotted sunfish		
Chain pickerel	Bluegill		
Silvery minnow	Redear sunfish		
Golden shiner	Spotted sunfish		
Spottail shiner	Largemouth bass		
Lake chubsucker	Black crappie		
Flat bullhead	Hogchoker		
Pirate perch			
Less than 1 percent of total sample			
American eel	Speckled madtom		
Spotted sucker	Pumpkinseed		
White catfish	Dollar sunfish		
Yellow bullhead			

diversity of these habitats were nearly identical, component groups of fishes were not equally proportional. This may reflect differences in water velocity.

The low impingement rate associated with the cooling water withdrawal from the canals renders analysis of causative factors difficult. The small sample sizes and high variability (McFarlane et al. 1978) associated with a particular pumping station generally reduce the potential to demonstrate statistical significance. The configuration of an approach channel intake, individual intake bays, and conventional vertical traveling screens is generally considered unfavorable for low impingement (Ray et al. 1976). Yet impingement here was insignificant when compared to that experienced by electric power plants (Freeman and Sharma 1977).

A recent survey (Loar et al. 1978) of impingement at power plants in the southeastern U.S. indicated that clupeids comprized 98% of the fish impinged at 24 plants sampled for at least 1 year. A single clupeid, the threadfin shad, accounted for 90% of all impingement. Peak impingement occurred during winter when water temperatures fell below 10C. Water withdrawn from rivers resulted in less impingement than equivalent stations on reservoirs.

At the SRP the 3 clupeids impinged (American, threadfin and gizzard shad) contributed 31.7% of total impingement, with the threadfin shad accounting for 18.5%. Perhaps of equal interest, no blueback herring were impinged at all. The American shad and blueback herring are anadromous in the Savannah River and adults are present from late winter to late spring. Although many American shad perish after spawning, very few subsequently became impinged, perhaps because they settle rapidly to the bottom. Juveniles of both species became abundant in late summer and fall, and their feeding activity in the canals at dusk was very conspicuous. The last of the juvenile fish migrated to sea by early December. Neither adult nor juvenile herring were impinged, and very few juvenile American shad were impinged. Thus impingement did not reflect the great abundance of these species in the canals, even though they were collected by electrofishing directly in front of the pumping station intake bays.

Gizzard and threadfin shad are found in the river throughout the year. Gizzard, and perhaps threadfin, shad spawn in the study area. Gizzard shad were collected in both electrofishing and impingement samples at a low, continuous rate all year. Threadfin shad are an uncommon, introduced species in the Savannah River. Only 5 threadfin shad were captured in the monthly electrofishing samples -- 3 in April, 1 in November and 1 in February. The same effort produced 55 gizzard shad, 170 American shad and 95 blueback herring. Even additional electrofishing specifically directed at collecting juvenile clupeids rarely turned up a threadfin.

Threadfin are immobilized by water temperatures below 10C (Griffith 1978). The Savannah River experiences temperatures below 10C for 1 1/2 to 2 months each winter, and reached as low as 5C on 20 January 1977 and 31 January and 9 February 1978. It was during this latter period that threadfin and gizzard shad impingement drastically increased. Fully 84% of threadfin and 47% of gizzard shad impingement occurred during January and February. Both American shad and blueback herring were absent from the river during this period, and they did not enter the river until water temperature reached 12-13C.

A number of species were impinged rarely or not all all. Gar and carp were visibly conspicuous in the canals but neither was impinged. Redhorse and mullet frequently appeared in canal electrofishing samples but were not impinged. Water velocities rarely exceeded 0.3 m/sec at low water levels and decreased as the river rose. Shoreline currents were very low or imperceptible. The virtual absence among the impingement samples of small fishes commonly encountered in the intake canals, such as mosquitofish, topminnows, silversides, and 6 species of minnows, indicated that many small, resident fishes had little problem in avoiding impingement.

Differential impingement of closely related species, similar in size and body form, suggests that the selected microhabitat and behavior of certain species may affect their susceptibility to impingement. For example, Table 9 compares the relative abundance of the *Lepomis* species in the electrofishing, fish trap, and impingement samples from the canals. Electrofishing was biased toward fish in the near-surface water while traps and impingement sampled bottom-dwelling fishes more effectively. While the impingement sample size was smaller than desirable, the comparison suggests that warmouth appeared in impingement samples more frequently, and bluegills less frequently, than expected.

TABLE 9. Comparison of relative abundance of 7 *Lepomis* species in canal electrofishing, fish trap, and impingement samples, A chi-square test of homogeneity (x^2=252.428; critical x^2(0.005, 8df)=21.955) rejects the null hypothesis that the proportions in each column are equal.

	Electrofishing		Fish Traps		Impingement	
	N	%	N	%	N	%
Redbreast	338	36.3	293	55.6	20	25.6
Bluegill	463	49.7	157	29.8	9	11.6
Redear	68	7.3	30	5.7	12	15.4
Warmouth	15	1.6	31	5.9	25	32.1
Others	48	5.2	16	3.0	12	15.4
Total N	932			527	78	

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