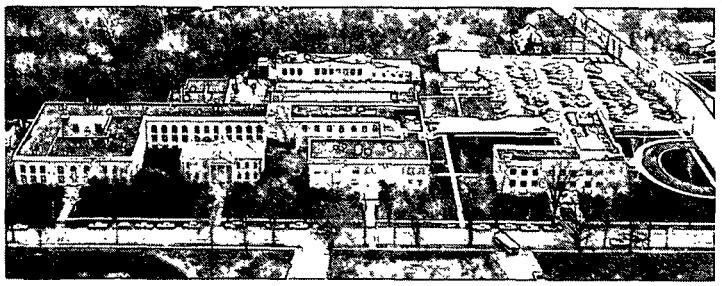

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MONITORING THE ECOLOGICAL IMPACT OF KRAFT MILL EFFLUENTS ON THE SACRAMENTO RIVER

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ABSTRACT

The Sacramento River in central California is a sensitive cold water aquatic ecosystem which sustains anadromous and resident Salmonid fish populations. For this reason unusually demanding waste treatment and impact assessment programs were required to ensure that this aquatic system was not being endangered. A two pronged program was conducted for the first years of the mill's operation which included flow-through toxicity testing on fish eggs as well as fingerlings, and a survey of river invertebrate communities to investigate direct effluent induced changes. Throughout the study period biologically treated effluents were found to be not acutely toxic to trout or trout eggs. At the same time the invertebrate studies documented that there were no changes in the resident invertebrate communities which could be attributed to effluents discharged by the mill.

INTRODUCTION

The integrated bleached kraft pulp and paper mill at Anderson, California, presently owned by Simpson Paper Company, first began production in 1964. Because the mill is located near the Sacramento River and discharges into these salmon spawning waters, the environmental constraints governing its operation were much more rigorous than those pertaining to other U.S. mill operations. Few mills even in 1980 have as severe effluent limits as did the Shasta Mill in the 1960's. As a result of these regulations, the mill has carefully monitored its biologically treated final effluents under both laboratory and field conditions. This program has produced a thorough history of biological community response to bleached kraft pulp and paper final effluents for a cold water receiving stream. The mill's commitment to protecting the Sacramento River has also produced some novel and successful approaches to effluent disposition.

The mill's environmental protection program includes two components of biological impact monitoring:

1. Laboratory acute and sublethal toxicity monitoring as developed and carried out by mill technical personnel, and

2. River faunal community impact assessment, focusing on macroinvertebrates, as contracted with The Institute of Paper Chemistry.

In an effort to predict and anticipate possible fish responses to acute toxicity, the mill has maintained a continuous acute toxicity monitoring program since February 1965. This has been coupled with periodic egg and larval sublethal toxicity assays. The biological community impact assessment surveys on the Sacramento River monitored the macroinvertebrate riffle communities for subtle changes which may indicate a response to mill discharge. The Simpson Mill provides a rare opportunity to evaluate final effluent impacts using both acute toxicity assays as well as actual biological community responses. It also provides the opportunity to combine and compare these two kinds of biological monitoring under similar conditions and over a long period of time.

THE RECEIVING STREAM

The Simpson Company Shasta Mill is located near the Sacramento River at Anderson, California. The study area is confined to the upper reaches of the 300 mile long Sacramento river (see Fig. 1, a map of the study area). The Sacramento drains an area of over 26,000 square miles of northern and central California and, along with its 39 tributary streams, carries about 32% of the State of California's total water supply. The river originates at the Shasta Dam and is influenced by the Keswick Dam to provide controlled flow, dictated by water use demands such as irrigation. The water temperature is normally between 8 and 16°C on an annual cycle.

The 30 mile study area is located in the upper portion of one of three major geographical regions of the Sacramento Valley. This region is characterized by a steep well-defined channel with rapidly flowing water and many closely spaced rapids. This length of river is navigable by motor driven boats even during low water. Benthic invertebrate communities are moderately diverse and highly productive throughout the whole area. The river also supports an important cold water fishery including resident rainbow trout and spawning populations of anadramous king salmon and steelhead trout.

The extensive sport fishery coexists with a variety of demands on the river for industrial, municipal and irrigation water. The upper Sacramento Valley is a major truck crop- and orchard-oriented agricultural complex largely maintained by irrigation water from the river.

THE MILL

The Shasta Mill of Simpson Paper Company is an integrated bleached kraft pulp and paper mill which produces 200 tons per day of bleached softwood pulp and 400 tons per day of coated and uncoated printing and writing papers. The bleaching sequence is CEHED. The mill uses 12 million gallons of water per day, supplied from seven deep wells.

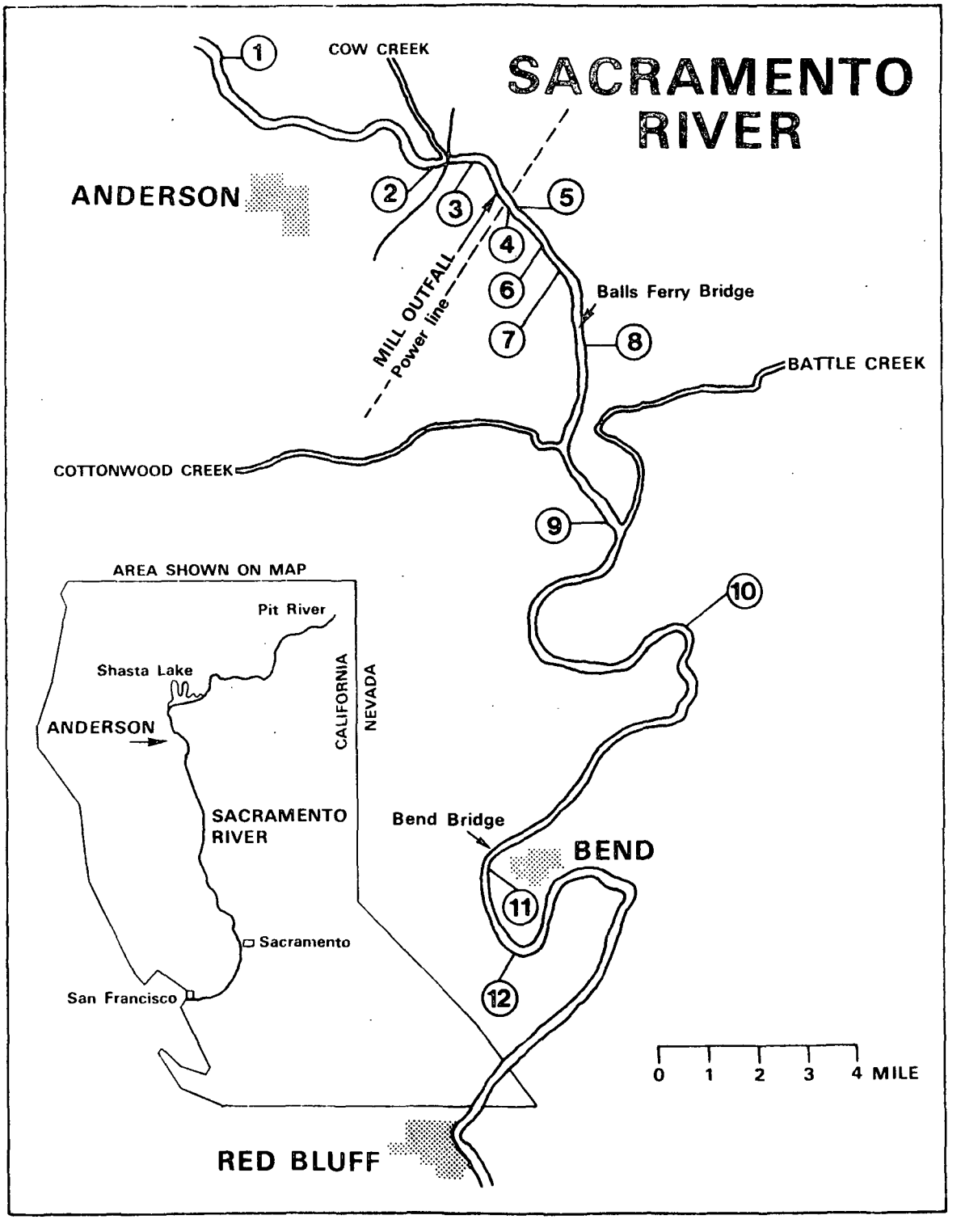

Figure 1. Map of the Study Area

Waste treatment methods have changed during the 16 years of the mill's existence. When it was built waste treatment consisted of primary clarification followed by a high rate contact stabilization air activated sludge system which treated 10 million gallons per day (MGD) of water.

In 1974 a mill expansion program was initiated which enlarged production to current levels and increased water usage to 12 MGD. In December 1975 the mill changed from activated sludge secondary treatment to two aerated stabilization basins[1]. These basins provide 12.58 hectares (31 acres) of capacity for secondary treatment. Aeration is provided by 15 surface aerators.

Of the total volume of effluent treated, up to 20% is used for irrigating a portion of croplands on 430 ha. (1100 acres) owned by the mill and located on the banks of the Sacramento River about 5 km from the mill site[2]. This unique effluent treatment procedure allows compliance with state NPDES permit limits but greatly enlarges the environmental protection activities of the mill. In addition to monitoring effluent parameters data are also collected on groundwater samples available from more than 70 wells and on samples of interstitial water from gravel bars in the river along the irrigated shoreline.

Because of the importance and fragility of the receiving stream the California NPDES permit limits were more rigid than those required by the EPA, especially with respect to toxicity (Table I).

TABLE I

SELECTIONS FROM EFFLUENT DISCHARGE RESTRICTIONS FOR THE SIMPSON COMPANY SHASTA MILL (1977)

	Category	Limit: Daily	Limit: 30-Day Average
Effluent:	pH	6.5-8.5	
	Toxicity emission rate per bioassay	20 Tu/MGD	10 Tu/MGD
	River flow = < 3500 CFS		
	BOD_5	4260 lb/day	2130 lb/day
	Suspended solids	4260 lb/day	2130 lb/day
	Settleable solids	0.1 mL/L	--
	River flow = 3500-9999 CFS		
	BOD_5	6640 lb/day	3320 lb/day
	Suspended solids	7440 lb/day	3720 lb/day
	Settleable matter	0.1 mL/L	
Receiving water:			
	Taste and odor in domestic water	None	
	Groundwater runoff	None	
	River dissolved oxygen	Not less than 9.0 mg/L	
	Interstitial gravel water oxygen	Not less than 7.0 mg/L	
	Oil grease foam	None	
	Receiving water "discoloration"	None	
	Fungus and slime growths	None	
	Alteration of bottom macroscopic fauna	None	
	Turbidity increases	< 10%	

EXPERIMENTAL

Toxicity Studies. Acute toxicity bioassay techniques were developed by Shasta Mill personnel and tests have been conducted on treated effluents by mill technical personnel since February 1965. Table II lists frequency and chronological period for the acute and sublethal bioassays performed. Test organisms were Salmonid fish native to the river. King salmon (Oncorhynchus tshawytscha) fingerlings (approximately 2.3 gm) were first preference as test organisms, however, when these were not available steelhead trout (Salmo gairdneri) and rainbow trout (Salmo gairdneri) were obtained from nearby federal, state or private hatcheries. Sand filtered river water was supplied for dilution water until 1978 when a change to well water was made due to flood damage to the pumping station. A temperature of 11.1°C (56°F) is maintained with a 5 ton Rheem chiller unit and aeration is provided by pure oxygen. Dilution water pH averaged 6.8 and electrical conductivity was about 120 micrometers/cm.

TABLE II

BIOASSAYS PERFORMED AT THE SIMPSON PAPER COMPANY SHASTA MILL

	1965-1967	1968-1973	1973-1975	1976 Sept. 79	Sept. 79-Present
96-Hour static acute TL50	weekly	--	--	--	
96-Hour continuous flow TL50 (metered)	--	weekly	--	--	--
96-Hour continuous flow TER (metered)	--	--	weekly	--	weekly
144-Hour continuous flow TER (automatic dilution)	--	--	--	weekly	
Sublethal egg bioassays	annually	annually	annually	annually	--
Interstitial gravel 96 hour acute				monthly	
River bank groundwater wells	--	--	--	monthly	

Fish were acclimated in dilution water and not fed during the experiments. Test containers were 246 liter glass aquaria. Twenty fish per concentration were used. The dilution water delivery system has changed over the course of time with the earliest method consisting of rotameters to control flow. In 1976 a solenoid controlled proportional diluter similar to that recommended by Mount-Brungs[3] was constructed for the mill by a private contractor.

Results were calculated for median survival when mortality exceeded 50% in any concentration. This was done using the graphical interpolation method[4] and expressed as TL50 (or TLM). Results were also calculated in terms of "Toxic Units" (Tu) or "Toxicity Emission Rate" (TER) to satisfy effluent toxicity limits set by the state of California. A toxicity unit (Tu) is defined as:

$$Tu = \frac{100}{TL50}$$

The TER is a function of effluent volume: TER = Tu • (discharge in MGD). Where no TL50 could be calculated the regulatory agency applied an empirical formula to generate toxic units:

$$Tu = \frac{\text{Log } (100-S) - 0.73}{0.97}$$

$$S = \% \text{ survival}$$

Sublethal Bioassays. Salmonid egg survival and growth bioassays were conducted from 1965 on an annual basis. From 1966-1974 the jar culture method was used[5]. This technique was replaced by a Heath verticle incubator[6] in 1974 which was used until 1979.

Jar culture assays employed 15 incubators with 1000 king salmon eggs in each. King salmon were

obtained locally during the spawning period from the Coleman Federal Fish Hatchery. Effluent dilutions of 10%, 5%, and 2.5% with 3 controls were used. Oxygen and temperature levels were maintained as described for acute bioassays. Eggs were monitored for 40 days until hatched and then fry were transferred to 10% effluent and monitored for 125 days or until they were approximately 5 grams in size. A continuous flow delivery system was used for control and experimental solution concentrations.

The Heath vertical incubators are a series of 8 trays containing 1000 eggs/tray (determined volumetrically) for a total of 8000 king salmon eggs. The most recent assay used two replicates of a dilution range which included 2.5%, 5.0% and 7.5% effluent plus a control. After hatching, the fry were transferred to aquaria and raised in 7.5% concentration effluent. Fish were weighed weekly and observed for a period of 130 days.

BENTHIC RIVER COMMUNITY SURVEYS

Benthic macroinvertebrate community sampling methods did not vary throughout the 18 year history of the study (begun two years before mill startup). Sample stations were located on shallow fast water riffles (see map, Fig. 1) upstream from the mill outfall and downstream for a distance of 25 river miles.

Samples were collected by means of a Surber square foot bottom sampler. This net enclosed device allows rock and gravel substrates to be collected from a square foot of river bottom. A net deployed downstream from the collected substrate captures animals which become dislodged from the rocks. The substrate is collected in pails, scraped and brushed to remove clinging invertebrates and discarded. The animal life forms were screened with a standard U.S. 30 mesh brass screen, preserved with 10% buffered formalin and shipped to the laboratory for processing. Four samples from each station were used to generate mean values for each station.

In the laboratory, technical support staff sorted and rough counted according to standardized methods and subsampling procedures. Sorted specimens were identified to the lowest possible taxonomic unit (taxon, pl = taxa) with the aid of published keys and references ([7-10] as examples).

Numerical data was computer tabulated using a program developed at The Institute of Paper Chemistry[11]. A numerical diversity index number was calculated for data collected since 1973 using the Shannon Weaver $\bar{H}$ index[12-16].

Comparisons of stations with respect to community changes were also made by using a computer calculated cluster analysis. This procedure is a comparison of the similarity of sampled stations based upon the number and types of taxa.

The program used for the analysis was devised by Pinkham and Pearson[16] and modified by Church[11]. This program generates a similarity coefficient for each possible station comparison using numerical abundance and species type for each organism at each sample station. Following all possible comparisons a matrix of paired comparisons is generated. This matrix is searched for comparisons with high similarity coefficients, and those stations which are similar are linked together. A continuous linkage is made by adding comparisons which are similar at different levels until a dendrogram of clusters has been created.

RESULTS AND DISCUSSION

ACUTE TOXICITY

While acute toxicity assays were initiated at the Shasta Mill in 1965 records of results generated during this period have become lost. The most useful information is that which is available from the period following the mill expansion program in 1974.

Within the period between 1974 and 1980, 180 different 6 day (144 hour) bioassays were begun and 63 conventional length 96 hour bioassays. The results from this extensive testing program are summarized in Table III. A success rate of 93% was achieved for this series of tests. Unsuccessful (approximately 7%) bioassays were those that had control mortality due to equipment failure or disease problems. Of the equipment involved, the water cooling apparatus was the most prone to failure.

TABLE III

SUMMARY OF ACUTE TOXICITY BIOASSAYS FOR SHASTA MILL TREATED EFFLUENTS 1975-1980

	96-Hour	144-Hour
Months of operation	15	44
Number of bioassays begun	63	180
Number of successful bioassays	58	168
Number with > 50% mortality	9	14
Number with > 90% survival in 100% effluent	47	131
Number of tests with a TL50	9	14
Average TL50 for tests with a TL50	76.5%	84.3%
Number of tests with a positive TER	7[a]	48
Number of tests with TER = 0	19	120
Average TER for positive tests as Tu/MGD	23.0	6.5
Average TER for all tests as Tu/MGD	6.3	1.9

[a] TER not calculated for early tests in this series. Average given is for the 7 numbers calculated.

Continuous surveillance using salmon or trout fingerlings revealed few occasions when a TL50 could be calculated for treated mill effluents. The 96-hour assays produced 9 with mortality higher than 50% and the 144-hour assays produced 14. Slightly more than 10% of all effluent test periods showed the presence of an effluent with a positive TL50. The average TL50 for all tests combined was 80.4% effluent by volume. Of the total acute tests completed,

78.7% showed fish survival at better than 90% in 100% treated effluent. The few episodes of toxic effluents were typically related to spills and mill downtimes.

For periods in which regulations were written in terms of allowable Toxicity Emission Rates (TER) the mill was out of compliance with weekly allowable levels only one time and not ever out of compliance for a monthly average.

In order to evaluate potential receiving stream impacts for irrigation disposal of part of the mill's effluent, groundwater samples were assayed weekly during the period January 1976 through August 1979. Fish were assayed in 100% groundwater from 6 wells located throughout the irrigation project. Tests were conducted as 96-hour acute bioassays. A total of 43 sets of assays were completed which consisted of 258 samples for testing. During this three and one-half year period no groundwater sample gave any evidence of acute toxicity. Fish survival was 95% or better in all samples tested. One exception occurred with one set of assays which failed when water cooling equipment malfunctioned.

SUBLETHAL EGG BIOASSAYS

Sublethal bioassays are difficult to conduct because of the sensitivity of the test specimens and duration of time for the experiments. Mill experience with sublethal bioassays extended over the course of 14 years. During this period a diverse combination of problems occurred which prevented the successful completion of most studies though in many cases some useful data were generated. These problems were almost always unpredictable or beyond control of the bioassay personnel and emphasize that hatching and growth sublethal studies are complicated and difficult to conduct.

As examples of problems which prematurely ended bioassays are: in 1971 fingerling fish plugged water ports and cut off circulation; in 1974 a Sphaerotilus outbreak retarded hatching; in 1975 the eggs did not become fertilized; in 1977 fumes from an epoxy paint being used near the bioassay site killed the test specimens; in 1978 heavy metals in the (Sacramento River) dilution water killed the eggs; on a couple of occasions the eggs obtained were diseased.

On those occasions when results were produced, the high concentration of 7.5% final effluent resulted in no difference in egg hatching rate from the control for 5 assays. In all but one of these assays survival and growth was similar between the control and the highest effluent concentration. During the 1971 assay, mortality occurred on one day of the 118 day exposure killing all test animals in 10% effluent. In 5% effluent there was 90% survival.

In Table IV results from the 1979 egg assay are summarized as an example of the information available from those tests. Survival and hatching of eggs in 7.5% effluent was better than that of the two controls. Following the growth study there was no difference in survival but the fry exposed to mill effluent showed a greater weight gain in all three concentrations than did the controls.

RIVER COMMUNITY IMPACT STUDIES

The second component of environmental monitoring for possible effluent impact consisted of a direct investigation of river animal communities. While toxicity testing documented the absence of acute toxicity to fish, these could not assure the lack of an effluent impact on other interrelated components of the river's trophic web. In order to monitor for possible impacts, a direct community assessment program was conducted.

TABLE IV

SUMMARIZED RESULTS FOR 1979 SUBLETHAL SALMON EGG ASSAY OF SHASTA MILL FINAL EFFLUENTS

Effluent Concentration	Mean % Egg Survival, Hatching	No. of Fish[a] Surviving Growth Study	Weight Per Fish, gm	% Weight Gain
Control 1	76.8	93	4.74	1281
Control 2	72.1	90	5.61	1498
2.5%	71.8	94	6.00	1614
5.0%	75.5	97	5.91	1611
7.5%	92.3	94	6.33	1695

[a] From an initial count of 100 fish per concentration.

Two components of faunal community structure contributed information useful to understanding changes in environmental quality. The parameter of community diversity or numbers of different species is a key concept for measuring water quality changes. Environmental modifications usually reduce or change niche availability. This causes a reduction in species diversity and composition which can be subjectively or objectively measured. The second parameter is density or number of organisms present in the community. The carrying capacity may be reduced or expanded by organic discharges and shifts toward greater or lesser numbers of individuals may be documented.

In Fig. 2 the number of different macroinvertebrate taxa sampled by station for all years surveyed is presented as a histogram. The bars differentiate between intolerant organisms and "facultative organisms"[17] which are more tolerant of changes in water quality. Normal communities include both types of organisms while water quality modified communities often show a predominance of facultative fauna. It is apparent that for combined annual data the species diversity varied little throughout the stations sampled. Upstream control stations and sites sampled downstream from the mill were not different. The relative proportion of intolerant vs. facultative organisms was also constant between stations.

A breakdown of diversity data by year (Fig. 3) shows a constant fauna in the river throughout the study series. The taxa increased beginning with the 1972 study due to a larger number of identified facultative taxa. This increase corresponds to an expansion of taxonomic expertise which allowed greater separation and identification of chironomid midge larvae. This increase is most probably an artifact rather than an indication of changes in the river community.

Macroinvertebrate community density can be summarized in a similar fashion for the studies conducted on the Sacramento River. Figure 4 depicts numerical density by station for a summary of all years studied on the river. This figure also compares the

most recent (1978) data with the study average for stations used during a majority of the studies. The most important fact revealed by these data is the lack of any difference in downstream vs. upstream communities. This uniformity indicates that there have been no persistent changes in water quality due to mill discharges. The graph which depicts 1978 data illustrates that for this collection period there was no density difference which could clearly be attributed to mill effluents. There was more station to station variability identified in the 1978 single year data display than in the data summarized for all collections.

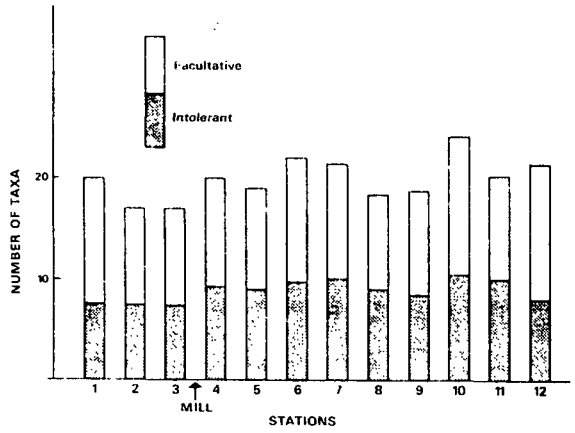

Figure 2. Summary of Taxa by Station for all Years Sampled

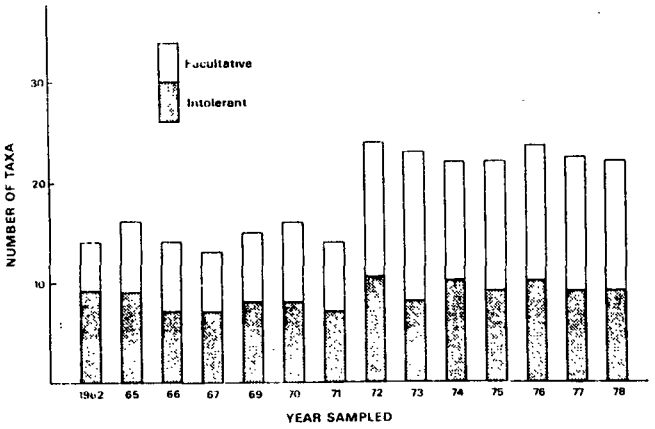

Figure 3. Summary of Taxa by Year for all Stations Sampled

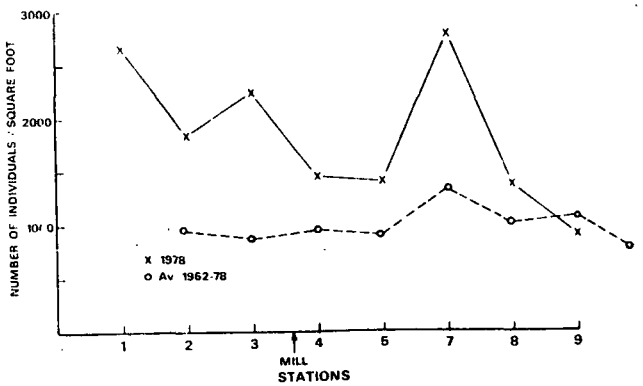

Figure 4. Numerical Density of Sacramento River Invertebrates for 1978 and an Average for the Period 1962-1978

One noticeable change has occurred in the river community and is evident in Fig. 4. For 1978 data, all but Station 9 show a much higher invertebrate density than is evident for averaged annual results. This phenomenon is more evident in Fig. 5. This figure shows data from all stations summarized by year to describe the river community as a whole. From this information there seems to be a distinct three year cycle for population density. There is also a very clear increase in invertebrate productivity throughout the river system which has occurred over approximately the last eight years. This phenomenon is not mill related because stations upstream demonstrate this same pattern individually. Other point and especially nonpoint nutrient sources probably contribute to this condition. While the comprehensive data collected during this study indicates increasing nutrient enrichment, it cannot determine the source or reasons for the response other than to confirm that point-source mill discharges were not at fault.

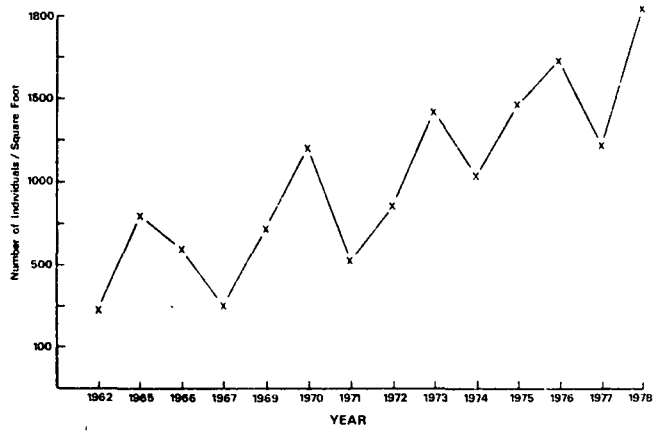

Figure 5. Numerical Density of Sacramento River Invertebrates as Average of all Stations by Year

Computer assisted numerical comparisons often add a dimension to the interpretation of community structure changes which may be difficult to do objectively. The cluster analysis procedure which compares similarity of communities at each station processes numerous comparisons to produce a similarity coefficient number. For the Sacramento River study program, Fig. 6 illustrates a dendrogram created for 1978 data. Stations with similar faunal communities are linked together on a scale of 0-1 with 1 representing complete similarity. It can be seen in this figure that all stations sampled are similar at the 0.9 level or higher. If mill effluents had caused changes in animal composition or distribution, downstream stations would have been dissimilar to upstream control stations.

CONCLUSIONS

The combination of laboratory fish toxicity monitoring with direct river community assessment has demonstrated conclusively that the Shasta Mill operated by Simpson Paper Company has had no measurable impact on the water quality of the receiving stream as it affects the river's ability to support animal life. Each of the two monitoring programs has contributed different but compatible information toward reaching this conclusion.

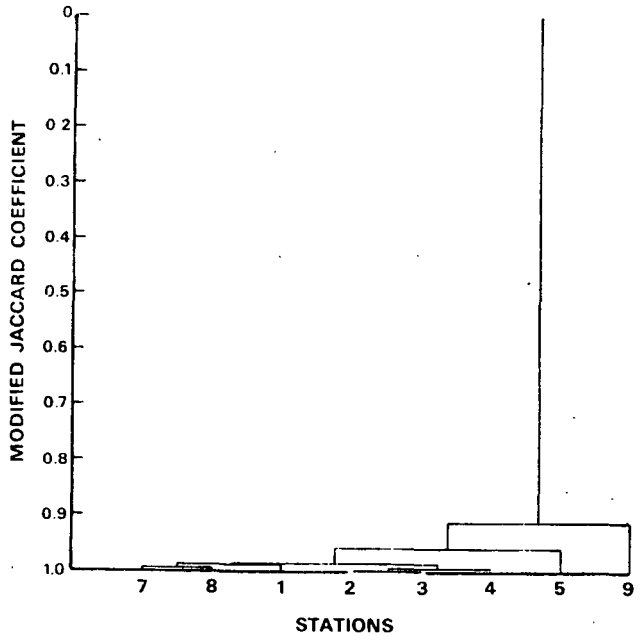

Figure 6. Dendrogram of Similarity Coefficient for Sacramento Invertebrate Communities for 1978 Data

The river community assessment program has also documented changes in the river's productivity and convincingly demonstrated that the mill has not been responsible for those changes.

This combination of biological assessment methods provides comprehensive and detailed information on mill effluent environmental impacts which contribute much to understanding and clarifying factual conditions.

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