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Fish-Habitat Relationships in the Streams of Fort Gordon, Georgia

by Jan Jeffrey Hoover, K. Jack Killgore

Prepared for U.S. Army Fort Gordon, Georgia

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Waterways Experiment Station
3909 Halls Ferry Road
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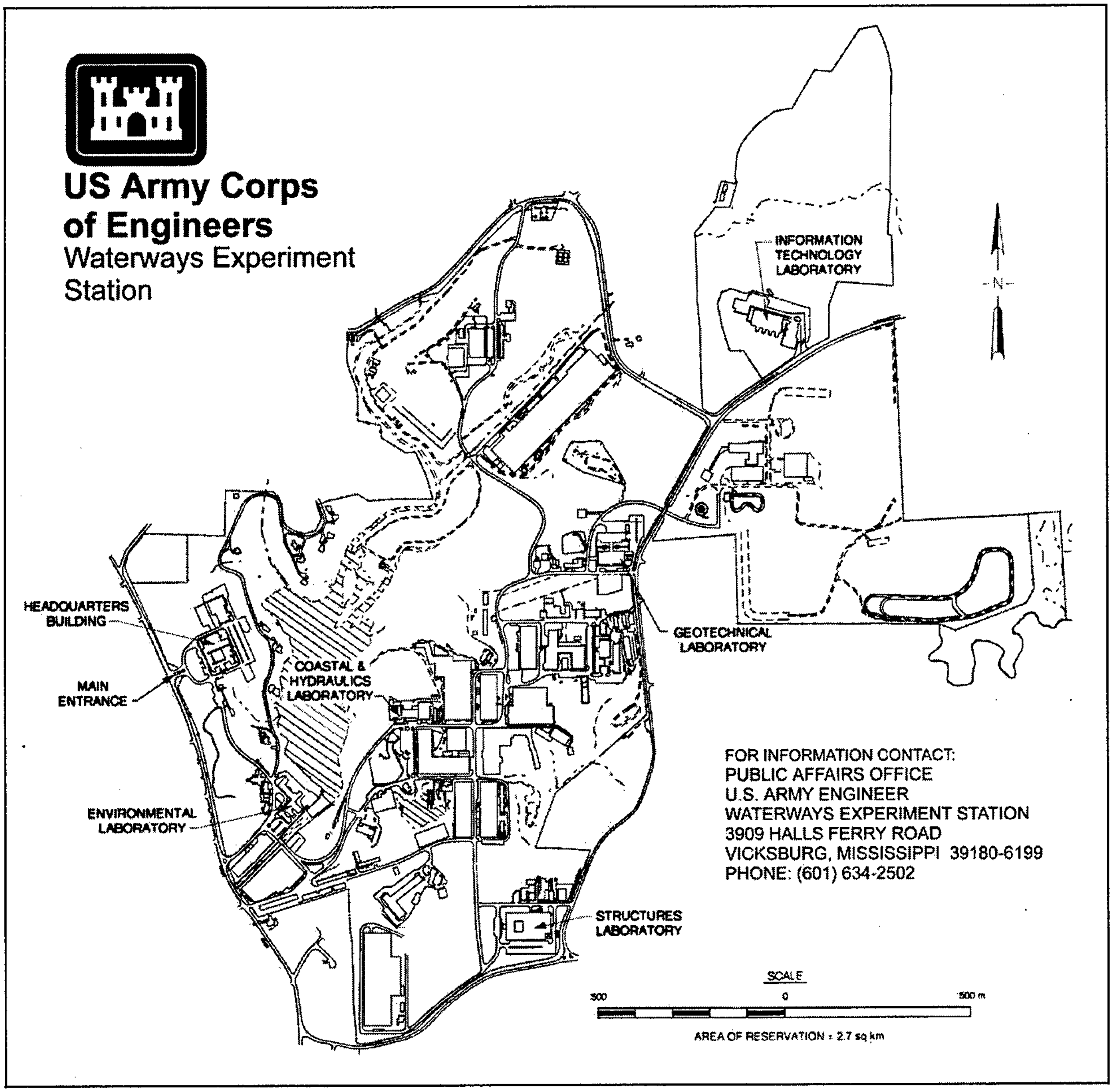

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Preface

This report describes fish assemblages in streams of U.S. Army Installation Fort Gordon, Georgia. Funding was provided by the U.S. Army Fort Gordon. Logistic support was provided by K. Boyd. Assistance in the field was provided by S. R. Adams, M. Chan, N. H. Douglas, S. G. George, S. L. Harrel. Fishes were identified and curated by N. H. Douglas. Mussels were identified by M. F. Vidrine and S. G. George. Assistance with the preparation of this report was provided S. R. Adams, S. G. George, and T. Robinson. This report was written by Drs. Jan J. Hoover and K. Jack Killgore, Environmental Laboratory.

During the conduct of this study, Drs. John Harrison and John Keeley were Directors, Environmental Laboratory; Dr. Conrad J. Kirby was Chief, Ecological Research Division; and Dr. Edwin Theriot was Chief, Aquatic Ecology Branch at the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. WES is a complex of five laboratories of the Engineer Research and Development Center (ERDC). Commander of ERDC during preparation of this report was COL Robin R. Cababa, EN.

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1 Introduction

Erosion degrades stream habitat and is associated with reduced fish diversity. Stream morphology is simplified as banks collapse, channels aggrade, and thalwegs loose longitudinal variation in width, depth and water velocity. Fish communities of southeastern blackwater streams are structured by hydraulic parameters (Meffe and Sheldon 1988) and changes in these parameters can result in significant alterations of fish habitat. Erosion also influences water quality by changing rates of flushing and mixing. Elevated suspended solids increase turbidity which impairs fish feeding and reproduction (Wilber 1983). Turbidity also reduces light penetration and aquatic plant growth that lowers diurnal pH and dissolved oxygen. Fish communities become numerically dominated by a few habitat generalists that tolerate reduced water quality (Ewing 1991).

Streams of Fort Gordon experience varying levels of erosion, but effects on fishes are undocumented. Aquatic resources on this military installation, including reservoirs managed for recreational fishing, are highly valued (Spinks 1991). There are no comprehensive surveys, however, of fish communities or fish-habitat relationships. Streams are tributary to the Savannah River, which along with the Ogeeche and Altamaha Rivers, harbor a fish fauna distinctive from that of other southeastern drainages (Swift et al. 1988). Communities are dominated taxonomically by specialized minnows, suckers, and darters, and several species are endemic. We present herein descriptions of fish communities and fish-habitat relationships for four streams that have not been intensively sampled and which exhibit a pronounced gradient of anthropogenic disturbance (Dahlberg and Scott 1971; K. Boyd, pers. comm.).

2 Study Area

Fort Gordon is approximately 135 km^2 of which 120 km^2 is forested land open to hunting and fishing; there are 26 lakes (Spinks, 1991). Eleven streams >2 km long occur in 3 separate drainages: Butler, Spirit, and Brier Creeks. Each discharges into the Savannah River and all streams occur just below the fall line between the piedmont and upper coastal plain (Dahlberg and Scott 1971). We sampled 19 stations in the Spirit and Brier Creek drainages (Figure 1).

Spirit Creek, 27 km long, experiences erosion in its upper reaches and discharge of sewage effluent in its middle reaches. Headwaters are extremely shallow, intermittent, and apparently uninhabited by fish (pers. obs.), so stations were restricted to middle reaches 15-18 km from confluence with Savannah River. Within Fort Gordon, Spirit Creek has 5 impoundments and 5 principal tributaries. Stations were sampled upstream from the outfall in McCoy's Creek, at the outfall, and two stations below the outfall, including the headwaters of Gordon Lake.

Sandy Run, 17 km long, experiences minor erosion and includes 3 main stem impoundments within the installation: Leitner, Lower Leitner and Union Mill Ponds. A large natural wetland occurs upstream from Union Mill Pond and area is used as a nature trail. Stations were sampled approximately 6, 9 and 11 km from stream's confluence with Brier Creek.

Boggy Gut, 20 km long, experiences minor erosion and is not impounded. Burch Mill Pond, 10 km upstream from the mouth of the creek, appears on older USGS maps (< 1977) and mill ruins create backwater. The stream flows through an military impact area but most impacts are not proximate to the stream. Stations were sampled approximately 5 and 10 km from confluence with Brier Creek.

Brier Creek, 115 km long, experiences minimal erosion and is not impounded. Stream has an extensive floodplain and hardwood forest. During high water, a dendritic series of channels, backwaters, and pools forms. Stations were sampled 79 and 81 km from the confluence with the Savannah River. Lower stations consisted of contiguous floodplain and main channel; upper stations included a secondary channel and a contiguous floodplain and main channel.

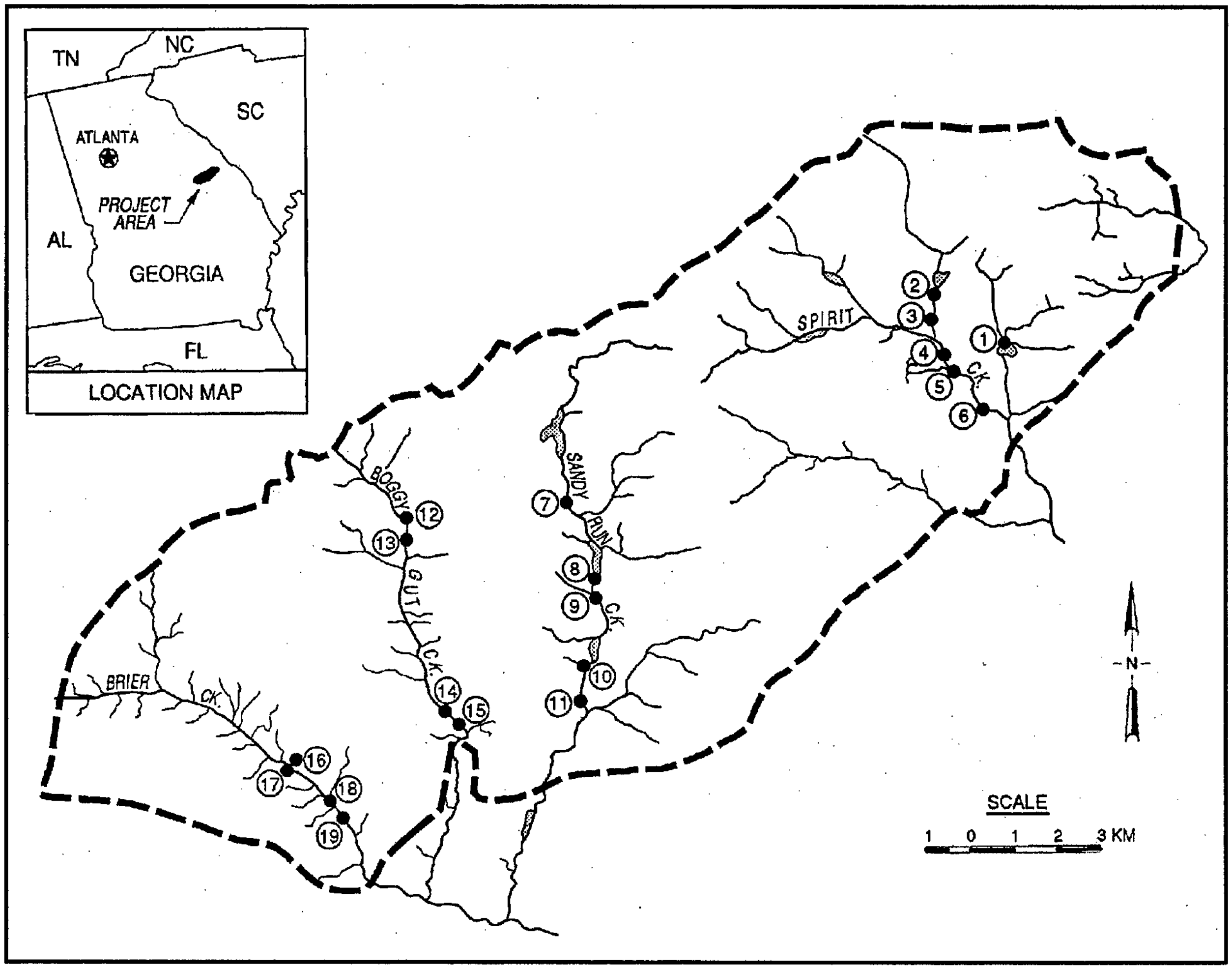

Figure 1. Fort Gordon, Georgia: Stations sampled for fishes

Stations varied in size and depth, but most consisted of riffles, runs, and pools. Vegetation occurred at all stations but was usually sparse, consisting of mosses and inundated grasses and forbs. Lush growths of a sedge (*Carex* sp.) occurred in Boggy Gut and dense water milfoil (*Myriophyllum* sp.) occurred at the uppermost site at the old mill.

3 Methods

Field Collections

Fishes and physical habitat data were collected concurrently at 18 stations (Table 1). Twelve stations were sampled quarterly; five stations were sampled three times, one station twice. One station, Mirror Lake (Station #1), was sampled qualitatively only once in October 1996. At that time, fishes were collected by seining, by picking up stranded individuals, and by observation. Sample design provided seasonal characterization of multiple stations for each stream, and a total of 14-20 samples per stream. Dispersion of stations allowed fish communities and fish habitat to be described for most of Fort Gordon with the exception of impoundments, urbanized and military impact areas (Figure 1). Stations represented small, low-order streams and larger, higher-order streams and were physically heterogeneous.

Fishes were collected using a 3.0 × 2.4 m seine with 5 mm mesh; standard effort was 10 hauls stratified among all apparent macrohabitats. Large, demersal fishes were collected with hoopnets 4.5 m long, 1 m diameter, with 2.5 cm mesh. Small fishes were preserved in 10% formalin, large fishes were identified in the field and released. Dissolved oxygen, temperature, pH, and conductivity were measured using a Hydrolab multiparameter water quality probe. Turbidity was measured with a Hach 2100P turbidimeter. Stream width was measured using a Lietz rangefinder. Water depth and velocity were measured at 10 points along a cross-sectional transect. Depth was measured to the nearest 3 cm using a Marsh-McBirney wading rod (<2 m) or a stadia rod (>2 m). Mean water column velocity was measured with a Marsh-McBirney Flo-Mate 2000; probe was set 60 percent from the water's surface in shallow water (depths <1 m), 20 percent and 80 percent in deeper water (depths >1 m), and velocity continuously measured for 10 seconds. When encountered, mussel specimens were collected by hand.

In the laboratory, fishes were washed, identified, and counted. Size (mm) was measured as total length (TL). Specimens were catalogued and deposited as holdings in the Northeast Louisiana University Museum of Zoology, or retained for collections at the Environmental Laboratory, Waterways Experiment Station. Taxonomy and nomenclature for most species conformed to that of Douglas

Table 1
Stations Sampled for Fishes at Fort Gordon, Richmond County, Georgia

Station No.	Stream	Location	Dec 95	Apr 96	Jun 96	Oct 96
1	Spirit Creek	Mirror Lake, 2.5 km W of Friendship Church, Sec. 12				X
2	Spirit Creek	McCoy's Creek, Signal Lake, Sec. 8	X	X	X	X
3	Spirit Creek	McCoy's Creek, North Range Road, Sec. 14	X	X	X	X
4	Spirit Creek	Sewage Outfall, 8 km SSE of Grovetown, Sec.14	X	X	X	X
5	Spirit Creek	0.4 km downstream from sewage outfall, Sec 14	X	X	X	X
6	Spirit Creek	Range Road, 100 m upstream Gordon Lake, Sec. 13		X	X	X
7	Sandy Run Creek	Between Leitner and Lower Leitner Lakes, Sec. 35		X	X	X
8	Sandy Run Creek	Outflow pool of Lower Leitner Lake, Sec. 34		X	X	X
9	Sandy Run Creek	300 m downstream from Lower Leitner Lake, Sec. 34		X	X	X
10	Sandy Run Creek	Outflow channel of Union Mill Pond, Sec. 33	X	X	X	X
11	Sandy Run Creek	300 m downstream from Union Mill Pond, Sec. 33	X	X	X	X
12	Boggy Gut Creek	50 m upstream from Gibson Road Bridge, Sec. 42/43	X	X	X	X
13	Boggy Gut Creek	50 m downstream from Gibson Road Bridge, Sec. 41		X	X	X
14	Boggy Gut Creek	Upstream from Harlem Road, Sec. 39	X	X	X	X
15	Boggy Gut Creek	Downstream from Harlem Road, Sec. 45	X	X	X	X
16	Brier Creek	2.5 km NNW of Avret Cemetery, floodplain, Sec. 49	X	X	X	X
17	Brier Creek	2.0 km NNW of Avret Cemetery, channel, Sec. 45/49			X	X
18	Brier Creek	1.2 km N of Avret Cemetery, confluence, Sec. 45/49	X	X	X	X
19	Brier Creek	1.2 km N of Avret Cemetery, braid, Sec. 45/49	X	X	X	X

(1974) and Mayden et al. (1992). Pygmy sunfishes were identified using Rohde and Arndt (1987). Spotted sunfish were identified according to Warren (1992). Mosquitofish were classified as eastern mosquitofish, *Gambusia holbrooki*, based on rationale and geographic ranges indicated by Wooton et al. (1988), although some variation in anal and dorsal ray counts were observed (N. H. Douglas, pers. comm.).

Fishes were quantified as catch-per-unit-effort: i.e., number collected in 10 seine hauls at a single station. Some analyses (e.g., community resemblance, distribution of species abundance) were performed on combined data for each stream (N = 4); other analyses (diversity measures, fish-habitat models) were performed with data from all individual collections in the study area (N = 66).

Community Resemblance

Resemblance of fish communities was expressed using a qualitative and a quantitative coefficient. Jaccard's index provides numerical expression of taxonomic similarity based on presence-absence of species (Jaccard 1908). It is calculated as

$$J = \frac{C}{A + B - C}$$

in which

C = number of taxa co-occurring in two species lists, a and b

A = total number of taxa occurring in species list a

B = total number of taxa occurring in species list b

J ranges from 0.00 (no taxa in common) to 1.00 (all taxa shared) and directly expresses the percentage of taxa shared between two collections. This index satisfies all logical conditions required of a binary (presence-absence) similarity index, although it exhibits slight curvilinear response to changes in species number (Hubalek 1982). It is, however, sensitive to variation in species occurrence, generally unbiased at small sample sizes, and interpreted unambiguously (Ludwig and Reynolds 1988).

Measures of Euclidean distance provide numerical expression of compositional dissimilarity based on abundances of species (Ludwig and Reynolds, 1988). Absolute Distance (AD) is calculated as

$$AD_{jk} = \frac{\sum_{i=1}^{S} [X_{ij} - X_{ik}]}{S}$$

in which

S = number of species for two sets of species-abundance data

X_{ij} = abundance of the i^{th} species at location i

X_{ik} = abundance of the i^{th} species at location j

AD ranges from 0 (every species is equally abundant at both locations) to infinity (value proportional to cumulative disparities in abundances of all species). Absolute Distance differs from other distance measures because it is sensitive to differences in absolute numbers of individuals (unlike percentage based functions) and because it is responsive to differences in abundance of uncommon species (unlike exponentially based functions). It was selected due to the variability in catch among streams and the relatively low abundance of many species. We summarize AD values as a dendrogram based on cluster analysis that employed group-average strategy (Ludwig and Reynolds 1988).

Station 1, Mirror Lake, was excluded from subsequent analyses since numbers did not result from a unit sampling effort and consequently were not comparable to other stations.

Fish Community Structure

Diversity was evaluated at three scales. We used an extrapolative technique (species-abundance analysis) to estimate total number of fish species in each stream, an interpolative technique (rarefaction) to compare species richness among streams, and a single measure (heterogeneity index) to describe diversity of individual samples.

Faunal diversity for each stream is described as a "dominance-diversity" curve: total fish collected (log scale) for individual species, from combined samples, plotted against rank of that species based on its abundance (e.g., Sheldon 1987). At least four patterns of species-abundance are possible (i.e., geometric, log-series, log-normal, and broken stick). Most communities, especially those consisting of moderate to large numbers of species, approximate a log-normal pattern, presumably a reflection of the Central Limit Theorem of statistics (Magurran 1988). Thus, our curve is tested for departure from log-normal distribution of species-abundance. Number of species observed for series of progressively doubling ranges (octaves) of fish abundance (0-1, 1-2, 2-4, 4-8, 8-16, 16-32, 32-64 individuals, etc.) is compared with that predicted by a derived log-normal model. Chi-square (x^2) analysis is used to compare the two (Ludwig and Reynolds, 1988). In subsequent iterations, two variables, S_o (modal number of species) and a (inverse measure of dispersion around that mode), are independently adjusted, so that model may better fit data, indicated by lower values for chi-square statistic. When chi-square is minimized or when model is judged to adequately fit data, a and S_o, may be used to estimate theoretical (total) number of species (S*) in that system, including those too rare to be observed, with this equation:

$$S^* = 1.77(S_o/a)$$

Species richness of fish communities in different streams is compared using rarefaction (Hurlbert 1971). This technique compensates for different fish abundances among samples and between streams. For series of samples, it expresses total number of species expected from a random subsample of specified size (e.g., 50 fish). This allows species richness for subsamples of equal size to be quantified. It allows direct comparisons of species richness among streams with different fish abundance. Construction of rarefaction curves (expected number of species for subsamples of increasing size) provides additional information (Ludwig and Reynolds, 1988). Slopes of the left-hand side of curve (i.e., at smaller sample sizes) and right hand side of curve (i.e., at higher sample sizes) allow, respectively, inference of equitability of species abundance ("evenness") and sampling effort required for detection of additional species. We present rarefaction data as a series of curves.

Numerous measures exist for quantifying diversity of individual collections, but frequently employed ratio-based indices of species richness and evenness are problematic when applied to small samples (Ludwig and Reynolds 1988; Magurran 1988). Shannon's heterogeneity index, H ′, incorporates both functions of diversity. It is discriminant, relatively unbiased, and satisfies logical and mathematical criteria specified in comparative studies of related indices. Several variants of this index exist, based on choice of log-function. We use a common variant based on natural log:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Values of H′ can range from near-zero (domination by a single species) to lnS (all species equally abundant). In most natural communities, H ′ ranges from 1.50-4.50 (citations in Magurran 1988). Values observed for most stream fish collections made using our field methodology typically range from 0.50-3.00.

Fish-Habitat Relationships

Hydraulic, geomorphic, and fish abundance data were $\log_{10}$ transformed because: (1) physical characteristics of stream channels are interrelated as power functions (Meffe and Sheldon 1988); (2) numbers of fishes varied by 2 orders of magnitude. Diversity measures and pH were not transformed because they are logarithmic functions. Transformed data provide homogeneity of variance and normal distributions of individual variables and improve linear relationships among variables. Such transformations also legitimize statistical tests of significance and reduce bias generated by outliers (Meffe and Sheldon 1988).

Physical similarity among streams was expressed using principal component analysis, or PCA (Gaugh 1982; SAS 1985). This provided an ordination of samples based on multiple habitat variables: turbidity, conductivity, pH, channel width, mean of velocity, mean depth. PCA allowed data reduction by plotting observations (samples), originally projected in a high-dimensional space (i.e., equal to the number of habitat variables) into a space of lower dimensions (2 principal components), while preserving as much of the original spatial configuration as possible. Parameters associated with the first and second principal component, PCI and PCII, were identified by disparately higher "loadings" or eigenvectors, which describe the degree of correlation between original habitat variable and the resulting component. PCA is frequently used to describe physical habitats of fishes (e.g., Matthews et al. 1985; Matthews et al. 1992).

We developed fish-habitat models for two groups of dependent (response) variables: "collective properties" of the fish community and abundance of individual species. For collective properties of fish communities (sensu Sheldon and Meffe 1995), we used total fish abundance and diversity (H '). These variables should reflect carrying capacity and habitat complexity, respectively. Also, diversity measures are frequently sensitive to environmental disturbances (Magurran 1988) and are positively correlated with habitat and water quality (Gorman and Karr 1978). Use of collective properties offers several advantages over single-species models: (1) obviates the necessity of subjectively selecting evaluation species; (2) represents habitat for majority of species in community; (3) provides dependent variable associated with community functions (e.g., stability, food web complexity, etc.); (4) provides statistical advantages (greater sample size, no zero observations, etc.).

Selection of individual species for habitat modeling was based on abundance, frequency of collection, and distribution. Habitat relationships were modeled for species represented by more than 60 specimens, occurred in more than 15 collections, and inhabited at least 3 of the four streams. These criteria compensated for small-scale zoogeographic effects (e.g., Rohde and Arndt 1987) and seasonal mass mortality of some species (e.g., Cowell and Resico 1975; Meffe et al. 1988). These criteria also reduced functional sample size but expanded ranges of independent variables and removed bias from large numbers of zero values which can create spurious correlations (Ludwig and Reynolds 1988).

Relationships between fishes and physical habitat are determined by correlating site-specific measures of fish abundance or diversity with habitat measurements. Those factors exhibiting high or significant correlations are presumed to influence the occurrence (richness) and/or abundance (evenness) of the greatest number of fish species, while those with low or nonsignificant correlations are presumed to influence fewer kinds or less abundant fish. Initially all samples (with the exception of Mirror Lake) were included in multivariate analyses. Station 16, upper Brier Creek floodplain, was subsequently excluded as an outlier (it was the only station not located at a stream thalweg, and stream width was not reliably measured).

Initially all physical variables were included. Temperature and dissolved oxygen were subsequently excluded as seasonal and diel effects. Physiologically extreme temperatures (>28 °C) and hypoxia (D.O. <4.5 mg/ℓ) were not observed. Mean values and ranges for these two variables were not appreciably different among streams. Consequently, neither should influence occurrence or abundance of most species. Exclusion of Station 16, temperature, and dissolved oxygen from multivariate analyses resulted in significantly improved fish-habitat models.

Stepwise linear regression procedure, MAXR (SAS, 1985) identified groups of habitat variables significantly correlated with abundance of individual species and with fish diversity. Models were considered statistically significant if $p < 0.05$. During iterations, variables added to model that increased $r^2 > 5\%$ and for which individual probability values <0.05 were retained. A maximum of three independent variables was included in each model. Final model was that with highest r^2 and lowest p values. Validity of individual correlates was confirmed by inspecting bi-variate plots of dependent (fish) variables and individual independent (habitat) variables. Variables for which correlations were generated by a few (or single) outlying samples were excluded from final model.

4 Results and Discussion

Fauna

Taxonomic composition

Forty-four species of fish were collected (Table 2). Most were sunfishes (10 species) and minnows (9 species). Darters and catfishes were moderately speciose (6 species each). There are 88 species native to the Savannah River drainage (Swift et al., 1988). Ichthyofauna is dominated by minnows (29 species) and sunfishes (16 species), but there are moderate numbers of suckers (9 species), catfishes (8 species) and darters (8 species). The fish fauna of Fort Gordon streams comprises approximately half of the species found in the entire drainage. Fishes not collected included minnows near the edge of their range or occurring above the Fall Line (e.g., bandfin and sandbar shiners), lowland forms (e.g., swamp darter, sailfin molly, several killifishes), large river and estuarine species (e.g., sturgeons, gars, herrings).

Five species accounted for more than half of all fishes collected (Table 2). Golden shiner (*Notemigonus crysoleucas*) was the most abundant species caught (32.3%) but most (1242/1277 fish) were collected once at a single station in Spirit Creek (#6). This species occurs throughout eastern North America and typically inhabits vegetated edges of ponds and lakes but makes diel migrations to feed on zooplankton (Barnett 1972; Hall et al. 1979). In Spirit Creek, we collected it early evening, possibly after it had migrated from Gorman Lake. There are few records of this fish in the western Savannah drainages so this population may have been introduced as forage or bait (Dahlberg and Scott 1971; Lee et al. 1980). Dusky shiner (*Notropis cummingsae*) were second in abundance (10.8%). Broadly distributed throughout Georgia and the Carolinas, disjunct populations occur in Florida and Alabama where the species is considered rare and of "special concern," respectively (Gilbert 1992; Schmidt 1996). Bluegill (*Lepomis macrochirus*), brook silverside (*Labidesthes sicculus*), and blackbanded darter (*Percina niogrofasciata*) were third- fourth- and fifth-ranked in abundance (7.5, 4.8, 4.2% , respectively). These species are broadly distributed throughout the southeastern states (Lee at el. 1980).

Table 2
Fishes of Fort Gordon, Richmond County, Georgia

	Spirit	Sandy	Boggy	Brier	Total
Number of samples	20	17	15	14	66
Esocidae, pikes					
Esox americanus, grass pickerel	2	12	19	34	67
E. niger, chain pickerel	1	12	10	5	28
Cyprinidae, minnows and carps					
Ctenopharyngodon idella, grass carp	1	-	-	-	1
Nocomis leptocephalus, bluehead chub	-	-	-	5	5
Notemigonus crysoleucas, golden shiner	1,276	1	-	-	1,277
Notropis chalybaeus, ironcolor shiner	-	-	8	129	137
N. cummingsae, dusky shiner	22	102	42	259	425
N. lutipinnis, yellowfin shiner	-	-	-	86	86
N. petersoni, coastal shiner	-	8	-	94	102
Opsopoeodus emiliae, pugnose minnow	-	-	-	6	6
Pteronotropis hypselopterus, sailfin shiner	-	-	129	-	129
Catostomidae, suckers					
Erimyzon oblongus, creek chubsucker	-	-	4	7	11
E. sucetta, lake chubsucker	9	-	6	-	15
Minytrema melanops, spotted sucker	0	2	3	2	7
Ictaluridae, catfishes					
Ameiurus brunneus, snail bullhead	-	-	-	1	1
A. natalis, yellow bullhead	1	4	3	-	8
A. nebulosus, brown bullhead	1	-	-	-	1
A. platycephalus, flat bullhead	1	-	-	-	1
Noturus gyrinus, tadpole madtom	-	5	-	-	5
N. leptacanthus, speckled madtom	-	115	27	3	145
Cyprinodontidae, killifishes					
Fundulus lineolatus, lined topminnow	5	43	79	2	129
Poeciliidae, livebearers					
Gambusia holbrooki, eastern mosquitofish	27	5	13	7	52
Aphredoderidae, pirate perches					
Aphredoderus sayanus, pirate perch	22	4	44	33	103

(Continued)

Table 2 (Concluded)					
	Spirit	**Sandy**	**Boggy**	**Brier**	**Total**
Amblyopsidae, cavefishes					
Chologaster cornuta, swamp fish	-	1	12	6	19
Atherinidae, silversides					
Labidesthes sicculus, brook silverside	-	142	40	8	190
Elassomatidae, pygmy sunfishes					
Elassoma okatie, bluebarred pygmy sunfish	-	-	23	-	23
E. okefenokee, Okefenokee pygmy sunfish	-	-	2	-	2
E. zonatum, banded pygmy sunfish	1	-	4	4	9
Centrarchidae, sunfishes and black basses					
Acantharcus pomotis, mud sunfish	-	-	3	-	3
Enneacanthus gloriosus, bluespotted sunfish	-	-	45	-	45
Lepomis auritus, redbreast sunfish	16	13	20	14	63
L. gulosus, warmouth	11	5	2	2	20
L. macrochirus, bluegill	198	51	1	48	298
L. marginatus, dollar sunfish	10	8	5	1	24
L. microlophus, redear sunfish	1	-	-	-	1
L. punctatus, blackspotted sunfish	3	19	47	12	81
Micropterus coosae, redeye bass	-	2	-	-	2
M. salmoides, largemouth bass	43	11	4	3	61
Percidae, perches					
Etheostoma fricksium, Savannah darter	1	38	59	8	106
E. fusiforme, swamp darter	6	-	2	-	8
E. inscriptum, turquoise darter	-	-	-	2	2
E. olmstedi, tesselated darter	-	4	-	54	58
E. serrifer, sawcheek darter	1	4	12	2	19
Percina nigrofasciata, blackbanded darter	31	95	35	7	168
Total number of species	23	27	31	29	44
Total number of fishes	1,690	707	703	844	3,944

Previous fish surveys at Fort Gordon indicated 8 species occurring in Fettig Pond (Terrell and Fox 1974) and 14 species in Headstall Creek (unpublished data, USFWS 1994). Most of these species were collected in our survey with some exceptions. Johnny darter (*Etheostoma nigrum*) was reported for Headstall Creek but, based on known geographic ranges, could be a misidentification of the tesselated darter (Dalhlberg and Scott 1971; Lee et al. 1980; N. H. Douglas, pers. comm.). River chub (*Nocomis micropogon*), margined madtom (*Noturus insignis*), and Christmas darter (*Etheostoma hopkinsi*) are also reported for

Headstall Creek but were not collected in this study. Populations at Fort Gordon would approximate edges of geographic ranges for all three (Lee et al. 1980).

Fishes of special status

We did not collect state-listed threatened or endangered species (Schmidt 1996). Four, however, are categorized as "special animals" by the Georgia Natural Heritage Program and a fifth, previously unconfirmed within the state, is likely to be listed (R. MacBeth, pers. comm.). All of these species were found in Boggy Gut, and three were restricted to that stream (Table 2).

Sailfin shiner (*Pteronotropis hypselopterus*) is a habitat specialist inhabiting high gradient streams of moderate to swift water velocity with sand and gravel bottoms; it often co-occurs with coastal and ironcolor shiners (Barnett, 1972). Other ecological information is sparse, but food habits have been studied. Like other species of semi-tropical shiners, it feeds on diatoms and a wide variety of macroinvertebrates but exhibits high selectivity for a few prey taxa (Cowell and Barnett 1972; Hoover 1981).

Bluebarred pygmy sunfish (*Elassoma okatie*) is a recently described species previously known from the Edisto, New, and eastern Savannah River drainages of South Carolina (Rohde and Arndt 1987). This, the first record from the western Savannah River drainage of Georgia, may constitute a rediscovery rather than a range extension. Faded museum specimens of pygmy sunfishes suggest that populations existed in Georgia tributaries of the Savannah River, including Boggy Gut, but recent collections failed to substantiate this (Rohde and Arndt 1987). Location of this population is notable for several reasons. It is the only confirmed report from the western Savannah drainage, 90 km NW of the previous northernmost record. It is remote, approximately 100 km from the Savannah River, whereas other documented populations occur within 30 km from the Savannah River (Hoover et al. 1998).

Mud sunfish (*Acantharcus pomotis*), uncommon across Atlantic slope, is apparently decreasing in geographic range (Cashner et al. 1989). In northern states, it is listed as "threatened" and is extirpated from some localities. Declines are attributed to reductions in wetland habitat (Pardue 1993). The mud sunfish is sedentary and experiences high annual mortality. Population sizes are usually low, but higher numbers are associated with aquatic vegetation (Tarplee 1979).

Savannah darter (*Etheostoma fricksium*) has an extremely small range but is not believed to be threatened (Kuehne and Barbour 1983). It is found in small to medium streams, in current, over sand and gravel, in or near areas of vegetation and woody debris. When co-occurring with swamp, tesellated, and blackbanded darters, it is usually the least abundant. It is unusually abundant, then, in Boggy Gut (Table 2). Life history has been documented for a population in the eastern Savannah River drainage (Layman 1993).

Sawcheek darter (*Etheostoma serrifer*) is sporadically encountered but believed to be in no immediate danger of extirpation (Kuehne and Barbour 1983). It occurs typically in swamps and backwaters, occasionally in lakes and impoundments, in vegetation and frequently in current. Species associates include swamp darter, redfin pickerel, pirate perch, tesellated and blackbanded darters. Life history information is limited (Kuehne and Barbour 1983).

Rare species

Several species were represented by 1-2 individuals and are considered rare on the installation. Pugnose minnow (*Opsopoeodus emiliae*) occur in slow, clear, weedy waters; extirpations in northern states are attributed to increased turbidity and siltation (Gilbert and Bailey 1972). There is little morphological variation in the subspecies occurring in the Savannah River, but pigmentation of the dorsal fin is believed to be associated with turbidity. Population in Fort Gordon occurs near eastern limits of geographic range.

Snail bullhead (*Ameiurus brunneus*) are considered common in rocky riffles, runs, and flowing pools (Rohde et al. 1994). Young specimens are found in small, clear streams. It is omnivorous but feeds frequently on snails.

Flat bullhead (*Ameiurus platycephalus*) occur in various habitats but are abundant in piedmont reservoirs (Olmstead and Cloutman 1979). Rarity in this survey may be attributed to reservoirs not being sampled. This fish is known to feed on moss animalcules (bryozoans) which we frequently encountered in outflow pools and channels from reservoirs.

Okefenokee pygmy sunfish (*Elassoma okefenokee*) inhabit quiet, weedy shallows or vegetated edges of open, deep water (Bohlke 1956; Barnett 1972). This fish frequently co-occurs with other species of pygmy sunfishes such as the banded pygmy sunfish (*Elassoma zonatum*) which is found in similar habitat (Barney and Anson 1920). We consider this record tentative. Species is not documented from the Savannah River drainage, but the closely related Everglades pygmy sunfish (*E. evergladei*) is recorded from the lower drainage (Lee et al. 1980; Swift et al. 1988).

Turquoise darter (*Etheostoma inscriptum*) are found in near large stones, near riffles, in large creeks or small rivers (Kuehne and Barbour 1983). There is little life history information available and darter biologists believe that it should be monitored for habitat-related declines.

Exotic species

Grass carp (*Ctenopharyngodon idella*), an Asian minnow used to control aquatic vegetation, was stocked at Fort Gordon in 1972 to assess possible impacts on native fisheries and potential for angling (Terrell and Fox 1974). They have been stocked repeatedly in all impoundments but recently stocked specimens are triploid (K. Boyd, pers. comm.). We observed one stranded individual at the Mirror Lake drawdown, but found no evidence of reproduction or dispersal in Fort Gordon streams.

Mussels

No mussel specimens were found in Spirit Creek or in Boggy Gut. Five species were recorded from Sandy Run (stations 12-15) and Brier Creek (stations 17-19):

	Stations						
	12	13	14	15	17	18	19
Eastern elliptio (*Elliptio complanata*)	+	+	+	+	+	+	+
Unidentified elliptio (*Elliptio* sp.)				+	+	+	+
Southern pondhorn (*Uniomerus obesus*)	+	+	+	+	+	+	+
Eastern creekshell (*Villosa delumba*)					+	+	+
Southern rainbow (*Villosa vibex*)					+	+	+

The southern rainbow was previously recorded from Brier Creek, along with two other species that we did not collect (USFWS, unpublished data). None of the five species collected are listed federally as species with special status; populations of all five species are considered "currently stable (Williams et al. 1993)."

Resemblance of Stream Fish Communities

Fish communities of Sandy Run and Boggy Gut exhibited high resemblance; resemblance was comparatively low between Spirit Creek and all other streams. Taxonomic similarity, based on presence-absence of individual species, was moderate in all pairwise comparisons among streams. For all species documented from either of two streams, approximately 55 percent occurred in both streams. Jaccard values were lowest for Spirit Creek and Brier Creek (J = 0.43) and highest for Sandy Run and Boggy Gut (J = 0.64). Compositional differences, based on abundances of individual species, were lowest between Sandy Run and Boggy Gut (AD = 49), highest between Spirit Creek and all other streams (AD >108) (Figure 2).

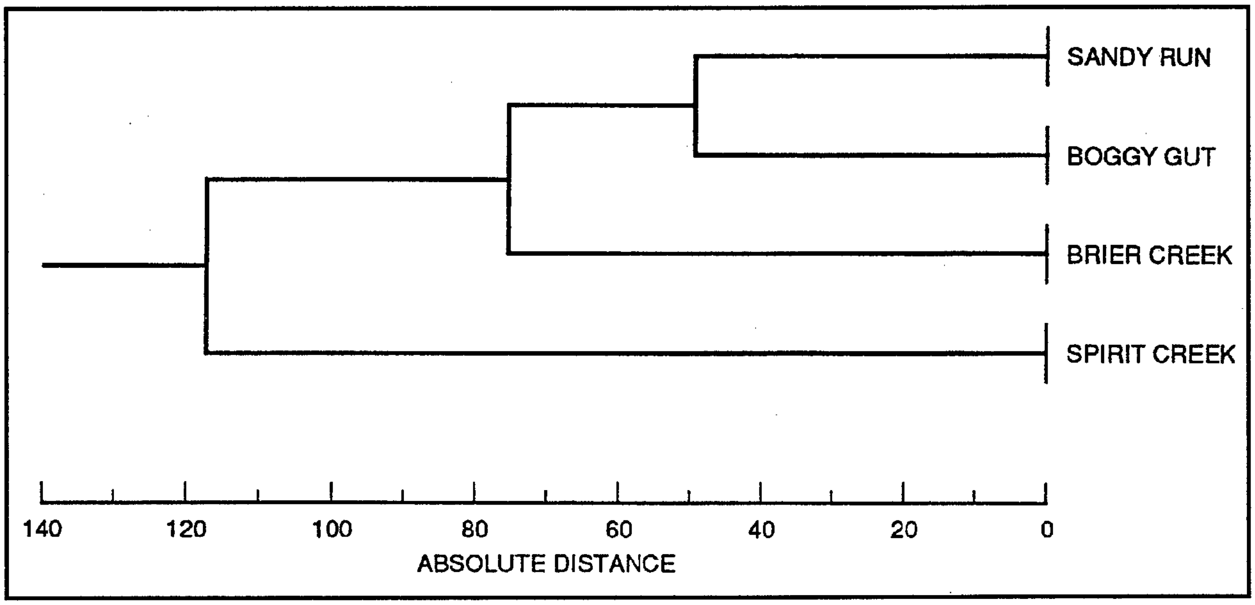

Figure 2. Dendrogram showing quantitative resemblance among fish communities in four streams

Community Structure

Species-abundance analyses

Dominance-diversity curves varied appreciably among streams (Figure 3) but log-normal models provided reasonable approximations of species-abundance pattern (Figure 4). Only a few species were very numerous or extremely rare; most fish were intermediate in abundance.

Dominance-diversity plots for Sandy Run and Brier Creek resembled sigmoid curves characteristic of log-normal pattern of species-abundance (Figure 3). Comparison of observed values with best-fit log-normal models for Sandy Run ($a = 0.220$, $S_o = 4.3$) and for Brier Creek ($a = 0.244$, $S_o = 5.3$) were not significantly different ($x^2 = 4.3$, 7 d.f.; $x^2 = 8.89$, 8 d.f.) (Figure 4). Spirit Creek, with fewer species and a steeper slope, resembles a log-series pattern of species abundance (Figure 3); true log-series distributions, however, are dominated by rare (1-4 individuals) species (Magurran 1988). Most Spirit Creek fishes were moderate in abundance (8-64 individuals) and a log-normal model ($a = 0.159$, $S_o = 2.4$) was not significantly different from observed values (Figure 4), although chi-square values reflected the lower degree of concurrence between observed and predicted values ($x^2 = 12.63$, 10 d.f.). Boggy Gut, with gradually decreasing abundances and an almost flat curve, resembles a broken-stick pattern of species abundance (Figure 3); broken-stick distributions are typically not speciose (Magurran 1988). A log-normal model ($a = 0.133$, $S_o = 4.8$) was not significantly different from observed values ($x^2 = 11.01$, 7 d.f.) (Figure 4).

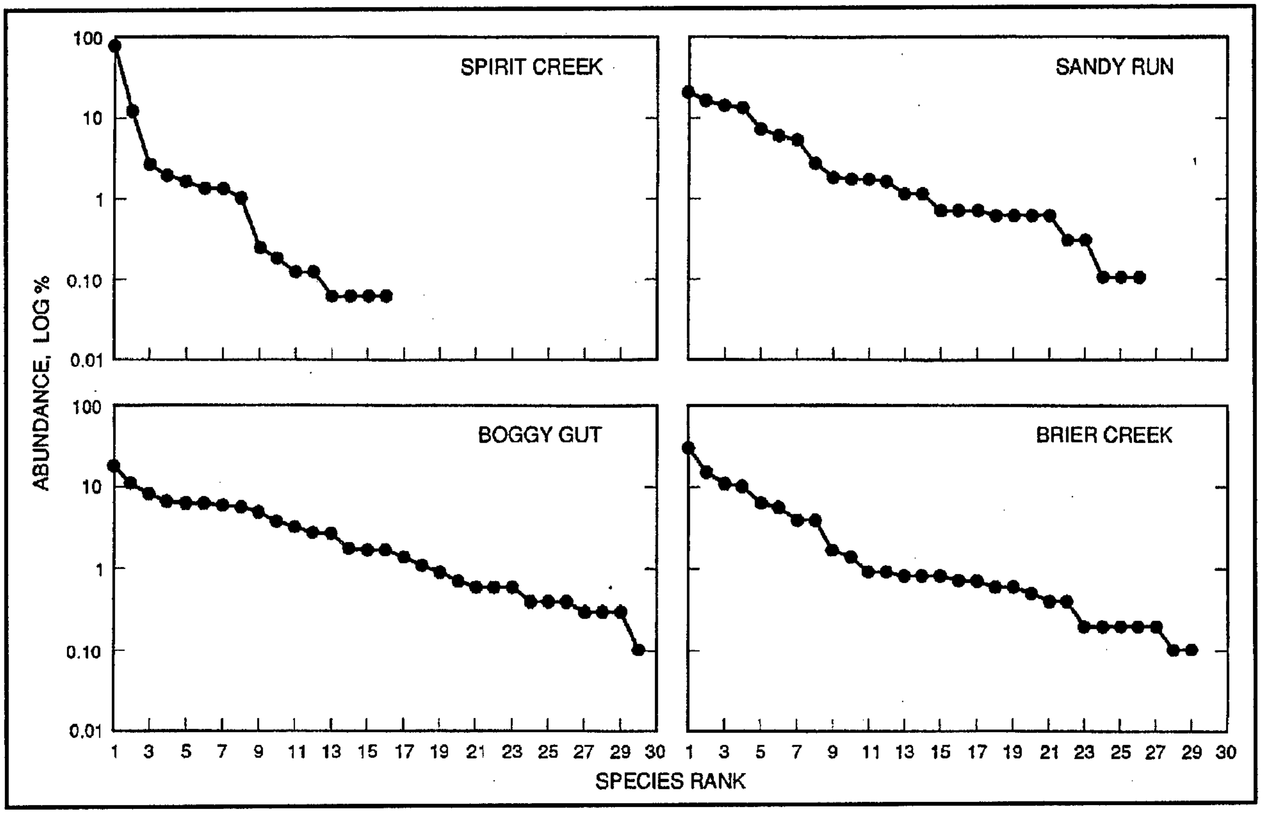

Figure 3. Dominance-diversity curves for fish communities in four streams

Estimates of total number of taxa (S*), based on log-normal models, indicated that fish fauna ranged from 27 species in Spirit Creek to 64 species in Boggy Gut (Figure 4). Values were moderate and comparable for Sandy Run (35 species) and Brier Creek (38 species). Differences between observed and predicted number of species (9-11 species) were comparable in Spirit Creek, Sandy Run, and Brier Creek. Boggy Gut, however, exhibited a disparity (34 species) suggesting that an alternative model may better describe species abundance relationships or that a large number of undetected species may inhabit that stream. New records and identification of unknown species are likely with additional sampling effort and is further supported by steep slopes of rarefaction curve (Figure 5).

Patterns of species-abundance other than log-normal are observed in environments that are either physically harsh, newly-formed, recently disturbed, or in which a single critical resource is equitably partitioned among all species (Magurran 1988). Log-normal distributions of species-abundance, however, comprise the predominant pattern observed in natural communities (May 1975; Ludwig and Reynolds 1988). Interpretation is that in speciose systems, relative abundances are a product of the interplay of many, independent factors. We address interactions of environmental factors on Fort Gordon stream fishes in a subsequent section using multiple regression models.

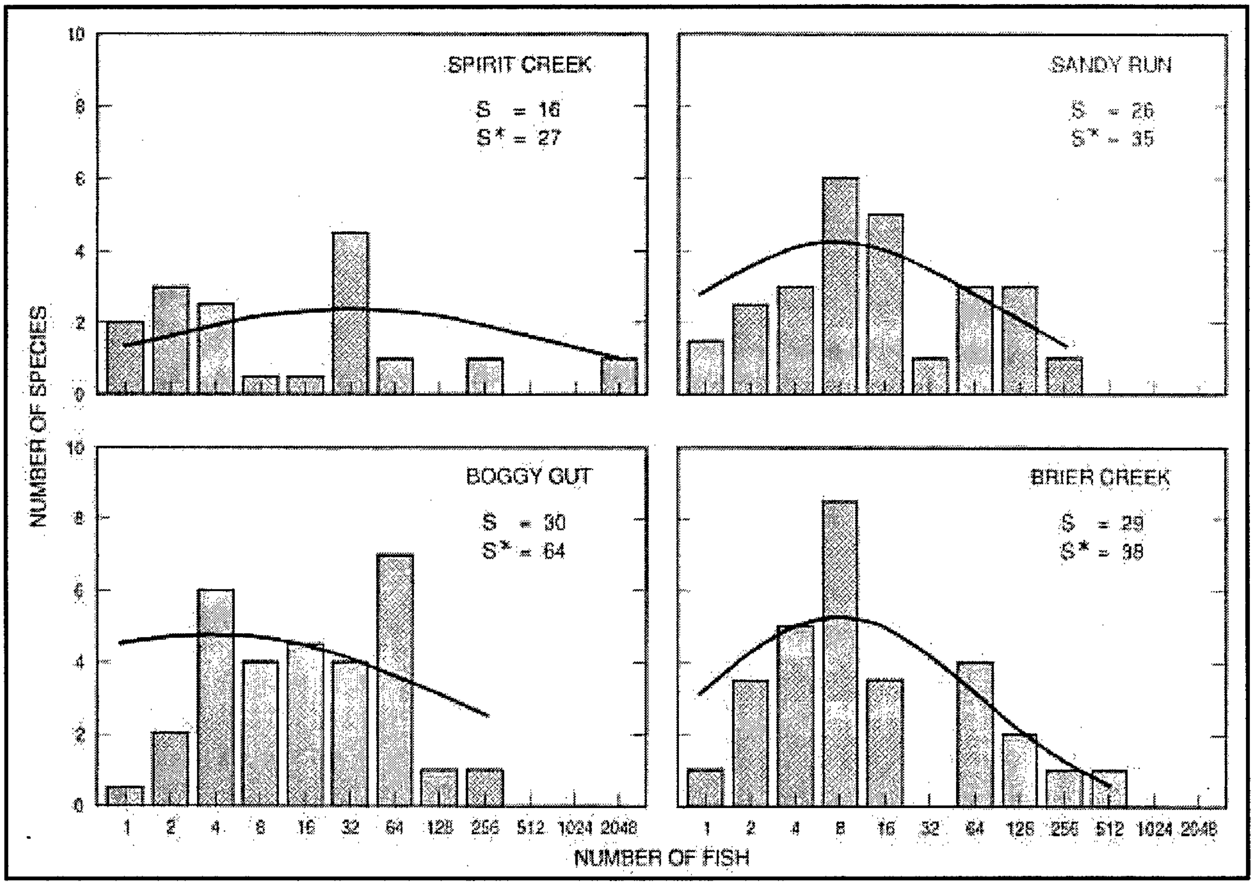

Figure 4. Species-abundance analysis for fish communities in four streams. Bars represent observed distribution of species number in progressively higher ranges of fish abundance. Curves represent predicted distribution of species number based on a log-normal model of species-abundance. S = number of species observed; S* = number of species predicted from log-normal model

Rarefaction

Curves indicated lowest fish diversity in Spirit Creek, highest fish diversity in Boggy Gut (Figure 5). For a sample size of 150 fish, expected number of species for Spirit Creek (12 species) was 40 percent lower than Sandy Run and Brier Creek (20 species) and 50 percent lower than Boggy Gut (24 species). Differences among streams was evident at relatively low sample sizes (50 fish) but larger samples (>200 fish) were required to detect differences in diversity between Sandy Run and Brier Creek. Equitability of abundance among species ("evenness") is suggested by curve shape (Ludwig and Reynolds 1988). Slopes are lowest for Spirit Creek, indicating disparate abundances among species, moderate for Sandy Run and Brier Creek, and highest for Boggy Gut, indicating equitable abundances among many species.

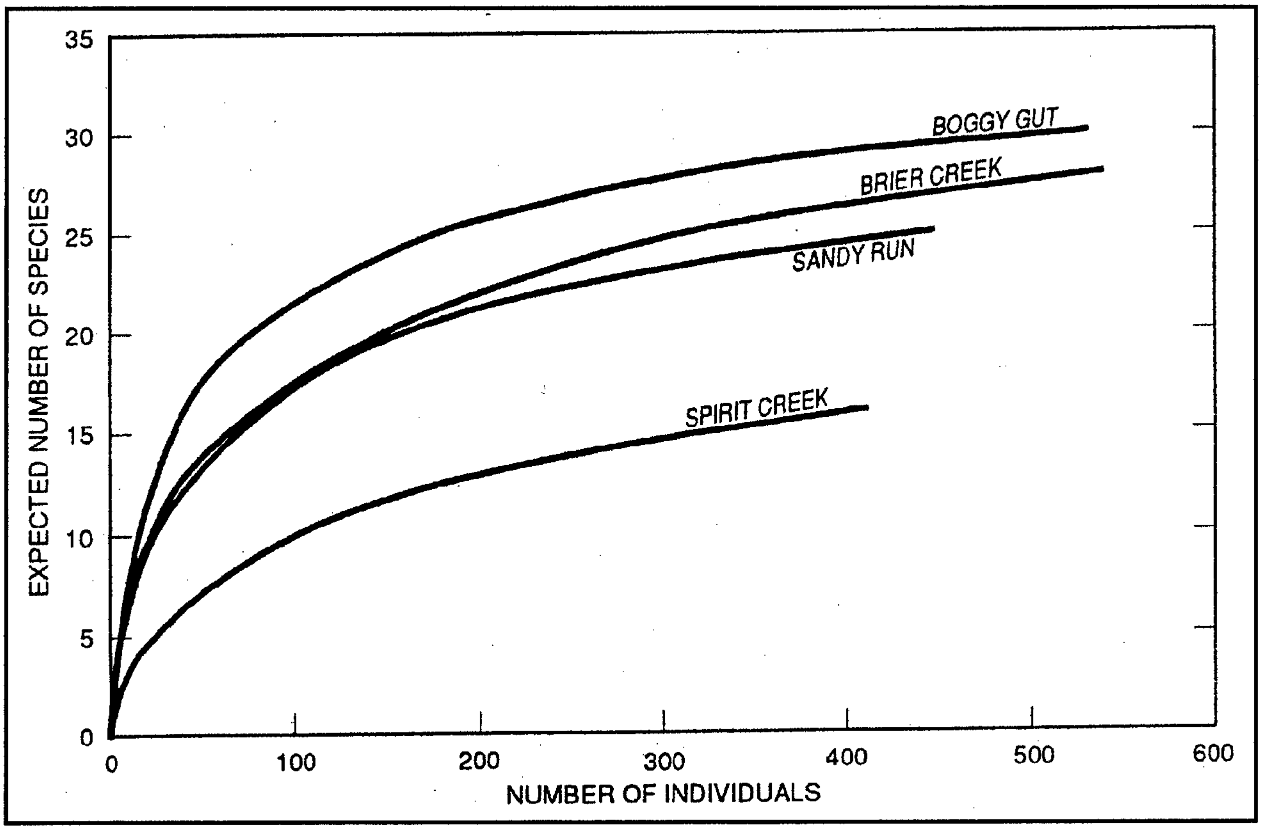

Figure 5. Rarefaction curves for fish communities in four streams

Heterogeneity indices

Abundance and diversity of fishes in individual samples was lowest in Spirit Creek. Abundance was highest in Brier Creek, diversity indices highest in Boggy Gut:

	Number/10 seine hauls		H'	
	Mean	**Range**	**Mean**	**Range**
Spirit Creek	10.7	1-67	0.71	0.00-1.59
Sandy Run	41.6	5-89	1.38	0.00-2.23
Boggy Gut	46.9	11-94	1.84	1.29-2.46
Brier Creek	63.6	15-131	1.63	0.85-1.63

We exclude here the anomalous occurrence of more than 1000 golden shiner at Spirit Creek (station #6) in July.

Fish-Habitat Relationships

Principal components analysis

Waters were typically clear, although frequently tannin-stained, acidic, shallow, with slow to moderate velocity, but differences in physical habitat was detectable among the four streams (Figure 6). PCI and PCII accounted for 42.5 percent and 27.9 percent of dataset variance respectively. Three variables were associated with (i.e., had high loadings on) PCI: conductivity (0.485), turbidity (0.450), and depth (-0.467). Samples at the left hand side of the abscissa were low in conductivity, clear, and deep; samples at the right were high in conductivity, turbid, and shallow. Two variables were associated with PCII: stream width (0.551) and velocity (-0.468). Samples at the lower half of the ordinate are narrow and fast-flowing, samples at the upper end of the ordinate are wide and slow-flowing.

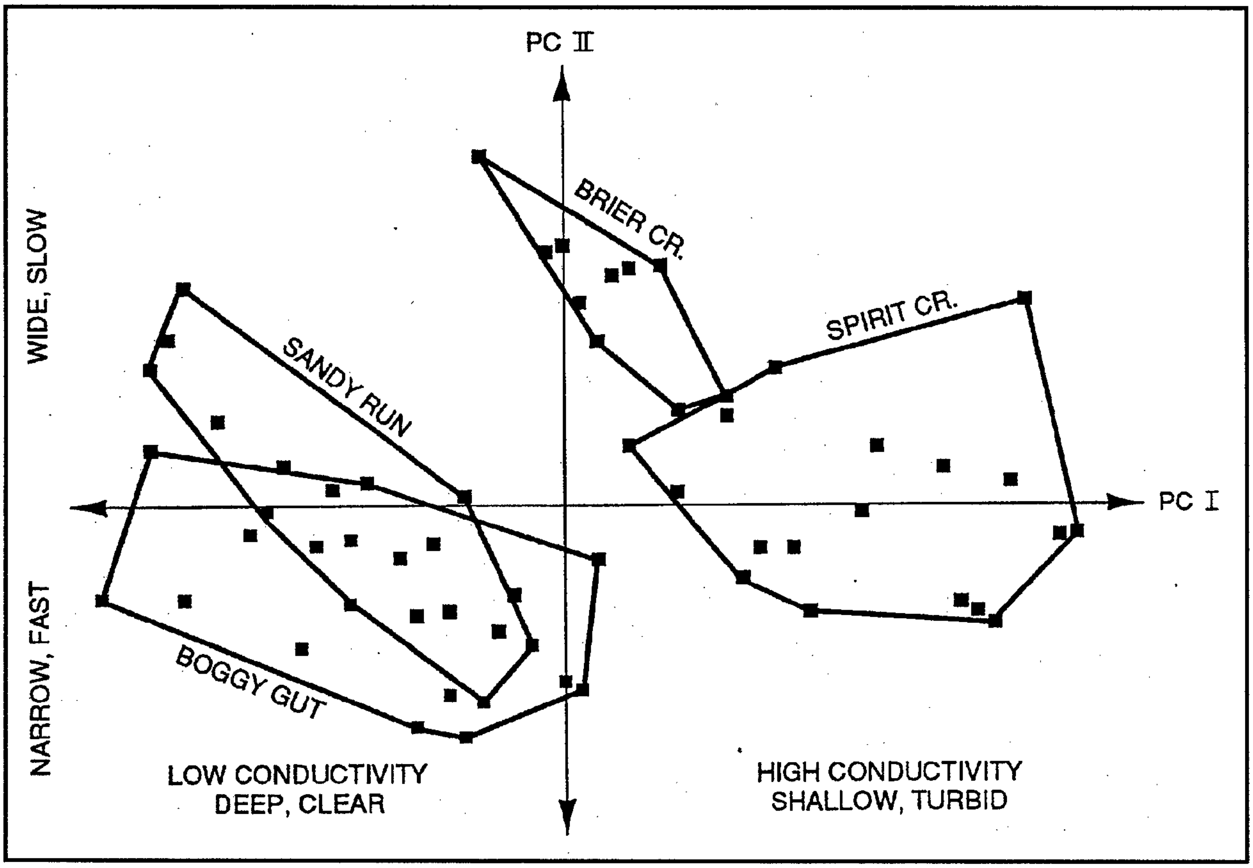

Figure 6. Principal component analysis of physical habitat. Polygons enclose point (samples) from a single stream

Spirit Creek is high in conductivity, turbid, shallow, narrow and slow (Table 3). Brier Creek is comparable in conductivity and turbidity, but is deeper, wider, and slower. Sandy Run and Boggy Gut are both lower in conductivity, clearer, shallower and intermediate in velocity.

Table 3
Mean and Ranges of Physical Variables Measured at Fort Gordon Streams

	Spirit Creek	Sandy Run	Boggy Gut	Brier Creek
Width (m)	6.1 (2.1-15.5)	11.6 (4.9-32.0)	7.9 (5.2-10.4)	32.6 (7.0-146.6)
Depth (m)	0.2 (0.1- 0.3)	0.5 (0.2- 1.0)	0.4 (0.2- 0.7)	0.6 (0.5- 0.8)
Velocity (cm/s)	22.9 (7.3-37.8)	16.8 (2.3-40.8)	5.8 (0.7-38.4)	14.0 (7.8-19.4)
Temperature (°C)	18.0 (11.4-26.9)	18.9 (11.1-28.0)	16.9 (8.5-23.5)	18.2 (12.6-24.4)
Conductivity (mhos)	100.4 (54.0-272)	19.6 (16.0-24.0)	20.3 (12.0-28.0)	107.2 (48.0-210.0)
Dissolved Oxygen (mg/ℓ)	8.6 (6.8-10.1)	8.2 (6.2-10.0)	8.0 (4.8-10.4)	7.5 (5.3- 9.7)
pH	6.4 (5.6- 7.3)	5.5 (4.9- 6.4)	5.1 (4.2- 6.1)	6.4 (6.2- 7.1)
Turbidity (NTU)	13.6 (5.4-32.0)	5.8 (2.8- 9.4)	5.3 (2.2- 9.6)	11.4 (8.3-14.0)

Species-habitat models

We generated habitat models for 10 representative species of fish (Table 4). Although we could not model those fishes restricted to Sandy Run and Boggy Gut (sailfin shiner, bluebarred pygmy sunfish, and bluespotted sunfish), they are probably characteristic of deeper, clearer waters, low in conductivity.

Table 4
Fish-Habitat Models for Streams of Fort Gordon, GA. Models were generated from data that were log-transformed. Independent variables are listed in descending order of correlation (based on individual r^2 values).

Dusky shiner	=	- 1.90 + 2.25(Width)	d.f. = 24, r^2 = 0.38, p < 0.01
Speckled madtom	=	- 1.38 + 3.20(Velocity) - 1.32(Depth) + 0.25(pH)	d.f. = 19, r^2 = 0.67, p < 0.01
Lined topminnow	=	1.77 - 1.12(Turbidity) - 1.69(Velocity)	d.f. = 15, r^2 = 0.51, p = 0.01
Brook silverside	=	Model not significant	d.f. = 15, r^2 = 0.22, p = 0.38
Pirate perch	=	Model not significant	d.f. = 26, r^2 = 0.15, p = 0.14
Redbreast sunfish	=	0.72 - 0.47(Turbidity)	d.f. = 24, r^2 = 0.21, p = 0.02
Bluegill	=	Model not significant	d.f. = 19, r^2 = 0.13, p = 0.53
Spotted sunfish	=	Model not significant	d.f. = 21, r^2 = 0.18, p = 0.31
Savannah darter	=	0.15 - 0.79(Turbidity) + 1.44(Velocity) + 0.42(Width)	d.f. = 27, r^2 = 0.42, p < 0.01
Blackbanded darter	=	1.06 - 0.67(Turbidity) - 0.704(Depth)	d.f. = 35, r^2 = 0.21, p = 0.02

Significant habitat models could not be generated for brook silverside, pirate perch, bluegill, and spotted sunfish (Table 4). Brook silverside make extensive movements, inhabit open water and vegetation, and occupy a broad range of velocities (Hubbs 1921; Cahn 1927; Barnett 1972). Likewise, pirate perch are habitat generalists (Meffe and Sheldon 1988). Abundance of both species at Fort Gordon, however, was significantly correlated only with water temperature. This probably resulted from seasonal aggregations and post-spawning mortality rather than habitat preferences (Barnett 1972; Murdy and Wortham 1980; Robison and Buchanan 1988). Brook silverside spawn late spring and early summer; they were more abundant at higher temperatures ® = 0.54, p = 0.03). Pirate perch spawn in winter; they were more abundant at cooler temperatures r = -0.40, p = 0.04). Unlike brook silverside and pirate perch, spotted sunfish characteristically occur near submersed structure and undercut banks in slow, wide, deep waters (Barnett 1972; Meffe and Sheldon 1988). Sampling structurally complex habitats is difficult with seines, so habitat preference (or lack thereof) may be artifactual.

Of the 6 remaining species, abundances of 4 were negatively correlated with turbidity: lined topminnow, redbreast sunfish, Savannah darter, and blackbanded darter (Table 4). Preference for or greater abundances of these species in clear water has been established previously (Ross and Baker 1983; Rohde et al. 1994, Kuehne and Barbour 1983). Lined topminnow typically occur in quiet waters (Rohde et al. 1994), which is supported by our negative correlation of topminnow abundance with water velocity. Redbreast sunfish occupy shallow, narrow streams (Meffe and Sheldon 1988), although we did not observe significant correlations with either width or depth. Blackbanded darter typically occur in a wide range of stream sizes, but attain greater abundance in larger streams (Kuehne and Barbour 1983; Meffe and Sheldon 1988). In an Alabama stream, this darter inhabited slow to moderate current and fine to medium gravel (Mathur 1973). Our results indicated that these darters were more abundant in shallow streams.

Diversity-habitat model

Fish diversity was positively correlated with depth and negatively correlated with turbidity:

$$\text{Diversity} = 1.86 + 0.98(\text{Depth}) - 0.69(\text{Turbidity})$$

$$r^2 = 0.29, p = .0001, \text{d.f.} = 60$$

Diversity increased with availability of deep, clear water. Habitat partitioning is enhanced with greater water depth (Ross 1986) and clarity (Wilbur 1983; Ewing 1991) allowing larger numbers of species to co-exist. Occurrence and abundance of shiners, specifically, is enhanced because minnows partition stream habitat vertically and are largely visual feeders on drifting invertebrates (Mendelson 1975; Baker and Ross 1981; Surat et al. 1982).

Total fish abundance was positively correlated with stream width and negatively with conductivity:

$$\text{Total fish} = 0.92 + 0.83(\text{Width}) - 0.48(\text{Conductivity})$$

$$r^2 = 0.31,\ p = .0001,\ \text{d.f.} = 60$$

Total fish standing crop probably increased with autochthonous production in streams. Primary productivity is higher in wider, less shaded streams (Vannote et al. 1980). Explanations for higher fish standing crops at lower conductivities, in an ecosystem characterized by low conductivity, are tenuous, however. Fish densities may respond to availability of dense vegetation (e.g., Boggy Gut) which may deplete dissolved nutrients from the water thereby lowering conductivity.

Engineered streams

Riprap, dikes, weirs and other structures can stabilize stream channels, improve habitat, and enhance fish diversity (Shields and Hoover 1991; Dardeau et al. 1995). The mill structure at Boggy Gut (station #12) impounds water behind it and creates distinct zones of high and low water velocity, habitat functions analagous to those of a weir. Habitat benefits are reflected in the high number of species observed there (27 species) relative to those of other stations sampled (4-22 species) and by the occurrence of fishes unknown elsewhere at Fort Gordon (e.g., bluebarred pygmy sunfish). It demonstrates that man-made structures designed to reduce erosion can substantially benefit fish communities in installation streams.

5 Conclusions

1. Ichthyofauna of Fort Gordon is moderately diverse: approximately half of all native species known from the Savannah River drainage were documented, and species-abundance data suggest that rarer species are likely to occur. Most common species are broadly distributed throughout the southeast, but several regionally endemic species were moderately abundant.

2. Fish diversity varies among streams and reflects a gradient of anthropogenic disturbance. Diversity is lowest in Spirit Creek, intermediate in Sandy Run, and high in Brier Creek and Boggy Gut.

3. Fish diversity and abundance of 4 species is negatively correlated with turbidity suggesting that erosion has negatively impacted fish communities. This is also supported by rarity of several species that preferentially inhabit clear water.

4. Boggy Gut, although small and lacking a significant floodplain, is inhabited by the most distinctive and speciose fish community. Resident fishes include 4 species of special status in the state of Georgia and another which represents a disjunct population of a highly endemic pygmy sunfish. Diversity is high and additional species are likely to be encountered in future collections.

5. A structure (ruined mill) at Boggy Gut creates aquatic habitat unique among the eighteen sites surveyed: i.e., a clear, vegetated backwater with fine depositional sediments. Similar man-made structures offer potential for habitat enhancement by stabilizing bottom sediments, enhancing sediment deposition and vegetative growth. These processes will provide habitat for many of the less common fishes in Fort Gordon streams.

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13. ABSTRACT (*Maximum 200 words*)

Field studies provided baseline data on fish species composition and abundance at Fort Gordon, Georgia. Four streams were sampled that represented varying levels of anthropogenic impacts: Spirit Creek (most impacted), Sandy Run, Boggy Gut, and Brier Creek (least impacted). Field surveys of juvenile and adult fishes and physical habitat were performed quarterly Dec 1995 to Oct 1996; 1-4 collections were made at 19 stations for a total 66 samples. Forty-four species of fishes were collected (or observed) representing approximately half of all native fishes known from the Savannah River drainage. Ichthyofauna was dominated taxonomically by sunfishes (10 species) and minnows (9 species), and to a lesser extent by darters and catfishes (6 species each). Abundant species included golden shiner, dusky shiner, bluegill, brook silverside, and blackbanded darter. Fishes of special status included sailfin shiner, mud sunfish, Savannah darter, and sawcheek darter. Bluebarred pygmy sunfish collected from Boggy Gut constitute the only confirmed collection of this species from the western Savannah River drainage and from the state of Georgia.

Fish communities, and physical habitat, were similar in Sandy Run and Boggy Gut; Spirit Creek was faunistically and physically dissimilar from the other streams. Diversity (Shannon heterogenity function, H') was negatively correlated with turbidity, positively correlated with water depth. Abundance of 4 common species was negatively correlated with turbidity. Spirit Creek, which experiences severe erosion and is extensively impounded, is turbid, shallow, and high in conductivity; fish densities are low and the community depauperate. Boggy Gut, which experiences minor

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erosion and is not impounded, is characterized by water that is clear, deep, and low in conductivity; fish densities are high and multiple measures of diversity (H', observed number of species, estimated number of species) were consistently higher than for any other stream. A man-made structure in Boggy Gut created a speciose, artificial backwater-channel system. Similar structures deigned to reduce erosion could create habitat for many species that are currently rare or have restricted distributions in or around Fort Gordon.