Using an Index of Biotic Integrity to Assess Gold Mine Impacts on Streams

Ronald C. Ahle, *Division of Wildlife and Freshwater Fisheries, South Carolina Department of Natural Resources, Columbia, SC 29202*

Gerrit J. Jobsis, *Division of Wildlife and Freshwater Fisheries, South Carolina Department of Natural Resources, Columbia, SC 29202*

Abstract: A fish community index of biotic integrity (IBI) was used to compare 6 streams with minor anthropogenic impacts to 3 streams receiving source and non-point source effluents from gold mine operations in the Piedmont of South Carolina. IBI ratings for streams receiving gold mine effluent ranged from very poor to marginally fair, whereas those for the remaining 6 streams ranged from fair to good. The stream selected as a "candidate" reference stream rated consistently good, establishing a potential baseline for attainable conditions for the ecoregion. The IBI supplied biological data that were useful in identifying perturbations based on alterations occurring in fish communities. The results of this study suggest the IBI could be an excellent tool for monitoring the biological components of streams in the Piedmont ecosystem.

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Our research used an Index of Biotic Integrity (IBI, Karr 1981) to compare the health of Piedmont streams in South Carolina. We evaluated fish community response to point and non-point discharges from gold mines and to perturbations unrelated to gold mine operations.

Gold ore production can lead to seepage and leaching of sulfuric acid into streams and ground waters, as well as silt and sediment loading. In streams with minimal buffering capacity, fish communities may simply disappear. Streams receiving acid mine drainage frequently lack higher aquatic plants and benthic macroinvertebrates, and have few fish species (Bell and Payne 1993). Ore mining operations also have wastewater discharges that often contain heavy metals, caustic or acidic wastes, suspended solids, iron, and naturally occurring radioactive materials. The effects of heavy metals on aquatic biota are well documented and include the following: (1) acute or chronic toxicity, (2) bioaccumulation and/or biomagnification, (3) declines in reproductive success, and (4) increased occurrences of mutations, deformities, diseases, and cancers (Bell and Payne 1993).

Using an IBI is a new method to assess the health of streams receiving discharges from gold mines in South Carolina. The IBI supplies biological data that can be used to identify perturbations and quantify effects based on alterations to fish communities (Karr 1981, Moyle 1994, Stewart and Loar 1994). The IBI has been used to assess anthropogenic disturbances such as excessive siltation (Berkman and Rabeni 1987), domestic sewage (Leonard and Orth 1986), and chlorine and ammonia (Karr et al. 1985).

IBI is a dynamic concept that requires an assessment and redefinition of its component metrics for each ecoregion where it is used. Since the use of an IBI in the Piedmont of South Carolina has not been widely practiced, this study will be used to verify metrics and identify potential reference streams.

Methods

Study Area

The study area was in the Piedmont of South Carolina and included 6 third-order streams with minor anthropogenic impacts selected as typical of the region (Harmon, Sawney's, Little Lynches, Deep, Horse, and Flat creeks). These were compared with 3 third-order streams receiving point and non-point source effluents from gold mine operations (Haile Gold Mine, Little Fork, and Bear creeks). The Haile Gold Mine Creek sample reach was immediately downstream from the Haile Gold Mine and crossed directly through the mine pit. The Little Fork Creek sample reach was immediately downstream from the Brewer-Springs Mine, where a fish kill occurred due to a cyanide spill in October 1990 (Sample 1990). The Bear Creek sample reach was about 1.5 km downstream of the Ridgeway Mine. The Ridgeway Mine has made considerable effort to reduce and capture runoff, thereby minimizing non-point source discharges to Bear Creek.

Third-order Piedmont streams generally have average water depths ranging from 0.5 to 1.0 m with average widths ranging from 3 to 8 m. The selected streams had flow velocities ranging from intermittent during the fall to 0.5 m/sec during the spring. Each stream segment contained pool-riffle-run habitats with substrates that graded from bedrock to coarse sand. Stream-specific habitat descriptions are provided in Ahle and Jobsis (1997).

Data Collection

Fish sampling was conducted in spring and fall 1993. Sample sections were 91 m long as recommended by the U.S. Environmental Protection Agency (USEPA 1989). Block nets were set across the upstream and downstream boundary of each sample section. Using a backpack electrofisher and 3 dip-net assistants, each section was surveyed using 3 passes. If new species were captured on the third pass, an additional pass was made. After each pass, fish were identified to species, measured to the nearest mm total length, and released into the stream outside the sampling area. Each fish captured was examined for physical abnormalities and diseases. Juvenile fish <3 cm long were excluded because they were generally difficult to sample and identify. By excluding the juvenile fish, sampling costs were lowered and the need for laboratory identification reduced.

IBI Method Description

The selected metric criteria for our IBI (Table 1) were chosen after review of other IBIs used in warmwater streams (Karr 1981, Karr et al. 1986, Twidwell and Davis 1989, N.C. Dep. Environ., Health and Nat. Resour. [NCDEHNR] 1995). Tolerance and trophic classification primarily followed those listed by NCDEHNR (1995) with minor variations based on recommendations provided by local ichthyologists. Proportion metrics were based on trophic guild classification listed in Karr et al. (1986). Scoring criteria for metrics 2, 3, 4, 6, 8, 9, 10, and 12 were taken directly from the North Carolina IBI (NCDEHNR 1995). Scoring criteria for metrics 1 and 11 were based on historical information (Bulak 1991) and on knowledge gained relative to catch/effort from extensive sampling in the Piedmont region. Metrics 5 and 7, with associated scoring criteria, were based on suggestions by Karr et al. (1986), and on historical information (Bulak 1991). Using the listed metrics and scoring criteria, each sample was assigned an IBI score based on the summation of the individual metric ratings. IBI scores were used to assign integrity classes with

Table 1. Scoring and evaluation criteria for an index of biotic integrity used on third-order South Carolina Piedmont streams. Metrics assigned number ratings with 5 being good; 3, fair; and 1, poor.

Category	Metric	(5)	(3)	(1)
Species richness and composition	1. Number of fish species	>14	9–14	<9
Species richness and composition	2. Number of darter species	3	1–2	0
Species richness and composition	3. Number of sunfish species	4	2–3	0–1
Species richness and composition	4. Number of sucker species	2	1	0
Species richness and composition	5. Number of catfish species	3	2	0–1
Species richness and composition	6. Number of intolerant species	3	1–2	0
Species richness and composition	7. Percent as tolerant individuals	<5%	5%–20%	>20%
Trophic composition	8. Percent as omnivores	<20%	20%–45%	>45%
Trophic composition	9. Percent as invertivores	>80%	40%–80%	<40%
Trophic composition	10. Percent as piscivores	>5%	1%–5%	<1%
Fish abundance and condition	11. Number of individuals	>150	50–150	<50
Fish abundance and condition	12. Percent as diseased individuals	<2%	2%–5%	>5%

58–60 being excellent, 48–52 good, 40–44 fair, 28–34 poor, and 12–22 very poor (Karr et al. 1986). We tested for statistical differences ($\alpha = 0.10$) between spring and fall IBI scores using Wilcoxon rank sum and Kolmogorov-Smirnov 2-sample tests. Differences between IBI scores from gold mine and non-gold mine streams were similarly tested.

Results and Discussion

A total of 3,598 individuals representing 43 species were captured (Table 2). The number of fish collected ranged from 0 to 58 individuals for the gold mine streams and from 47 to 1,183 at the other streams. Species richness also varied widely with 0–11 species collected from the gold mine streams and 12–30 at the other streams. More detailed reporting of fish collection results can be found in Ahle and Jobsis (1997).

Scores based on the value of each metric were summarized by season (Table 3). Streams receiving gold mine effluents had lower IBI scores than other streams (Fig. 1). Statistical analysis of spring and fall IBI scores indicated no difference between seasons using Wilcoxon ($P = 0.59$) and Kolmogorov-Smirnov ($P = 0.70$) tests. Spring and fall samples were then combined to test for differences between gold mine and non-gold mine streams. IBI scores from gold mine streams were significantly different than those from non-gold mine streams when tested with Wilcoxon ($P > 0.001$) and Kolmogorov-Smirnov ($P = 0.002$) tests.

Comparisons of metric values reveals how the IBI distinguished different streams. Metrics 1 and 2 showed lower species richness numbers of darter species (Percidae) in gold mine streams (Fig. 1). Metric 3 indicated lower numbers of sunfish species (Centrarchidae) in gold mine streams during spring samples but similar numbers in fall samples (Fig. 2). Metric 4 revealed only 1 sample from gold mine streams contained sucker species (Catastomidae). Metric 5 showed lower numbers of catfish species (Ictaluridae) in gold mine streams during fall samples. Metric 6 indicated that no intolerant species were captured in gold mine streams, whereas at least 1 intolerant species was captured in every other sample (Fig. 3). The proportion and trophic composition attributes, metrics 7, 8, 9, and 10, showed little differences among streams. Metric 11 showed lower numbers of individuals occurred in gold mine streams (Fig. 2). Though little differences were noted among samples for metric 12, Bear Creek had the only spring sample that included diseased individuals.

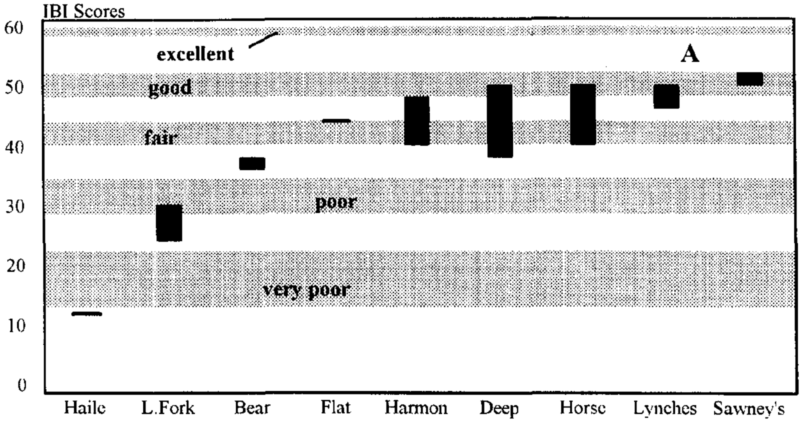
Further understanding of how the IBI measures fish community attributes is gained by examining habitat characteristics and IBI metric scores for each stream. Haile Gold Mine Creek was found to have poor biotic integrity with no fish captured. It was suspected that acid mine drainage was the agent causing toxicity. Acid mine drainage occurs when flowing water causes the oxidation of pyrite, a process that produces sulfuric acid and ferrous sulfate. The ferrous ions are then oxidized to form ferric ions that can be hydrolyzed to insoluble ferric hydroxide. This process lowers pH in stream systems (Bell and Payne 1993). An orange-tinted precipitate thought to be ferric hydroxide was observed in Haile Gold Mine Creek.

Table 2. Tolerance level and trophic classification for species captured in survey of South Carolina Piedmont streams. Tolerance and trophic classification primarily followed those listed by the North Carolina Department of Environment, Health and Natural Resources (NCDEHNR 1995) and minor variations based on recommendations provided by local ichthyologists.

Scientific name	Common name	Tolerance	Trophic guild
Petromyzon marinus	Sea lamprey (ammocoetes)	intermediate	planktivore
Esox americanus	Redfin pickerel	intermediate	piscivore
Anguilla rostrata	American eel	tolerant	insectivore
Clinostomus funduloides	Rosyside dace	intermediate	insectivore
Hybognathus nuchalus	Eastern silvery minnow	intermediate	herbivore
Nocomis leptocephalus	Bluehead chub	intermediate	omnivore
Notemigonus crysoleucas	Golden shiner	tolerant	omnivore
Notropis alborus	Whitemouth shiner	intolerant	insectivore
N. altipinnis	Highfin shiner	intermediate	insectivore
N. chalybaeus	Ironcolor shiner	intolerant	insectivore
N. chiliticus	Redlip shiner	intermediate	insectivore
N. chloristius	Greenfin shiner	intermediate	insectivore
N. chlorocephalus	Greenhead shiner	intolerant	insectivore
N. cummingsae	Dusky shiner	intolerant	insectivore
N. hudsonius	Spottail shiner	intermediate	insectivore
N. lutipinnis	Yellowfin shiner	intermediate	insectivore
N. procne	Swallowtail shiner	intolerant	insectivore
N. pyrrhomelas	Fieryblack shiner	intolerant	insectivore
N. scepticus	Sandbar shiner	intermediate	insectivore
Erimyzon oblongus	Creek chubsucker	intermediate	omnivore
Hypentelium nigricans	Northern hog sucker	intermediate	insectivore
Minytrema melanops	Spotted sucker	intermediate	omnivore
Moxostoma pappillosum	V-lip redhorse	intermediate	insectivore
M. robustum	Smallfin redhorse	intermediate	insectivore
M. rupiscartes	Striped jumprock	intolerant	insectivore
Ictalurus natalis	Yellow bullhead	tolerant	insectivore
I. platycephalus	Flat bullhead	intermediate	insectivore
Noturus insignis	Margined madtom	intermediate	insectivore
Aphredoderus sayanus	Pirate perch	intermediate	insectivore
Gambusia holbrooki	Mosquito fish	tolerant	insectivore
Lepomis auritus	Redbreast	intermediate	insectivore
L. cyanellus	Green sunfish	tolerant	insectivore
L. gibbosus	Pumpkinseed	intermediate	insectivore
L. gulosus	Warmouth	intermediate	piscivore
L. macrochirus	Bluegill	intermediate	insectivore
L. microlophus	Redear sunfish	intermediate	insectivore
Micropterus salmoides	Largemouth bass	intermediate	piscivore
Etheostoma collis	Carolina darter	intolerant	insectivore
E. flabellare	Fantail darter	intolerant	insectivore
E. olmstedi	Tesselated darter	intermediate	insectivore
E. thalassinum	Seagreen darter	intolerant	insectivore
Perca flavescens	Yellow perch	intermediate	piscivore
Percina crassa	Piedmont darter	intolerant	insectivore

Table 3. Fish community IBI metric values and IBI scores for selected South Carolina Piedmont streams, 1993. Refer to Table 2 for metric descriptions. Haile Gold Mine Creek not listed because no fish were captured during sampling.

		Metric												
Stream	Season	1	2	3	4	5	6	7	8	9	10	11	12	IBI
L. Fork	spring	2(1)	0(1)	1(1)	0(1)	1(1)	0(1)	66.7(1)	0(5)	100(5)	0(1)	3(1)	0(5)	24
Creek	fall	4(1)	0(1)	2(3)	0(1)	1(1)	0(1)	0(5)	25.0(3)	62.5(3)	12.5(5)	8(1)	0(5)	30
Bear	spring	11(3)	1(3)	3(3)	0(1)	2(3)	0(1)	0(5)	11.8(5)	79.4(5)	5.9(5)	34(1)	3.4(3)	36
Creek	fall	10(3)	1(3)	3(3)	2(5)	0(1)	0(1)	0(5)	25.9(3)	72.4(3)	1.7(3)	58(3)	0(5)	38
Flat	spring	15(5)	2(3)	3(3)	1(3)	3(5)	2(3)	0.2(5)	32.0(3)	67.3(3)	0.7(1)	442(5)	0(5)	44
Creek	fall	12(3)	2(3)	1(1)	2(5)	2(3)	2(3)	0(5)	15.3(3)	85.5(5)	0.2(1)	1183(5)	1.4(5)	44
Harmon	spring	13(3)	2(3)	3(3)	1(3)	3(5)	3(5)	3.1(5)	9.2(5)	89.3(5)	1.5(3)	65(3)	0(5)	48
Creek	fall	13(3)	1(3)	3(3)	1(3)	2(3)	2(3)	0(5)	33.3(3)	64(3)	2.7(3)	75(3)	1.3(5)	40
Deep	spring	14(3)	2(3)	5(5)	0(1)	1(1)	2(3)	6.4(3)	12.8(5)	78.7(3)	8.5(5)	47(1)	0(5)	38
Creek	fall	22(5)	3(5)	4(5)	1(3)	2(3)	5(5)	1(5)	39.4(3)	56.5(3)	3.3(3)	276(5)	0(5)	50
Horse	spring	14(3)	1(3)	3(3)	3(5)	1(1)	3(5)	1.4(5)	30.4(3)	69.6(3)	0(1)	69(3)	0(5)	40
Creek	fall	15(5)	1(3)	3(3)	2(5)	3(5)	2(3)	1.3(5)	16.2(5)	81.2(5)	0.6(1)	154(5)	1.3(5)	50
Lynches	spring	15(5)	1(3)	4(5)	1(3)	2(3)	1(3)	0(5)	20.8(3)	77.5(3)	1.7(3)	356(5)	0(5)	46
Creek	fall	17(5)	2(3)	4(5)	1(3)	3(5)	2(3)	0.6(5)	10.2(5)	86.5(5)	3.3(3)	303(5)	3.3(3)	50
Sawney's	spring	20(5)	3(5)	6(5)	0(1)	3(5)	3(5)	9.1(3)	9.1(5)	88.9(5)	2.0(3)	198(5)	0(5)	52
Creek	fall	30(5)	2(3)	5(5)	4(5)	2(3)	6(5)	9.9(3)	17.1(5)	67.7(3)	1.7(3)	344(5)	0.9(5)	50



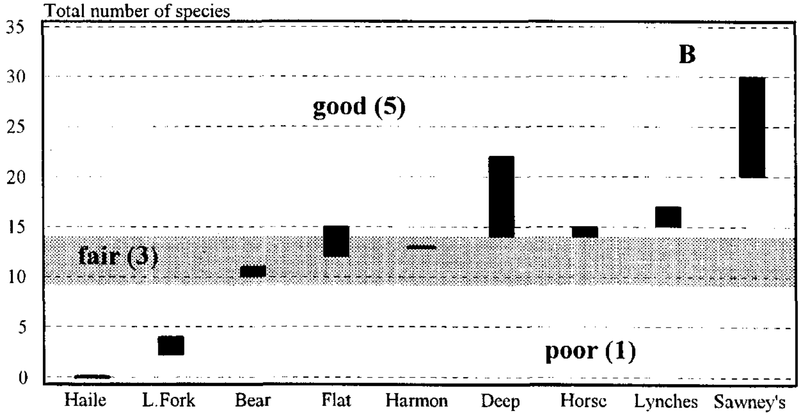


Figure 1. Graphical comparisons of IBI scores and individual metrics for each stream sample. Vertical bars depict the high and low values (one spring, one fall). Graph A compares IBI scores with integrity classes (excellent-very poor) included for reference. Graph B has metric ratings (good, fair or poor) given for reference. B compares metric 2, the number of fish species. C compares metric 1, the number of darter species. The first 3 streams on each graph (Haile, Little Fork and Bear) are streams that had gold mine impacts.

Although the oxidation of pyrite could be the primary cause of acidification, soluble metals can become the primary reason for instream toxicity problems. With decreasing pH, metallic ions can be dispersed at concentration levels that disrupt the life cycles of aquatic biota (Bell and Payne 1993). Haile Gold Mine Creek below the mine discharge has been reported to have elevated concentrations of chromium, copper, nickel, lead, and zinc in sediment samples, as well as low pH. Samples taken from Haile Gold Mine Creek below the discharge were reported to have a mean pH of 3.87 (H. Sutton and C. Rockett, unpubl. data).

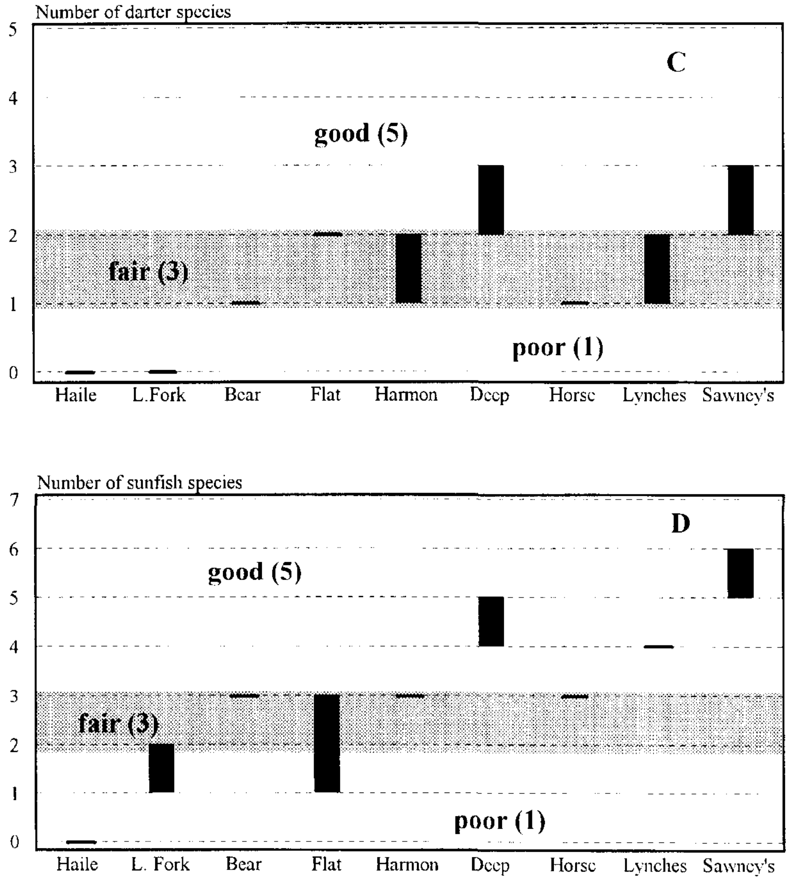
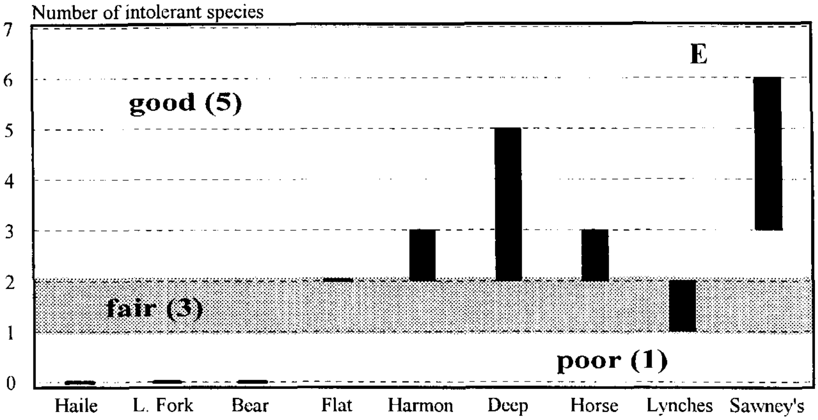


Figure 2. Graphical comparisons of individual metrics for each stream sample. Vertical bars depict the high and low values (one spring, one fall). Graphs C and D have metric ratings (good, fair or poor) given for reference. C compares metric 1, the number of darter species. D compares metric 3, the number of sunfish species. The first 3 streams on each graph (Haile, Little Fork and Bear) are streams that had gold mine impacts.

Little Fork Creek had poor biotic integrity with only 11 fishes captured, even though the physical habitat appeared good. Low fish abundance can be attributed to degradation from toxic substances (USEPA 1989). Toxic effects were further indicated by the absence of the less tolerant fish species such as darters, suckers and shiners (Cyprinidae). Community response to acidic discharges appeared to be reduced species richness and diversity (Bell and Payne 1993).

Substrate contamination may be a problem in Little Fork Creek. As in Haile Gold Mine Creek, an orange-tinted precipitate thought to be ferric hydroxide was observed. Instream substrates covered with ferric hydroxide have fewer benthic in-



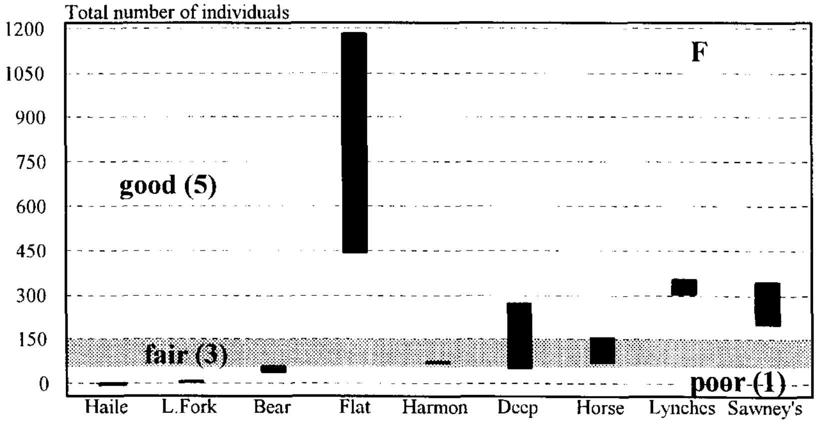


Figure 3. Graphical comparisons of individual metrics for each stream sample. Vertical bars depict the high and low values (one spring, one fall). Graphs E and F have metric ratings (good, fair or poor) given for reference. E compares metric 6, the number of intolerant species. F compares metric 11, the number of individuals. The first 3 streams on each graph (Haile, Little Fork and Bear) are streams that had gold mine impacts.

habitants than those in streams with similar pH and clean substrates (Bell and Payne 1993). Further evidence of substrate contamination was revealed when no juvenile fish were captured. The lack of juveniles indicates reproduction may be limited by fouling of spawning habitat or by toxicity to early life stages (Conquest et al. 1994). In 1990, Little Fork Creek was affected by a cyanide spill (Sample 1990). Cyanide spills can have both lethal and chronic sublethal effects on fish and the toxicity of cyanide can be enhanced by low pH (Bell and Payne 1993).

Bear Creek, though not showing impacts similar to those of the other gold mine streams, had biotic integrity ratings of poor to fair. These low ratings resulted from reduced number of species, absence of intolerant species and reduced numbers of individuals. Bear Creek impacts included sedimentation from land clearing activities and non-point source discharges from the gold mine. Although only moderate amounts of silt were noted during sampling, surveillance of upstream reaches revealed silt in the substrate increased toward the mine. Silt accumulation is known to disrupt spawning beds (Jones 1964) and smother food organisms that live in the substrate (Boyd 1979). Degradation of spawning habitat may have contributed to the reduced number of species.

Deep Creek had integrity ratings of fair and good with a large discrepancy in IBI scores. The spring score of 38 was thought to be a misrepresentation based on review of historical data. Upstream reconnaissance revealed the spring sample reach may have been affected by a beaver (*Castor canadensis*) dam. The beaver dam appeared to block the migration of sand and caused substrate scouring downstream. The scouring effect diminished sand and gravel riffle habitat while increasing pool and run habitat. This could explain the absence of cyprinid species with a corresponding increase of predator species. Predatory pressure can result in major decreases in cyprinid abundance and fish density (Schlosser 1987). A more representative stream segment was selected for the fall sample and, as a result, the IBI score was elevated to 50, the second highest score in the survey. The fall sample contained 5 intolerant species and 3 species of darters. The presence of these intolerant species suggests minimal stream impacts and high biotic integrity in Deep Creek (Leonard and Orth 1986).

Sawney's Creek rated the highest integrity and is a "candidate" reference site for the Piedmont ecoregion. IBI scores of 50 and 52 demonstrate a consistency that occurs at high-quality sites (Karr et al. 1987) and illustrates ecosystem stability. High-quality sites are characterized by having centrarchids and catostomids in pools, cyprinids, and percids in shallow areas and enhanced trophic complexity. Enhanced trophic complexity involves fish populations balanced by competition and predation (Schlosser 1987).

Sawney's Creek had 7 intolerant species including the Carolina darter (*Etheostoma collis*), a species listed as "State Concern" by the South Carolina Heritage Trust. The presence of numerous intolerant species suggests minimal stream impacts. The large number of sunfish species was indicative of well developed pool environments with abundant instream cover (USEPA 1989). The number of sucker species varied from none in the spring to 4 in the fall. Since many individuals were juveniles, it appeared adults had migrated through the area in the winter and the juveniles were emigrating downstream in the fall. Many sucker species are known to make spawning runs to stream headwaters during the winter (Mansueti and Hardy 1967). The metric for proportion of tolerant species rated fair in both samples. Normally, tolerant species occurrence increases as disturbance levels increase (USEPA 1989). In Sawney's Creek the reason for high proportion of tolerant species was the abundance of green sunfish (*Lepomis cyanellus*). Because 6 other sunfish species were captured, the presence of green sunfish may have been a colonization effect rather then a response to perturbation.

Flat Creek rated fair with spring and fall IBI scores of 44. This consistency of IBI scores, though indicative of stability, may indicate minor habitat degradation. One possible reason for fair biotic integrity was limited pool development. Uniform shallow habitat, as found in Flat Creek, often results in simple fish communities dominated by minnows (Schlosser 1987). This community response was evident with 71% of the population being cyprinids. Another potential impact to Flat Creek could be nutrient enrichment. Streams receiving nutrients commonly exhibit skewed community trophic composition with an increased abundance of omnivorous species (Karr et al. 1986). This occurred when bluehead chub (*Nocomis leptocephalis*) comprised 32% of the spring sample.

Harmon and Horse creeks were good examples of minimally impacted streams located in steeply sloping terrains where rapid runoff occurs. As a result, these 2 streams were subject to intermittent flows. Even though both streams had good riparian buffer zones, good canopy cover and stable banks, the dewatering may have affected biotic integrity resulting in inconsistent scores. An unstable environment resulting from lack of flow can create disequilibria in fish communities (Gorman and Karr 1978).

While the fall integrity rating was good for Horse Creek, it was only fair for Harmon Creek. This may be due to adequate maintenance of intermittent pools in Horse Creek and the absence of suitable intermittent pools in Harmon Creek. Survival of fishes during dry seasons in small streams is often possible when persistent pools remain habitable (Harrel et al. 1967). In Harmon Creek, severe drought may have caused mortality due to oxygen depletion and terrestrial predators. The abundance of redbreast sunfish (*L. auritis*) in Harmon Creek may have been indicative of their ability to recolonize intermittent streams once flow has been reestablished. Stream fish assemblages are known to recover rapidly from droughts and floods (USEPA 1989). This could explain the variation in IBI scores; the fall score was 40 and the spring score was 48 at Harmon Creek. In Horse Creek, this relationship was reversed with high biotic integrity maintained during intermittent flow. Studies in Texas reported high biotic integrity could be maintained during summer in streams with low flow regimes and high temperatures when fish migrate away from dewatered areas and take refuge in perennial pools (Twidwell and Davis 1989, Ahle 1991).

Little Lynches Creek had a good biotic integrity with scores of 46 and 50. It appeared to be a stable ecosystem where substantial flows were maintained year round. However, some degradation was indicated by the low number of intolerant forms. Species loss with increasing stream degradation generally follows an anticipated order based on tolerance rankings (Leonard and Orth 1986). The decline in intolerant fish species allows more tolerant species to inhabit newly available niches. This relationship was evident with the tessellated darter (*E. olmstedi*), a species considered intermediate in tolerance, being very abundant in the absence of other darters. Since intolerant species generally represent a small proportion of a fish community, their absence may have little effect on trophic community structure. A balanced trophic community was present in Little Lynches Creek with an abundance of invertivores, minimal occurrence of omnivores, and moderate populations of piscivores.

Conclusion

In summary, the IBI indicated streams receiving discharges from gold mines in the Piedmont of South Carolina had degraded fish community assemblages and were not reaching attainable biological conditions. Fish communities in these streams exhibited reduced numbers of fish species, fishes, darter, and sucker species and an absence of intolerant forms. The IBI also gave insight to other potential perturbations occurring in streams not affected by gold mines.

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