Evaluating aquatic macroinvertebrate communities in the vicinity of a kraft mill discharge

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ABSTRACT: A study of aquatic macroinvertebrates in the vicinity of the discharge from an 1100-ton/day unbleached kraft linerboard mill showed that the treated effluent had no significant impact on downstream aquatic communities. All major taxonomic groups found upstream of the discharge were observed within the zone of influence of the discharge, including many pollution-sensitive species. Mean Shannon–Weiner diversity upstream was 3.1, compared with a mean of 2.7 downstream. Similarly, the mean organism density upstream was 2585 organisms/m^2 with a mean species richness of 32, compared with respective downstream values of 2920 organisms/m^2 and 28 species.

KEYWORDS: Biology, container boards, discharge, effluents, Florida, liner boards, mills factories, packaging papers, paper board grades, pollution, pulps, rivers, southeastern USA, southern USA, unbleached pulps, wastes, water biology, water pollution.

The Valdosta mill is an 1100-ton/day unbleached kraft linerboard mill located in the state of Georgia. However, the extensive wastewater treatment system extends across the state line into Florida, with the ultimate discharge to the Withlacoochee River, as seen in **Fig. 1**.

The mill's wastewater-treatment system has been upgraded over the years to achieve a consistent BOD (biochemical oxygen demand) removal of greater than 95%. The secondary treatment system consists of a series of seven ponds covering 344 ha (850 acres). The first four ponds provide anaerobic/facultative treatment, followed by an aerated stabilization basin, a 141.8-ha (350 acre) facultative holding pond, and a final polishing pond. The 350-acre pond is designed for hold-and-release discharge through a submerged diffuser, with the volume of discharge based on river flow and the level of dissolved oxygen in the river.

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Because the mill's final discharge is in Florida, this is the state that regulates the discharge and issues the wastewater discharge permits for the mill. In 1989, the mill and the Florida Department of Environmental Regulation agreed to undertake a cooperative study of the river in the vicinity of the mill discharge. The study extended through a wet/dry cycle. The purpose of the investigation was to determine if the discharge met Florida water quality standards via the biological integrity rule (BIR).

The BIR uses macroinvertebrates as an indicator of water quality. Community structure in the waters upstream and downstream of the mill discharge is determined by the Shannon–Weiner (SW) diversity index. BIR compliance is certified if the background conditions established upstream of the mill discharge do not drop more than 25% downstream from the mill.

The data obtained during the course of the study also were evaluated using a second criterion, the Florida index (Beck's biotic index). The mill also conducted additional quantitative and qualitative sampling in an effort to provide a more comprehensive picture of the river in the vicinity of the discharge.

Background

Drainage basin characteristics

The Withlacoochee River lies principally in the lower coastal plain of southern Georgia and northern Florida. With the headwater located near Tifton, GA, the river flows approximately 138 km to the Suwannee River (1). The drainage basin is relatively small, encompassing 5698 km². The resulting river flows range from less than 5.7 m³/s during dry periods to more than 283 m³/s during the rainy season. Variation in flow volume of this magnitude can occur over a time period as short as a few weeks.

In Florida, the river traverses mature karst development. Sinkholes, stream sinks, and springs are typical terrain features (2). The numerous springs contribute a significant amount of water to the base flow of the river. The Floridan aquifer that underlies the entire system is characterized by a high porosity and hydraulic conductivity. Nonuniformity of the aquifer results in caverns and solution holes that contribute large volumes of flow into the river (3).

I. Effluent and river data for the study period

Sampling period		Effluent flow, m³/day	BOD mg/L	BOD kg/day	BOD kg/m³s	TSS, kg/day	River flow, m³/s
1989							
November	(11/1–11/29)	33,308	11	361	68.9	256	5.3
1990							
January	(1/24–2/21)	182,437	11	1564	24.0	1016	78.2
March	(3/21–4/18)	106,737	8	836	17.6	917	52.6
May	(5/15–6/13)	26,117	13	345	65.7	655	5.3
Annual average data							
1987		88,569	13	1140	65.7	771	67.3
1988		82,513	10	796	48.1	765	39.1
1989		84,027	7	570	49.7	727	22.2
1990		63,210	10	653	68.9	668	26.3
1991		168,433	6	1018	22.4	1336	140.5

Physical/chemical features of the river

The Withlacoochee River has steep banks with a mostly undeveloped shoreline. The river consists of a series of pools and riffles, with the channel gradually becoming wider and deeper as it flows south.

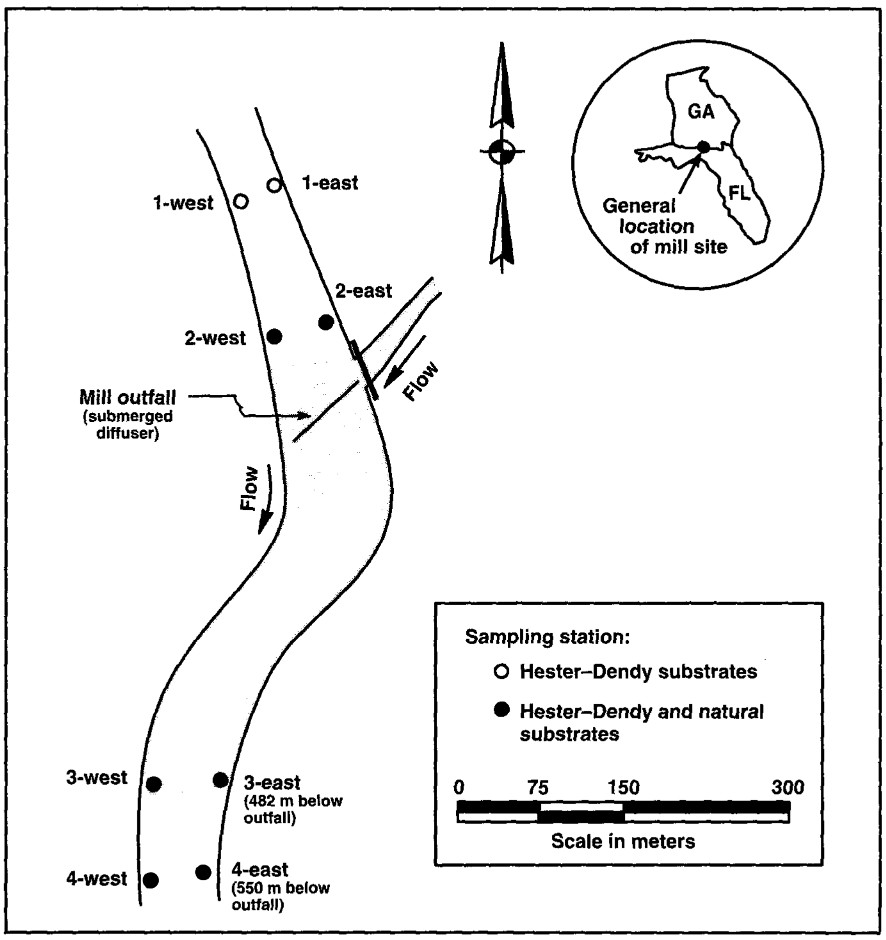
Water quality in the river varies primarily with flow regimes and changing land use. The drainage basin reflects a general rural and agricultural character. However, during periods of moderate to elevated rainfall, stormwater runoff from nearby swamps and forests results in high color levels.

The river is a class III surface water. As such, it is designated as "fishable and swimmable" for recreational purposes.

River biology

The biological assemblage in the river includes a mixed community of plants, vertebrates, and invertebrates that supports a recreational fishery for local residents. Fishes in the river are those found commonly within the Suwannee River drainage basin. These form a population of bass and sunfish, catfish, and small forage species. Gars and bow-

1. Sampling locations on the Withlacoochee River in the vicinity of the mill's outfall

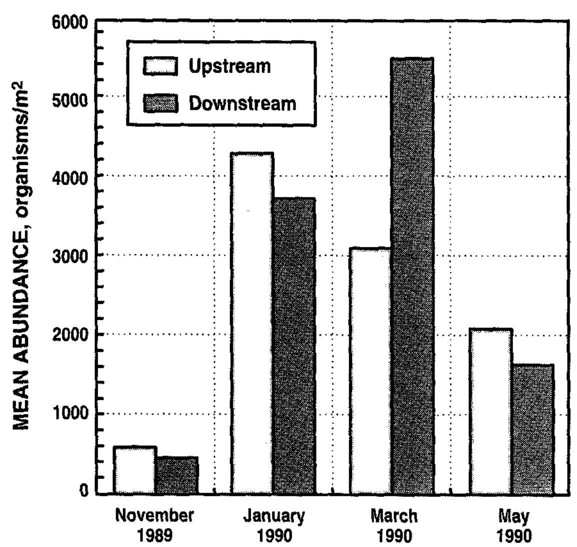


II. Mean values for data from Hester–Dendy multiplate substrates; individual sampling periods and total study period

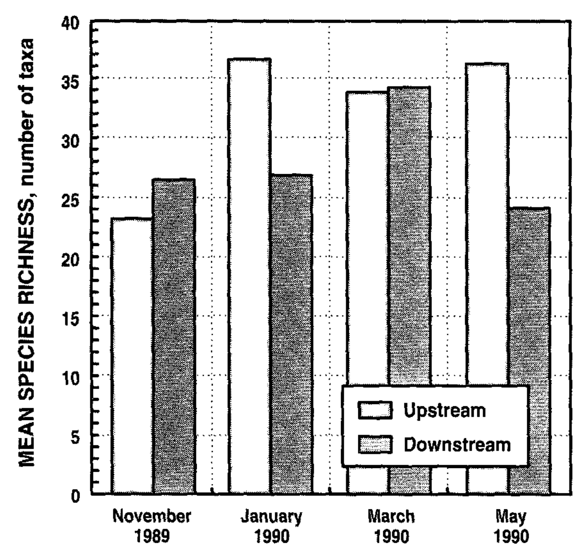
Sampling period	*Location*	*Species richness, number of taxa*	*Abundance, organisms/m²*	*SW diversity (Base 2[a]) All data*	*SW diversity (Base 2[a]) Adjusted data[b]*	*Florida index*
November 1989	Upstream	23	609	3.13	3.13	14
	Downstream	27	487	3.28	3.28	14
	Florida BIR, %	...	...	105	105	...
January 1990	Upstream	37	4288	2.85	3.67	32
	Downstream	27	3735	2.40	3.49	25
	Florida BIR, %	...	...	84	95	...
March 1990	Upstream	34	3121	3.21	3.67	30
	Downstream	34	5494	2.44	3.68	30
	Florida BIR, %	...	...	76	100	...
May 1990	Upstream	36	2061	3.37	3.37	18
	Downstream	24	1644	2.70	2.70	13
	Florida BIR, %	...	...	80	80	...
Overall mean values						
	Upstream	32	2585	3.11	3.47	24
	Downstream	28	2920	2.70	3.33	21
	Florida BIR, %	...	...	87	96	...

[a]Index calculated using logarithms in base 2
[b]Values for *Rheotanytarsus exiguus* gr. and *Simulium* sp. omitted from the data

2. Mean abundance of organisms colonizing the Hester–Dendy substrates above and below the outfall during the four sampling periods



3. Mean species richness of organisms colonizing Hester–Dendy substrates above and below the outfall during the four sampling periods



III. Mean values for data from Hester–Dendy multiplate substrates; individual sampling stations for each sampling period [a]

Sampling period	Station [b]	Species richness, number of taxa	Abundance, organisms/m²	SW diversity (Base 2) All data	SW diversity (Base 2) Adjusted data [c]	Florida index
November 1989	1W	22	627	3.01	3.01	13
	1E	23	526	3.30	3.30	11
	2W	23	847	3.10	3.10	12
	2E	25	434	3.11	3.11	18
	3W	20	536	2.79	2.79	10
	3E	22	297	3.07	3.07	9
	4W	31	606	3.61	3.61	21
	4E	33	509	3.65	3.65	14
January 1990	1W	34	13,073	0.98	3.35	32
	1E	51	1,115	4.32	4.37	32
	2W	26	2,298	2.08	2.97	27
	2E	35	666	4.00	3.97	36
	3W	29	2,035	2.96	3.57	21
	3E	20	3,839	1.78	3.50	20
	4W	22	5,379	2.20	2.72	23
	4E	36	3,685	2.64	4.16	34
March 1990	1W	34	3,733	2.44	3.55	34
	1E	42	3,084	3.95	4.01	33
	2W	27	4,596	2.83	3.25	25
	2E	32	1,069	3.62	3.86	29
	3W	39	4,202	2.35	3.94	30
	3E	26	835	2.94	3.53	21
	4W	35	8,446	1.76	3.83	33
	4E	37	8,493	2.69	3.41	34
May 1990	1W	29	1,078	3.43	3.43	16
	1E	43	3,043	3.31	3.31	19
	2W	ND	ND	ND	ND	ND
	2E	ND	ND	ND	ND	ND
	3W	21	967	2.86	2.86	11
	3E	ND	ND	ND	ND	ND
	4W	28	2,373	2.79	2.79	16
	4E	24	1,593	2.45	2.45	11
Upstream						
Upper limit [d]		36	4,254	3.54	3.69	29
Average		32	2,585	3.11	3.47	24
Lower limit [d]		27	916	3.25	3.25	20
Std. dev.		8	3,185	0.83	0.41	9
Downstream						
Upper limit [d]		31	4,262	2.97	3.58	25
Average		28	2,920	2.70	3.33	21
Lower limit [d]		25	1,578	2.43	3.08	16
Std. dev.		6	2,651	0.53	0.49	9

[a]ND = no data (samplers lost or vandalized)
[b]Stations 1 and 2 are upstream; Stations 3 and 4 are downstream.
[c]Values for *Rheotanytarsus exiguus* gr. and *Simulium* sp. omitted from the data
[d]Upper and lower limits expressed at 95% confidence interval

fin also are part of the resident fish community. Marine anadromous species such as the Gulf sturgeon occasionally find their way into the Withlacoochee River to spawn. A survey by the Florida Game and Fresh Water Fish Commission documented 37 species in the vicinity of the study area (4). Species commonly favored by anglers are members of the sunfish family.

Mill discharge to the aquatic environment

The effect of pulping effluents on the aquatic environment has been an object of ongoing research for many years. The selected parameter for biological monitoring is commonly the benthic macroinvertebrate community. Effects of mill discharge on this biological compartment are assessed via population size or biomass per unit area and species composition. Community struc-

IV. Distribution of organisms colonizing Hester–Dendy substrates above and below the effluent discharge

Taxonomic group	November 1989 Above	November 1989 Below	January 1990 Above	January 1990 Below	March 1990 Above	March 1990 Below	May 1990 Above	May 1990 Below
	Mean abundance, organisms/m²							
Insecta								
Coleoptera	0	0	11	0	2	2	4	2
Chironomidae	1669	1158	848	2316	2240	4478[a]	1720	1264
Diptera (other)	0	0	3278[b]	1288[b]	2	2	27	3
Ephemeroptera	42	31	91	98	5	4	7	2
Megaloptera	0	0	3	0	6	1	0	0
Odonata	1	2	1	1	2	0	3	1
Plecoptera	0	0	7	1	38	14	0	0
Trichoptera	9	28	15	21	5	5	3	3
Others								
Acari	0	0	5	0	4	0	0	0
Amphipoda	4	24	9	3	0	5	0	0
Decapoda	0	2	0	0	0	0	2	0
Gastropoda	0	1	1	2	9	20	11	2
Isopoda	0	0	16	1	5	3	0	0
Oligochaeta	0	0	3	5	4	15	0	3
Turbellaria	0	0	2	0	1	6	0	0

[a]Primarily *Rheotanytarsus exiguus* gr.
[b]Primarily *Simulium* sp.

ture is expressed by various indices, the presence or absence of pollution-sensitive organisms, and functional group relationships (*5*).

Table I shows the effluent and river flows during the study period. Effluent flow to the river ranged from 26.1 x 10^3 m^3/day (6.9 million gal/day) to 182.4 x 10^3 m^3/day (48.2 million gal/day). Table I also shows BOD and total suspended solids (TSS) characteristics of the effluent. Over a five-year period, the annual average BOD and TSS reached maxima of 1140 kg/day (2513 lb/day) and 1336 kg/day (2946 lb/day), respectively.

Study method

Sampling strategy

In this study, the sampling regime was designed to

- Determine whether natural patchy distribution of life forms would significantly affect the SW diversity index in this reach of the river
- Ensure appropriate statistical treatment of the data.

Because of the possible confounding influence of patchy distribution, it was decided that a mere two stations—one above and one below the confluence—would not be adequate to distinguish patching effects from effluent impacts. Therefore, four sampling locations were designated above the mill's discharge, and another four sampling locations were established downstream. Locations are illustrated in Fig. 1.

Regulations in the state of Florida require the use of Hester–Dendy multiplate samplers for collection of aquatic macroinvertebrates in fresh water. However, many species do not colonize these artificial substrates because the devices do not provide suitable habitat. Supplementary data relating to this aquatic community were obtained by collecting 2-h timed qualitative samples using dip nets (U.S. Standard No. 30 mesh) at the six sampling locations illustrated in Fig. 1.

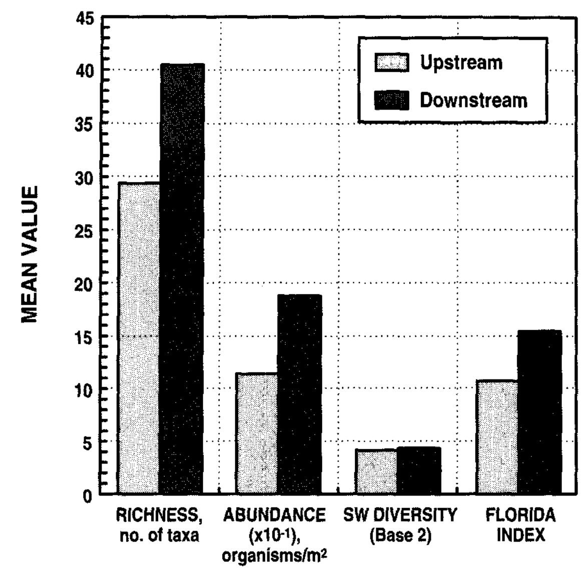
Explanation of indices

The SW diversity index is required to demonstrate compliance with the Florida BIR. The SW diversity index is determined by two components: the degree of evenness in the distribution among species (or distinct taxonomic groups) and the number of species (or distinct taxonomic groups). The index generally ranges from 0 to 4. Moderately high to high values (3–4) indicate clean water conditions, whereas low to moderately low values (0–2) are characteristic of stressed waters.

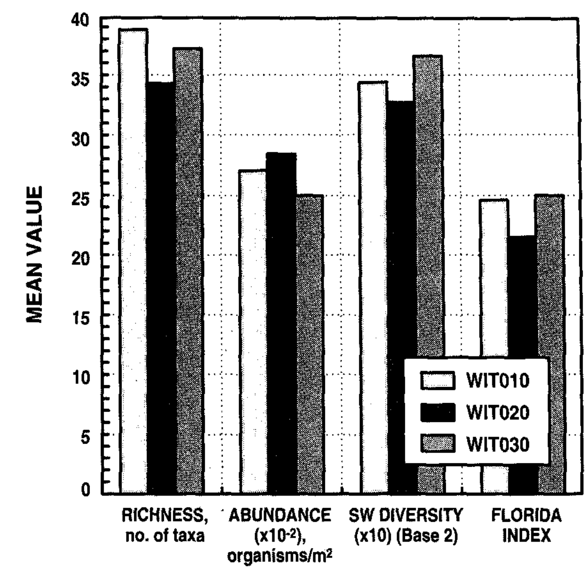
There are other indices that can be used to evaluate the quality of the macroinvertebrate communities. One of these useful for riverine water-quality evaluation is the Florida index (Beck's biotic index), which is specifically designed for use in flowing waters. The index is calculated from the number of species within a selected grouping that has been classified as intolerant of organic pollution (*6*). Ten is designated as the lowest acceptable value indicative of good water quality.

Species richness (the number of distinct species within a given collection of organisms) and macroinvertebrate abundance (the total number of organisms per square meter) are also important parameters frequently used to describe the status of the macroinvertebrate community.

4. Mean values for qualitative samples obtained from natural substrates at Stations 2–4 (March 21 and May 16)



6. Mean values for studies reported by the Suwannee River Water Management District, March 1989 through June 1990. Organisms were collected from Hester–Dendy substrates. WIT010 is above the outfall; WIT020 and WIT030 are below the outfall.



Sample collection and processing

Hester–Dendy multiplate samplers were placed in the Withlacoochee River at the eight locations shown in Fig. 1 during four 28-day sampling periods (Nov. 1–29, 1989; Jan. 24–Feb. 21, 1990; March 21–April 18, 1990; and May 15–June 13, 1990). Four samplers were incubated for a 28-day period at each location. Stations 1 and 2 were located above the outfall, and Stations 3 and 4 were downstream. Samplers were placed on the east and west banks of the river at each sampling station.

The Florida Department of Environmental Regulation (FDER) collected and processed samples from the east bank of Stations 2 and 3. Samples from the remaining six locations were collected by the mill's consultant. Three samplers from each location were processed, and the fourth sampler was archived. Both groups worked closely together in setting up the sampling and processing methodology to ensure that the data would be comparable. All data were shared.

The timed qualitative samples were collected from the east and west banks of Stations 2, 3, and 4 on March 21 and May 16. Natural substrates were sampled from the stream banks using dip nets (U.S. Standard No. 30 mesh). Organisms were sorted in the field for 2 h at each sampling location.

Samples were inventoried at the laboratory. Each was assigned a sequential number, which was entered into the sample logbook. Stages of processing in the laboratory included "picking" or sorting (removal of organisms from the substrate), enumeration, and identification of the specimens.

Results of the study

Hester–Dendy multiplate sampler data

Table II shows that mean values of SW diversity for the four sampling periods from November to June ranged from 3.1 to 3.4 above the mill's outfall and from 2.4 to 3.3 below. During each downstream sampling period, the mean SW diversity was greater than 75% of the corresponding upstream value.

Mean data for the eight individual sampling stations during each sampling period are listed in **Table III**. The individual SW diversity indices varied considerably because of patching and seasonal pulsing both above and below the discharge. For this reason, compliance with Florida's BIR is more appropriately based on means from multiple sampling events rather than single-event analysis from individual collection points.

5. Shannon–Weiner diversity of organisms colonizing Hester–Dendy substrates at individual sampling stations for each of the four sampling periods. Left graph: results for all data collected. Right graph: adjusted results (data for *Rheotanytarsus exiguus* gr. and *Simulium* sp. omitted). Wide variations in graph at left illustrates the impact of spatial patching and temporal patching. The graph at right has been adjusted to compensate for this patching, resulting in a much more uniform distribution of values.

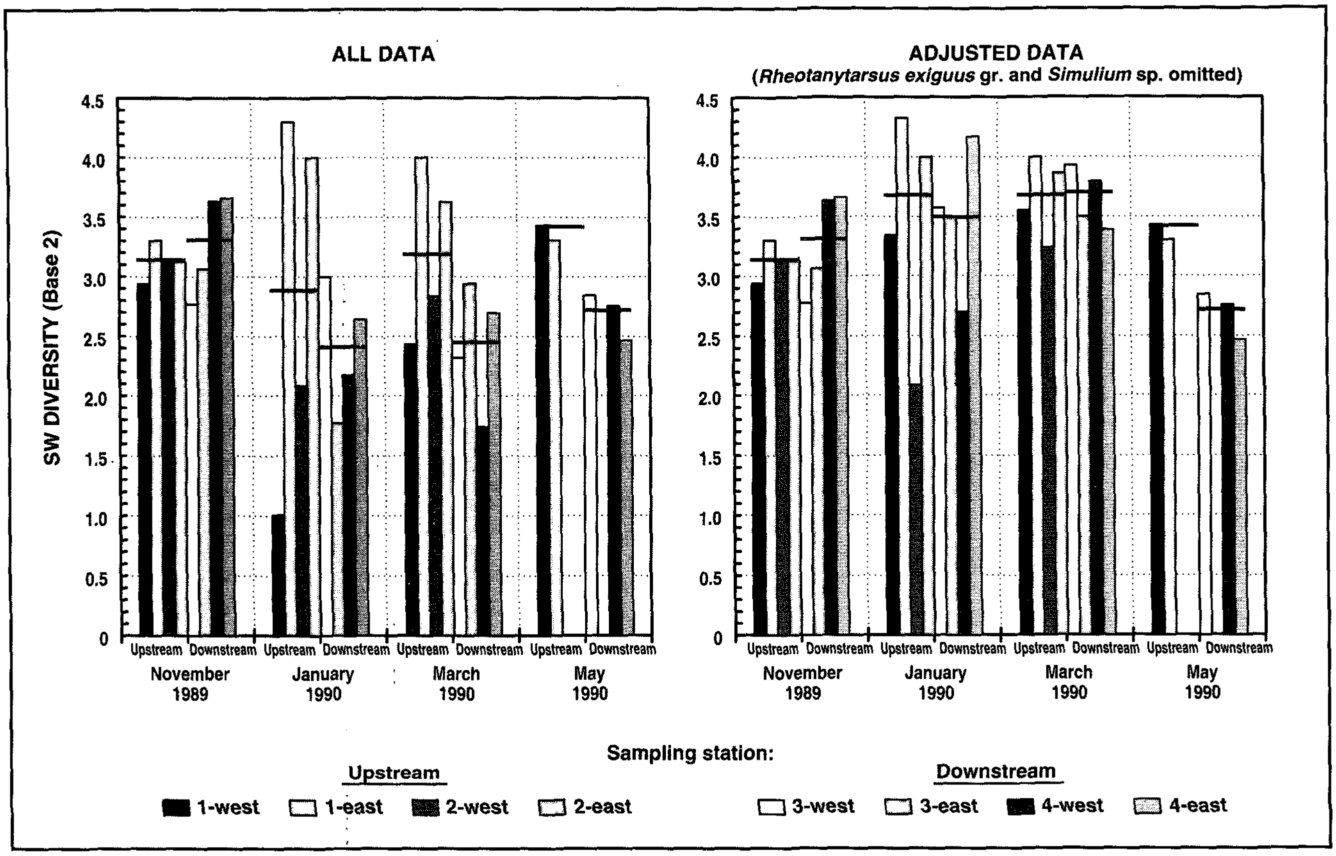


Figure 2 shows the mean abundance of macroinvertebrates above and below the discharge during the four sampling periods. Mean abundance was lowest during late fall, with a range of 500–600 organisms/m^2. Maximum abundance above the discharge was observed in January ($\approx$ 4300/m^2), while maximum abundance below the discharge occurred in March ($\approx$ 5500/m^2). Based on the mean for the entire study period, abundance above the discharge ($\approx$ 2600/m^2) was not significantly different from that below ($\approx$ 2900/m^2).

Figure 3 shows the mean species richness above and below the discharge during the four sampling periods. The maximum mean species richness was 37 taxa, which occurred in January above the discharge. Overall species richness observed above the discharge was 32, not significantly different from the species richness of 28 below the discharge. During late fall and early spring, the number of species collected below the discharge was equal to or greater than upstream species richness. Fewer species were observed below the discharge in winter and late spring.

Throughout the study, Chironomidae dominated the macro-invertebrate community, as seen in **Table IV**. Intermittent pulsing by *Rheotanytarsus exiguus* gr. (family Chironomidae) and *Simulium* sp. (order Diptera) also is apparent in Table IV. This pulsing accounted for a decrease in SW diversity index, which could affect interpretation of the BIR. Ephemeroptera and Trichoptera were secondary dominants during fall and winter, while Plecoptera filled this niche in early spring.

Based on means for all stations, the Florida index was above 10 for the four sampling periods, as seen in Table II. The poorest water quality occurred during the fall, when the index average was 14 above and below the outfall. Similarly, the highest overall index values were observed in March, when means above and below the discharge were 30.

Data from natural substrates

Samples were gathered from natural substrates in the river to supplement the collections from the Hester–Dendy artificial substrates. The natural-substrate samples were gathered in early spring (March 21) and in late spring (May 16). These qualitative data were independently analyzed using SW diversity index and the Florida index, although this information is not significant for regulatory compliance. Overall results for both sampling periods are given in **Fig. 4**.

For these two periods, mean values for the SW diversity index ranged from

3.9 to 4.1 above the discharge and from 4.0 to 4.3 below the discharge. The Florida index below the discharge was equal to or higher than the index above the discharge. On March 21, the average Florida index values above and below the discharge were 8 and 13 respectively. On May 16, the average Florida index above the discharge was 13, compared with 17 below the discharge. **Table V** shows the distribution of organisms among the natural substrates.

V. Distribution of organisms among natural substrates above and below the effluent discharge

Taxonomic group	Mean population* March 21, 1990 Above	Mean population* March 21, 1990 Below	Mean population* May 16, 1990 Above	Mean population* May 16, 1990 Below
Insecta				
Coleoptera	3	7	11	12
Collembola	0	1	1	0
Chironomidae	5	22	8	19
Diptera (other)	1	4	3	6
Ephemeroptera	3	2	6	19
Hemiptera	1	3	2	4
Odonata	0	6	10	24
Trichoptera	0	2	2	3
Others				
Acari	1	13	7	4
Amphipoda	5	27	16	43
Decapoda	8	6	18	10
Gastropoda	2	2	4	6
Isopoda	1	1	4	10
Oligochaeta	17	3	7	5
Pelecypoda	1	1	2	8
Porifera	0	0	1	1
Turbellaria	0	0	1	1

*Values represent population means for a 2-h collection period at the east and west banks of Stations 2, 3, and 4.

Discussion

Historical record

Prior to mill construction, the Institute of Paper Chemistry (IPC) conducted surveys of the Withlacoochee River. During the summers of 1952 and 1953, collections were made of the macroinvertebrate fauna between Clyattville, GA, and Old Town, FL. This early qualitative sampling showed a macroinvertebrate assemblage composed of mayflies, stoneflies, caddis flies, dragonflies, and various species of midges (*7, 8*).

After the mill came on-line, the surveys were continued in an effort to characterize the macroinvertebrate community above and below the discharge. Data collected from 1962 through 1976 (*9*) show 25 taxa as the average species richness in the river above the discharge vs. 23 within a 914-m reach below. The ratio of organisms intolerant of pollution to the total population above the discharge ranged from 0.18 to 0.92, with a mean of 0.69. Below the discharge, the ratio varied from 0.07 to 0.74, with a mean of 0.38. However, on average for the period of record ending in 1976, the mean number of intolerant organisms below the discharge of the mill was 997. An average number of 769 organisms was observed above the discharge. On average, total organisms per sample below the discharge was 2963 vs. 1087 above. These results, along with increased biomass of macroinvertebrates below the discharge, followed trends noted by NCASI in an extensive review of similar studies (*10*).

In these studies of macro-invertebrate characterization, NCASI reported that approximately 50% (23 of 40 sites) showed some effect that was attributed to pulping effluent (*10*). No clear distinction could be made between bleached or unbleached operations. At 18 of the 23 sites, effects were noted only in the immediate mixing zone within several hundred meters of the discharge point. In the remaining five cases, effects extended beyond the mixing zone, but usually not more than 3 km downstream. The effects that were noted within the mixing zone included:

- An increase in the abundance of species tolerant of organic enrichment
- A shift in functional feeding groups
- Reduced diversity.

In most cases, shifts in the community structure suggested organic enrichment effects rather than toxicity or other physical/chemical impacts of the effluent. In such cases, an overall decrease in species diversity was not accompanied by a reduction in macroinvertebrate density or biomass. Consequently, higher life forms were not deprived of available food.

"Patching" and data interpretation

Analysis and interpretation of macroinvertebrate data can be influenced by the surface distribution and periodic population pulsing of selected species. Many aquatic organisms, particularly immature aquatic insects, are found in very specific microhabitats. Most of the immature aquatic insects remain in the area in which the eggs were originally deposited by clinging to or burrowing into the substrate. Thus, immature aquatic insects occur in patches. Aquatic species may be clumped temporally as well as spatially, occurring in abundance at specific times of the year.

The phenomena of spatial patching and seasonal peaks in abundance pose problems when attempting to evaluate SW diversity index values, which are

VI. Overall mean values for species richness, abundance, Shannon–Weiner species diversity index, and Florida (Beck's) index above and below outfall[a]

Parameter	*Upstream*	*Downstream*	*Change, %*	*Significance*[b]
Species richness,				
number of taxa	31.86	28.2	-11.5	NS
Abundance, organisms/m^2	2585	2920	13.0	NS
SW diversity index				
All data	3.11	2.70	-12.9	NS
Adjusted data[c]	3.47	3.33	-4.0	NS
Florida index	24.0	20.5	-14.6	NS

[a]Data collected from Hester–Dendy multiplate substrates
[b]NS = no significant difference based on Student *t* test, $p = 0.05$
[c]*Rheotanytarsus exiguus* gr. and *Simulium* sp. omitted from the data

greatly influenced by evenness of distribution (abundance) among the species present (*11*). The SW diversity index can be lowered drastically by the high abundance of one or more species. Consequently, it can be difficult to determine whether low SW diversity index values are the result of patching, normal seasonal pulses in abundance, or deleterious water quality.

Where these natural phenomena may occur, the study design must take into account such confounding parameters to provide statistically meaningful results. The use of multiple stations within a relatively short distance is necessary to differentiate patching effects from water-quality impacts. **Figure 5** (left graph) shows the wide variation among the individual stations, both upstream and downstream. It is evident that the variation among upstream stations is as great or greater than the variation between upstream and downstream stations.

The low individual SW diversity index upstream of the discharge at Station 1W in January (Table III and Fig. 5, left graph) is an example of the effects of spatial patching and seasonal pulses on SW diversity index. In this case, the lowering of SW diversity index is caused by a pulse in abundance of black flies, *Simulium* sp. This suggests that sufficient nutrients and food are available upstream of the discharge to support such a pulse and that similar pulses in abundance downstream of the confluence are probably not caused by paper mill discharge. In March, a similar pulse in *R. exiguus* was observed at other stations.

During these pulses, diversity was primarily affected by the abundance of *R. exiguus* and *Simulium* sp. Generally, diversity values were low when these species were most abundant. These species are known to periodically attain extremely high population levels under normal conditions in Florida streams. In an unpublished paper, the FDER has suggested that during periods of extreme abundance, such species may be treated as "invisible species" and may be eliminated from the data for purposes of evaluating the BIR (*12*). *Rheotanytarsus* and *simuliids* were specifically mentioned as potential "invisible species."

After *R. exiguus* was omitted from the March data, the index values for the individual stations were much more uniform. Table II shows that the mean downstream diversity (3.68) was approximately the same as the mean upstream diversity (3.67). The greater uniformity of the modified data are apparent by comparing the left and right graphs in Fig. 5.

In situations such as this, the natural variables can overwhelm assessment objectives. With multiple close-range sampling stations, the use of the mean index values for comparison of upstream and downstream water quality is more appropriate and provides a more accurate assessment of any impacts from the discharge. Therefore, for each sampling period, mean upstream and downstream SW diversity index values were calculated for use in determining compliance or noncompliance with the BIR. Mean values for the entire study period are listed in **Table VI**.

Likewise, a more representative picture of the macroinvertebrate communities is obtained by excluding organisms such as *R. exiguus*. The SW diversity index data presented in Tables II and III show mean values for the different sampling periods (Table II) and for the individual sampling stations during each sampling period (Table III). SW diversity index results with and without exclusion of *R. exiguus* are listed as well. The mean values were compared for the compliance calculation in the Florida BIR. In both cases, the results show that compliance with the rule is being met.

The qualitative data, although not applicable for determining regulatory compliance, provide additional support for the conclusion that the discharge is in compliance. The qualitative SW diversity index and Florida index values for the downstream stations were equal to or higher than the upstream stations.

Other studies

Additional information can also be gained by review of other macroinvertebrate studies in this vicinity of the Withlacoochee River. The macroinvertebrate collections by IPC prior to and following mill operation contained a diverse population including mayflies, caddis flies, stoneflies, and dragonflies. These species, which are recognized as pollution-intolerant forms, continue to be a part of the biological community above and below the discharge of mill effluent to the Withlacoochee River. Because of differing collecting methods, succinct comparisons cannot be made with these early investigations. However, some insight can be gained by examining the number of taxa and number of organisms with the historical record.

The early IPC study reported mean species richness above and below the discharge as 25 and 33, respectively. Our study showed a mean of 32 taxa above and 28 taxa below the discharge. Comparisons beyond the number and the presence of intolerant species are not valid because of different collecting techniques. The results reported herein show that the macroinvertebrate community in the river, with regard to number of species and the presence of clean-water forms, has not altered during the years of mill operation.

Another macroinvertebrate study is being conducted by the Suwannee River Water Management District as part of Florida's surface-water management program. This study is being carried out to assess current water quality and long-term trends. Three monitoring stations are maintained on the Withlacoochee River. Station WIT010 is upstream and WIT020 and WIT030 are downstream of the mill's discharge. Data from these stations are of interest, even though the distance of many kilometers between stations means that there can be factors other than the mill's discharge influencing the results. Comparison of data for WIT010 and WIT020 in **Fig. 6** indicates slight impact on the downstream benthos. More importantly, the data show good water quality at all stations, with mean SW diversity index values between 3 and 4 and Florida index values above 20 at each site.

Conclusion

Results of this study show that design and data-evaluation criteria are critical if meaningful conclusions about water quality are to be derived from investigations of macroinvertebrate communities in receiving waters. Significant variation was observed in the sample communities between individual stations as the result of patching, a natural phenomenon that occurs because of seasonal peaks in abundance of certain species and uneven spatial distribution. Because of this patching, comparison of upstream and downstream water quality is best assessed using mean index values. Such an approach provides a more statistically accurate assessment of any impacts from the discharge.

Based on quantitative and qualitative evaluation of various indicators of water quality, the discharge from the 1110-ton/day unbleached kraft linerboard mill in Valdosta, GA, has no significant impact on the macroinvertebrate community of the Withlacoochee River. Species richness and the presence of pollution-intolerant forms are similar to the community structure observed almost four decades ago in a study conducted by the IPC, prior to the mill's operation.

The SW diversity index and Florida index values indicate that similar, healthy, and well-balanced populations exist above and below the discharge. Water quality as determined by the Florida index (Beck's biotic index) was not affected by the discharge from the mill. The mean SW diversity index value downstream was 87% of the upstream mean SW diversity index value using all data. Using adjusted data, SW diversity index downstream was 96% of the upstream value. These results demonstrate compliance with the Florida BIR, which requires a downstream SW diversity index of at least 75% of the upstream value. TJ

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