IMPACTS OF THE JOHN MORRELL MEAT PACKING PLANT ON MACROINVERTEBRATES IN THE BIG SIOUX RIVER IN SIOUX FALLS, SOUTH DAKOTA

Craig N. Spencer, Gwen Warkenthien, Steven F. Lehtinen,
Elizabeth A. Ring, and Cullen R. Robbins
Biology Department
Augustana College
Sioux Falls, South Dakota 57197

ABSTRACT

We measured significant changes in the macroinvertebrate community in the Big Sioux River downstream from the John Morrell meat packing plant in Sioux Falls, SD. We used a biomonitoring approach, placing artificial substrates in the river at sites above and below the plant allowing colonization by macroinvertebrates over a 37-day period during the Fall of 1996. We documented a classic water pollution response below the plant, evidenced by declines in the more sensitive macroinvertebrate taxa together with increases in the more tolerant taxa. The density of Trichoptera declined significantly at all three sites below the plant, falling to 6.7 organisms per sampler at the most downstream site 3.5 km below the plant, compared to average densities of 59-91 organisms per sampler at upstream reference sites. By contrast, the density of Chironomidae increased more than three-fold at the site immediately below the plant, reaching a mean of 185 organisms per sampler compared to 33-67 organisms per sampler at the reference sites. The total biomass of all macroinvertebrates was significantly lower at all three sites below the plant, compared to the upstream sites, suggesting that impacts on the invertebrate community were caused by toxicity problems in the effluent rather than changes in food availability.

The John Morrell plant in Sioux Falls seems to have satisfied requirements for water quality monitoring and effluent discharge standards during the time period of this study. However, results from our research lead us to conclude that existing monitoring programs, conducted by regulatory agencies as well as point source dischargers, are not sufficient to protect water quality in South Dakota or to ensure that existing state antidegradation regulations are met. We urge adoption of biomonitoring studies as routine complements to existing water quality monitoring efforts.

INTRODUCTION

In February of 1996, John Morrell and Company of Sioux Falls, South Dakota, pleaded guilty to polluting the Big Sioux River (Walker, 1996). Officials from the meat packing plant adrnitted to filing false discharge monitoring reports as well as violating the Clean Water Act, including repeatedly violating the company's permit for discharge of ammonia into the Big Sioux River. John Morrell and Company has since been sold by its parent company, Chiquita Brands International Inc., to Smithfield Foods Inc., and efforts have been made to improve wastewater treatment at the plant (Pieterick,1997).

The present study was initiated to evaluate the impact of current operations at the John Morrell plant on water quality in the Big Sioux River. This large meat packing plant processes over 10,000 hogs per day and discharges an average of 2.2 million gallons (8.3 million L) of treated wastewater per day into the Big Sioux River. We utilized a biological monitoring approach to evaluate the impacts of this wastewater through a comparison of the aquatic macroinvertebrate community living in the Big Sioux River above and below the plant.

Biomonitoring of organisms in their natural environment is becoming increasingly used for water quality assessment as a supplement to the more traditional physical and chemical approaches (Rosenberg and Resh, 1996). Current monitoring requirements for John Morrell and Company, as well as other large pointsource dischargers in South Dakota, rely upon analysis of grab samples of sewage effluent for water quality characteristics and in certain instances determination of toxicity using standard test organisms in laboratory studies. Analyses of grab samples describe conditions that existed at the time of sample collection and, as such, may miss critical discharge events. Goodnight (1973) concluded that the most important sampling times for water quality assessment were not during typical, average conditions, but rather during “extreme conditions,” which may be missed by periodic sampling. Such extremes, however, will not be “missed” by the biota living in the receiving stream, especially the more sensitive taxa. Biomonitoring offers another advantage in that monitoring of the natural biota in the receiving stream largely eliminates the difficult step of attempting to use laboratory data to accurately predict impacts of sewage effluent on biota in the actual stream environment. Furthermore, biological responses may be elicited in the natural stream biota at chemical concentrations below analytical detection limits or after chemical exposure has ceased (Rand et al., 1995). Thus, the natural stream biota can serve as continuous monitors of water quality, subject to both acute and chronic impacts of water pollutants.

Macroinvertebrates are the most frequently used group of aquatic organisms used in biomonitoring (Hellawell,1986). Macroinvertebrates offer several advantages over other aquatic biota. “They are ubiquitous and, consequently, are affected by perturbations in many different aquatic habitats; and, the large number of species exhibit a range of responses to environmental stress” (Rosenberg and Resh, 1996). Furthermore, macroinvertebrates are relatively long lived and generally sedentary, unlike fish, which may move out or return as water quality conditions fluctuate (Welch, 1980).

STUDY SITE AND METHODS

The Big Sioux River originates in northeastern South Dakota and flows through predominately agricultural land and small towns before passing through the city of Sioux Falls. At Sioux Falls, the river has a drainage area of approximately 13,509 km^2. The John Morrell meat packing plant is located along the river in the northeastern part of the city. Five monitoring sites were selected near the plant (Fig. 1). Two reference sites were located 100 and 300 meters upstream from the effluent release point, and the other three sites were located 100, 1050 and 3500 meters downstream from the plant. Sites were carefully chosen based upon homogeneity of water velocity, depth, and substrate characteristics. Mean water velocity at the five sites ranged from 0.23 to 0.28 meters per second, and depths ranged from 40 to 50 centimeters. The substrate at each site was primarily sand with lesser amounts of silt and gravel.

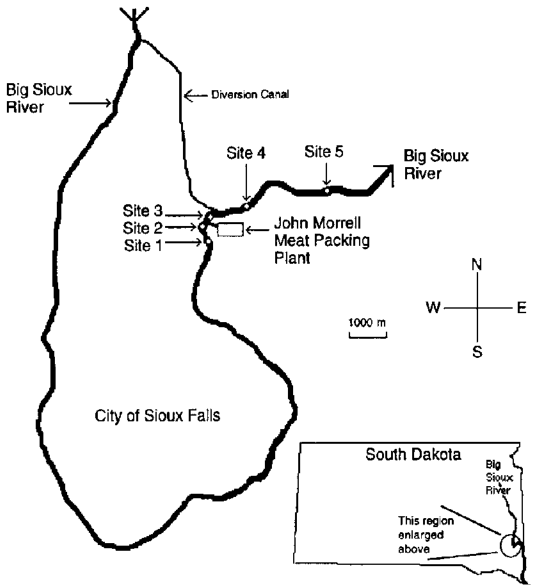

Figure 1. Map of the study area showing the five study sites along the Big Sioux River. Effluent from the John Morrell meat plant enters the river between site two and site three.

The macroinvertebrate community was quantified at each site using standard multiple plate samplers (Hester and Dendy, 1962). These samplers were chosen because they were easy to use and they provided identical substrate conditions for all study sites. We recognize that macroinvertebrate samples from the natural substrate would likely have yielded a higher diversity of organisms; however, the heterogeneous nature of the riverine environment in our study area would have necessitated the collection of large numbers of replicate samples from each site in order to allow meaningful statistical comparisons to be made among the sites. In addition, some of the study areas included deep, fast flowing waters that would have provided an additional challenge with respect to quantitative sampling of the natural substrate.

Each Hester-Dendy sampler was secured in the river on a steel rod driven into the river sediments. The samplers were attached to the rods approximately 10 cm above the river bottom. On September 30,1996, four replicate samplers were placed at each of the five study sites. All samplers were collected on November 5, after 37 days in the river. Upon retrieval, individual samplers were placed in plastic bags, preserved in 70% ethanol, and taken back to the laboratory for analysis. The samplers were disassembled and scrubbed with brushes to remove all invertebrates and material (aufwuchs) attached to the artificial substrates. Larger macroinvertebrates were handpicked from the samples, and smaller organisms were removed with the aid of a dissecting microscope. The organisms were identified, enumerated, and dried to constant mass to determine biomass. Most organisms were identified to the genus level based upon taxonomic keys by Merritt and Cummins (1996), Pennak (1989), and Wiggins (1996). The Chironomidae were identified only to the family level due to time constraints. The Oligochaeta were identified only to class level because the segmented worms became fragmented during the course of preservation and sample processing, making further classification problematic. Statistical comparisons among sites were made using one-way analysis of variance.

RESULTS AND DISCUSSION

Data from this study provide evidence that the John Morrell meat packing plant continues to have an adverse impact on water quality in the Big Sioux River. This impact is evidenced by shifts in the species composition and abundance of macroinvertebrates colonizing samplers located downstream from the plant.

Over 96% of the macroinvertebrates collected at each site were from one of three taxa: Trichoptera, Chironomidae, and Oligochaeta. Among these three groups, the Trichoptera (caddis flies) are widely reported to be the least tolerant of poor water quality (Gaufin andTarzwell,1956;Hynes,1960; McGanigle and Lucey,1983). The abundance of Trichoptera declined significantly below the plant, falling from mean densities of 59 and 91 organisms per sampler at the reference sites to 29 organisms per sampler at site three, 100 m downstream from the wastewater outfall pipe (Fig. 2a). Mean densities were further depressed at the lower two sites, falling to 9.7 Trichoptera per sampler at site four and finally 6.7 organisms per sampler at site five. The abundance of Trichoptera at site five, located 3.5 km downstream from the plant, was 10-fold lower than densities found at the two reference sites upstream from the effluent pipe.

The Chironomidae (midges) exhibited a response nearly opposite to the Trichoptera. (Fig. 2b) As a group, the Chironomidae are well known for their tolerance of polluted conditions (Gaufin and Tarzwell,1956; Hynes,1960; McGarrigle and Lucey, 1983), and the density of these organisms increased significantly to 185 organisms per sampler at site three below the plant, more than threefold higher than upstream reference densities of 33-67 Chironomidae per sampler. Unlike the Trichoptera, the Chironomidae returned to background densities relatively quickly. Densities declined to 92 and 27 organisms per sampler at sites four and five, respectively, and these densities were not significantly different from abundances measured at the reference sites.

The Oligochaeta (aquatic earthworms), like the Chironomidae, include a number of species that are tolerant of poor water quality (Goodnight and Whitley, 1961). Oligochaetes were relatively common at sites three and four below the plant (35 and 45 organisms per sampler, respectively), and those densities were comparable to mean densities found at the reference sites of 28 and 49 organisms per sampler. (Fig. 2c) However, the density of Oligochaetes declined to 15 organisms per sampler at the most downstream site, which was significantly lower than the density measured at any of the other sites.

Although the absolute density of Oligochactes did not increase below the plant, their relative abundance did. Increased relative abundance stemmed largely from the significant decline in Trichoptera numbers below the meat packing plant. The net result is that the relative abundance of the-more pollution tolerant taxa, the Oligochaeta and Chironomidae, was very high at the three sites below the sewage outfall, accounting for 85 to 90% of all macroinvertebrates on the samplers, compared to 30 and 66% at the two reference sites (Fig. 3).

The samplers were colonized by small numbers of other macroinvertebrates from a variety of additional taxa including Amphipoda, Gastropoda, Corixidae, Ephemeroptera, Plecoptera, Diptera (Simuliidae), and Coleoptera. Taken together, these taxa accounted for less than 4% of all macroinvertebrates found on the samplers and their densities were too low to allow meaningful statistical comparisons to be made among the various sites.

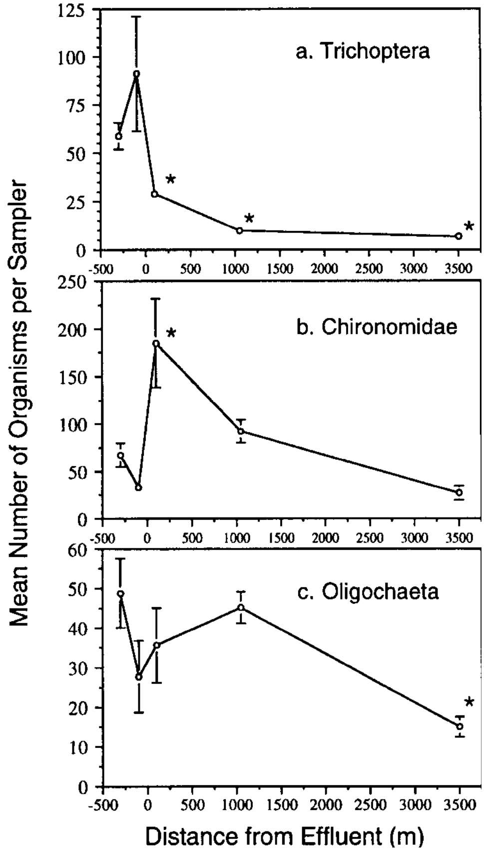

Figure 2. Mean abundance of the three most common macroinvertebrate taxa: (a) Trichoptera, (b) Chironimidae and (c) Oligochaeta, colonizing artificial substrates at five sites along the Big Sioux River. The first two sites were located just upstream from the John Morrell meat packing plant while the remaining three sites were downstream from the plant. Error bars represent standard errors around the mean. The asterisks indicate that the sites were significantly different ($p<0.05$) from the two upstream reference sites as determined by one-way analysis of variance.

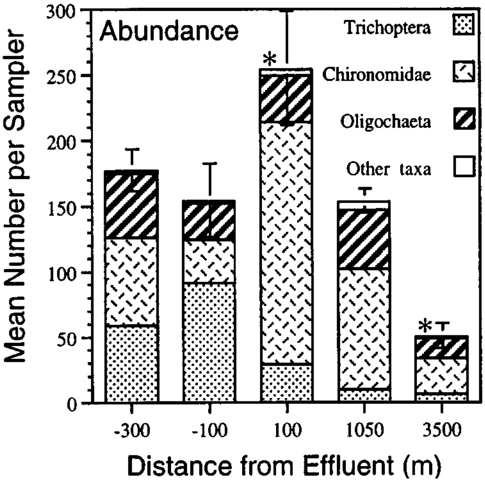

Figure 3. Mean abundance of all of the various macro invertebrates colonizing the artificial substrates at five sites along the Big Sioux River. The first two sites were located just upstream from the John Morrell meat packing plant while the remaining three sites were downstream from the plant. Error bars represent standard errors around the mean for total abundance. The asterisks indicate that the sum of all the abundances of the various macroinvertebrates at these sites were significantly different ($p<0.05$) from the two upstream reference sites as determined by one-way analysis of variance. The horizontal scale on this figure is not continuous.

Other studies have documented similar changes in the macroinvertebrate community in response to the discharge of wastewater into rivers and streams. In studies of a secondary wastewater treatment plant in Virginia, Kondratieff and Simmons (1982) reported that the macroinvertebrate community in a stream below the outfall was dominated by a few tolerant taxa from the Chironomidae and Oligochaeta. Upstream sites were more diverse and included pollution sensitive aquatic insects in the orders Trichoptera, Ephemeroptera, and Plecoptera. In a classic early study, Gaufin and Tarzwell (1956) reported a dramatic reduction in macroinvertebrate abundance and species diversity in an Ohio stream receiving municipal wastewater. Again, the more sensitive taxa declined below the outfall, and the remaining depauperate macroinvertebrate community was dominated by a few tolerant taxa, including the Oligochaeta.

These and other studies of sewage effluent typically report a zone of greatest impact below the outfall followed by a "recovery zone" extending some distance downstream (Hynes, 1960). Data from our study suggest that the wastewater impact zone extends at least 3.5 km downstream from the meat packing plant (Fig. 2a). The more sensitive Trichoptera showed no evidence of recovery at this location. Additional study sites located further downstream would be necessary to quantify the total extent of the impact and recovery zones.

Mechanisms

The most obvious explanation for the alteration of the macroinvertebrate community documented in this study is a decline in water quality in the Big Sioux River owing to the input of wastewater from the meat packing plant Nevertheless, there are several other factors that should be considered. First, a diversion canal joins the Big Sioux River between sites three and four (Fig. 1). Influx of water from this flood control structure could have altered water quality in the river, which in turn may have affected the invertebrate community. We offer several reasons why it is unlikely that the diversion canal affected our results in a significant way. First, our data indicate significant impacts on the macroinvertebrate community beginning at site three, which lies upstream from the canal and thus remains unaffected by the water from the canal. Second, although the canal could have affected conditions at sites four and five, it is doubtful that water in the canal, which bypasses Sioux Falls, would be of lower quality than the river water flowing through the city. In fact, we expected that this diversion canal might actually ameliorate conditions in the river, by providing additional dilution water to the river.

The only other factors we identified that could have influenced water quality conditions in the vicinity of our study sites are several storm drains that enter the river between sites three and five. We do not believe that these drains, which carry surface run-off to the river during rain storms, had a significant impact on the macroinvertebrate community in our study. First we never observed water flowing from these drains during our repeated visits to the river. Even if there was some flow of water through these drains, we believe the potential impact of these inputs would have been minor compared to the 2.2 million gallons per day of wastewater that enters from the meat packing plant. Finally, significant impacts on the macroinvertebrate community were clearly evident at site three which is located upstream from the storm drains and thus outside of their influence.

Taken together, all available evidence points to the meat packing plant effluent as the principal cause of the impact on the macroinvertebrate community documented in our study. In his book *Ecological Effects of Wastewater*, Welch (1980) describes several reasons why the discharge of organic wastewater may lead to characteristic downstream changes in the macroinvertebrate community. First, the increasing severity of the physical and chemical environment below the outfall may eliminate intolerant macroinvertebrate species, allowing the remaining tolerant species to flourish. Second, the effluent may stimulate growth of some taxa due to a more favorable food supply such as organic material in the wastewater or stimulation of microbial growth in the river by nutrients in the effluent. Increased growth of these taxa may result in decreased abundance of other taxa through interspecific competition for resources such as space.

Evidence from our study points to a toxicity problem rather than a change in food availability. If the principle mechanism for alteration of the invertebrate community had been due to increased availability of food resources from the efffluent, then we would have expected a stimulation in the growth of macroinvertebrates below the outfall. Since biomass is a better indicator of food availability than the previously described data on abundance, we looked for evidence of enhanced growth by comparing the biomass of macroinvertebrates found above and below the outfall. The total biomass of macroinvertebrates did not increase below the plant; rather, it was significantly reduced at all three

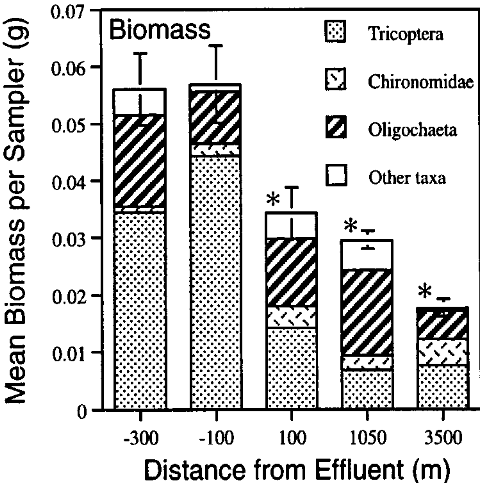

Figure 4. Mean biomass of all of the various macroinvertebrates colonizing the artificial substrates at five sites along the Big Sioux River. The first two sites were located just upstream from the John Morrell meat packing plant while the remaining three sites were downstream from the plant. Error bars represent standard errors around the mean for total biomass. The asterisks indicate that the sum of all the biomasses of the various macroinvertebrates at these sites were significantly different ($p<0.05$) from the two upstream reference sites as determined by one-way analysis of variance. The horizontal scale on this figure is not continuous.

sites below the outfall compared to upstream reference sites (Fig. 4). Thus, it is unlikely that a more favorable food supply was responsible for the observed alteration of the macroinvertebrate community. Instead, we suggest that the shift in species composition and abundance of macroinvertebrates documented below the outfall was most likely caused by toxicity problems in the effluent.

We did not conduct chemical or physical analyses of the effluent from the plant; therefore we can only speculate as to the possible nature of toxic material(s) in the effluent. We suggest several possibilities for consideration. First, reduced dissolved oxygen concentrations caused by excessive organic material (BOD) in wastewater efffluent may have significant impacts on aquatic biota. Oxygen depletion problems were relatively common in rivers receiving sewage emuent prior to development of modern secondary waste treatment facilities (Gaufin and Tarzwell,1956; Welch,1980). However, the waste treatment facility at the John Morrell plant includes secondary treatment, and with proper operation, the final effluent should not produce oxygen depletion problems in the river. Another possibility is excess ammonia in the effluent, which can be toxic to aquatic organisms (Russo, 1985). The John Morrell plant has had problems with elevated ammonia concentrations in the past (Walker, 1996). In addition, most state and federal water quality criteria for ammonia are based upon concentrations of unionized ammonia (NH_3), with little concern for the more common, ionized, form (NH_4^+). A recent study indicates that the latter form can be the more toxic form to some macroinvertebrates (Ankley et al., 1995). A third possibility is chlorine or chlorinated organic compounds, which also can be toxic to aquatic organisms (Horne and Goldman,1994; Rand, 1995). These potential toxins can result from the wastewater disinfection process. The final effluent at the John Morrell plant is first chlorinated and later dechlorinated before the wastewater is discharged into the river. It is possible that toxic, chlorinated organic compounds are being produced in the effluent immediately prior to the dechlorination process, or that excess residual chlorine is present in the final effluent. In addition to these possibilities, there could be some other toxic factor(s) unknown to us, that could be present in the wastewater.

Ecosystem Implications and the Fishery

Shifts in the species composition and abundance of macroinvertebrates below the John Morrell meat packing plant are indicative of a deterioration of water quality in the river. In addition to serving as indicators of water quality, the macroinvertebrates are important in their own right as members of the aquatic food web. They are important in the diet of most fishes, often serving as critical intermediate links in the food web between the higher trophic levels and the algae and organic matter at the bottom of the food web.

The present study documents impacts on the macroinvertebrate community in the Big Sioux River in Sioux Falls. Evidence from other studies indicates that the fish community in the Big Sioux River also becomes altered below Sioux Falls (Sinning, 1968; Dieterman et al., 1996). Above Sioux Falls, the river supports moderate and balanced densities of walleye and northern pike, whereas densities of these two species are much reduced below Sioux Falls. Common carp and channel catfish serve as the primary gamefish below Sioux Falls. These studies discuss a number of factors that may explain this shift in the fish community below Sioux Falls including lack of deep water habitat, increased siltation, lack of sand/gravel substrate, and decreased water quality.

It is important to note that the fishery studies discussed above are broad studies of the entire river rather than specific studies focusing on the John Morrell plant, as was the case in our research. If declining water quality does contribute to the observed shift in the gamefish community below Sioux Falls, then numerous sources of water pollution could be involved in addition to the John Morrell plant, such as the Sioux Falls municipal wastewater treatment plant as wel1 as numerous other point and non-point pollution sources along the river.

Upstream Water Quality Not Ideal

The present study provides evidence indicating that effluent from the John Morrell plant is impacting the Big Sioux River ecosystem; however, the river can hardly be considered to be in pristine condition upstream from the meat packing plant. Macroinvertebrates in the orders Ephemeroptera and Plecoptera, which are generally considered to be indicators of good water quality, accounted for less than 1% of the organisms found on samplers at the two reference sites above the meat packing plant. Furthermore, the Trichoptera that were relatively abundant at our reference sites were entirely from the genus *Hydropsyche*. Among Trichoptera, the non-case building Hydropsychidae, including *Hydropsyche* spp., are the most tolerant members in this group (Hawkes, 1962; McGarrigle and Lucey, 1983; Gaufin and Tarzwell, 1956). We did not find any of the more sensitive, case-building Trichoptera at our reference sites.

In addition tothe present study, there is other evidence of water quality problems in the river above the John Morrell plant. A 1994 assessment of water quality in South Dakota indicated that much of the Big Sioux River "is not supporting its fishable/swimmable beneficial uses" (DENR, 1994). The report indicates that the upper portion of the river above Sioux Falls has problems with excessive total suspended solids, excessive concentrations of un-ionized ammonia, and elevated fecal coliform concentrations. The report also notes a trend of "noticeable nutrient enrichment" for many water bodies in the Big Sioux River Basin. Sources of these problems are identified as discharges of municipal wastewater from a number of communities located along the Big Sioux River and nonpoint source pollution from agriculture, including stream bank erosion and runoff from farmsteads, feedlots, and animal holding sites.

Furthermore, the city of Sioux Falls takes approximately 50% of its drinking water from the river just before it enters the city, and water treatment operators periodically have to contend with taste and odor problems from excessive algae growth in the river during low flow periods and from the flushing of areas of standing water into the river in early spring (Janssen, 1997). In addition, visitors traveling to Sioux Falls to view the waterfalls are often greeted with the sight of a brown, sediment laden river, which during high flow periods is often characterized by a large build-up of foam at the base of the falls and a strong organic odor more commonly associated with sewage aeration basins in wastewater treatment plants.

Finally, a hazardous waste site was recently discovered along the river in Sioux Falls, approximately 2 km upstream from our reference sites. The site contains waste from an abandoned coal gasification plant that operated in the late 1800's, and these wastes have apparently been leaching into the river for decades. Cleanup work on this site began during the summer of 1997 through the U.S.E.P.A.'s Superfund program.

Data from our study, taken together with the observations noted above, are indicative of an already stressed riverine ecosystem that is being further impacted by wastewater from the John Morrell plant in Sioux Falls. We suspect that the impact documented in our study would have been even greater if the research had taken place during a drought period. The last few years have been characterized by relatively big river flows in the upper Midwest. For example, discharge in the Big Sioux River ranged from 292 to 500 cubic feet per second (cfs) during our study, well above the 26-year median annual discharge of 178 cfs for this site. These values come from the USG gaging station located at North Cliff Ave., which lies just upstream from site four (USGS, 1997). We estimate that wastewater from the John Morrell plant (3.4 cfs) accounted for about 1% of the water volume in the Big Sioux River below the plant during the time period of our study. During low flow periods, the wastewater concentration would climb considerably. For example, USGS data from the last two decades indicate that the river discharge at this site falls below 23 cfs for 10%

of the time. Under these conditions, the John Morrell effluent would account for 15% or more of the river volume. The concentration would increase to near 50% of the river volume during the Q 7, 10 for this site (minimum flow for seven consecutive days occurring with a 10-year frequency = 7.1 cts). Thus we expect that the negative impacts documented on stream biota during the fall of 1996 would be even more severe during drought periods when the stream biota are subjected to much higher concentrations of wastewater effluent.

State Water Quality Regulations and Implications

The State of South Dakota has existing water quality statutes that include specific antidegradation language. Section 74 of the State Water Quality Standards contains the following provisions. “All waters of the state must be free from substances whether attributable to human-induced point source discharge or nonpoint source activities, in concentrations or combinations which will adversely impact the structure and function of indigenous or intentionally introduced aquatic communities... Toxic pollutants which are or may become injurious to public health, safety, or welfare; plant, aquatic, and animal life; or the designated uses of waters may not be present in the surface waters ofthe state” (DENR, 1991). Although some exemptions have been made by the state in applying these antidegradation standards to certain water bodies of exceptionally poor quality or “to accommodate important economic or social development,” there seems to be no justification for exempting the Big Sioux River as it is classified for beneficial use as a fishable/swimmable water, a warmwater permanent fishery, and a river which provides drinking water for a number of communities in South Dakota.

Results from the present study indicate to us that effluent from the John Morrell meat packing plant is at variance with antidegradation provisions of Section 74 of the South Dakota water quality standards. In contrast to our findings, records provided by the U.S.E.P.A. indicate that water quality monitoring data provided by John Morrell show that the company had no water quality violations during the time period of our study, and that they seem to be in compliance with their National Pollutant Discharge Elimination System (NPDES) permit for discharge of wastewater into the Big Sioux River (Heimdal, 1997). There are several possible explanations for the apparent contradiction between our findings and those reported by the company and govemmental regulatory agencies.

It is possible that John Morrell and Company provided inaccurate data to governmental regulatory agencies. Although the company pleaded guilty to such activity in the past, we suggest this explanation as an unlikely possibility today for several reasons including the widespread negative publicity, monetary fine, and prison terms assessed in the 1996 water quality proceedings against John Morrell and Company, as well as the recent change in company ownership. In our view, a more likely explanation is that current monitoring activities mandated and or conducted by the South Dakota Department of Environment and Natural Resources and the U.S.E.P.A. are not adequate to detect the type of water quality degradation documented in our study.

To our knowledge, neither the company nor the various governmental regulatory agencies have conducted biomonitoring studies on the Big Sioux River in the vicinity of the John Morrell plant. In addition, there seems to be only minimal monitoring of water quality in the river through more traditional analyses of grab samples by the regulatory agencies. The inadequacy of existing monitoring efforts on the Big Sioux River is well illustrated by the fact that government regulatory agencies failed to detect any evidence of past, repeated ammonia discharge violations on the part of John Morrell and Company in Sioux Falls. These violations, which served as the basis for the recent legal action, became apparent only through self-reporting on the part of the company as it was in the process of being sold.

Although there seems to be minimal monitoring of water quality in the Big Sioux River, John Morrell and Company is required to periodically monitor the quality of its effluent as part of the company's NPDES permit. As part of the permit requirements, the company routinely collects grab samples of their effluent and analyzes these samples for selected physical and chemical parameters. In addition, the company is required to collect additional grab samples on a quarterly basis for toxicity tests. These tests are conducted by an independent laboratory and include standard, 7-day toxicity tests on one fish species and one invertebrate species. Although the requirement for periodic toxicity tests on whole effluent represents an improvement over simple physical and chemical analysis of the effluent, results from our study suggest that current requirements for toxicity testing are still not sufficient to ensure the nondegradation of water quality mandated by the state's water quality regulations. Again there are several possible explanations for the apparent discrepancy between the results of our macroinvertebrate study (which indicate degradation of water quality) and results of existing toxicity tests and monitoring data from John Morrell's (which indicate no violation of their NPDES permit).

First, current monitoring efforts by the company are based upon analysis of grab samples, which, as discussed in the introduction, may miss key discharge events. For example, no toxicity tests were conducted by the company during our 5-week biomonitoring study. The closest sampling date for their quarterly lab toxicity tests was mid-November of 1996, a week after our study was completed.

Second, the toxicity tests currently mandated by state and federal regulations include relatively short-term, 7-day toxicity tests. As noted by Hynes (1960) in his classic book on water pollution, "One of the drawbacks of laboratory tests of toxicity is the fact that it is difficult to run experiments for long periods: thus the poisonous properties of toxins which act very slowly may be entirely overlooked." For example, in a study of selenium toxicity on fish survival, Hamilton et al. (1986), found no significant effect after 30 days of exposure, but that fish mortality increased significantly to 99.1% after 60 days exposure to selenium compared to only 4.7% mortality in the control group.

Third, the test organisms used in lab toxicity tests may not mimic the response of the natural biotic community in the river. The fish species used in the toxicity tests, the fathead minnow (*Pimephales promelas*), is widely recognized as a "hardy species…known for its tolerance for [adverse conditions including] high temperature, extreme turbidity, and low oxygen…During extended dry periods, the fathead minnow along with a few other species including the black bullhead (*Ictalurus melas*) often comprise the entire fish population in stagnant pools in prairie streams, simply because they are one ofthe few fish species that can tolerate such conditions" (Pflieger,1975). Thus, the inherent ability of the fathead minnow to tolerate a wide variety of water quality conditions seems to make it useful as a test organism for revealing only the most severe toxicity problems. The species seems to be a poor choice as a test organism for revealing less severe impacts.

The other standard test organism used in toxicity tests on the John Morrell effluent is an invertebrate species, *Ceriodaphnia dubia,* which seems to be more sensitive to a number of toxicants than the fathead minnow (Cooney, 1995). Although the ecology of this species is not especially well known (Cooney, 1995), there are a number of daphnid species that can tolerate relatively low dissolved oxygen concentrations (Pennak, 1989). Furthermore, cladocean zooplankton, such as *Ceriodaphnia dubia,* are typically found in lakes and ponds (Pennak, 1989). They are uncommon in fast flowing environments, as found below the John Morrell plant and thus are not ideal test organisms for predicting toxicity impacts on riverine species.

Finally, current toxicity tests are conducted on grab samples of the plant effluent and could miss the possibility of synergetic interactions between the John Morrell effluent and other pollutants already present in the river. For example, Allen et al. (1946) demonstrated that chlorine from wastewater and organics in the receiving water may interact to produce substances more toxic than the individual compounds. Obviously the macroinvertebrate community living in the river, which formed the basis of our biomonitoring study, would have been subject to these or other potential synergisms between the effluent and the river water.

CONCLUSIONS AND SUGGESTIONS

1. The present study presents quantitative evidence linking wastewater effluent from the John Morrell and Company rneat packing plant in Sioux Falls with adverse impacts on water quality in the Big Sioux River. This evidence includes a decline in the abundance of Trichoptera below the outfall together with an increase in Chironomidae. In addition, there was a significant decline in total macroinvertebrate biomass below the plant. The company should take necessary steps to ensure that their effluent does not continue to harm the biological integrity of the Big Sioux River.
2. Current monitoring efforts by government regulatory agencies together with required monitoring on the part of John Morrell and Company failed to detect any adverse impacts of the effluent on the river. We attribute this failure to shortcomings in existing monitoring efforts and regulations.
3. In order to better protect our valuable multiple-use aquatic resources we feel it is imperative that water quality monitoring efforts be expanded in South Dakota. This recommendation is based not only upon present water quality conditions in the state, but also in light of future threats to water re-

sources such as the potential influx of large hog confinement facilities into South Dakota. We feel strongly that current chemical and physical monitoring activities by the regulatory agencies should be expanded and that these efforts be coupled with implementation of a new biomonitoring program using macroinvertebrate communities in their natural environment as indicators of water quality. We understand that the South Dakota Department of Environment and Natural Resources is currently working with the U.S.E.P.A. to develop some initial biomonitoring protocols for South Dakota. We applaud these efforts and hope that they lead to widespread application of biomonitoring efforts on rivers and streams throughout the state as a vital complement to more traditional efforts focused on laboratory analyses of grab samples.

4. We suggest that artificial substrates may be appropriate for monitoring macroinvertebrates in some situations, as in the case of our relatively short-term study of a specific point source. In other cases, it may be more appropriate to monitor the macroinvertebrate community on natural substrates, as for example in the case of a long-term monitoring program to be used in quantifying the entire benthic macroinvertebrate community in a watershed. The latter approach would necessitate a much more involved sampling protocol and degree of effort than the use of artificial substrates due to increased sampling difficulties, increased variability resulting from the heterogeneous nature of natural benthic substrates, and the changing physical environment due to periodic, random disturbances such as floods and droughts. In some cases, it may be wise to monitor the macroinvertebrate community using both natural and artificial substrates.
5. We recognize that despite the findings of the present study, efforts have been made to improve wastewater treatment over the last several decades at the John Morrell facility and other large point sources along the Big Sioux River, most notably through the installation of modern secondary wastewater treatment facilities. These improvements have been beneficial to water quality in the river, especially with regard to dissolved oxygen and ammonia concentrations (Dieterman, 1995). As noted in the past, periodic fish kills resulting from discharge of poorly treated sewage into the river (Sinning, 1968) do not seem to be a major concern now. Further, there is some evidence that the fishery in the river has improved in recent years (Dieterman and Berry, 1995). Nevertheless, our study clearly indicates that point source pollution remains a problem in the Big Sioux River and that more improvements are needed. Other studies describe ongoing water quality problems resulting from nonpoint source pollution in the river basin (DENR,1994). Finally, numerous point sources continue to discharge high concentrations of nutrients (phosphorus and nitrogen) into the Big Sioux River and other waters throughout South Dakota. Indeed, a recent study of water quality trends documents a significant increase in nitrate and phosphorus concentrations in the Big Sioux River below Sioux Falls over the last 20 years (Dieterman, 1995). By contrast, nutrient loadings to surface waters have been reduced in some other parts of the country through various means including phosphate detergent bans, installation of tertiary wastewater treatment facilities, and

non-point source control measures. In states bordering the Great Lakes various nutrient control measures have been put in practice in the last 2 decades with notable improvements in water quality (Schelske and Hodell, 1995). Thus, much additional work remains before the Big Sioux River and other surface waters in South Dakota comply with the goals of federal water quality legislation initiated over 2 decades ago with the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) and the Federal Clean Water Act of 1977 (PL 95- 217). These acts had as legislative objectives to "restore and maintain the physical, chemical, and biological integrity ofthe Nation's waters…and further, the elimination of discharges of pollutants to surface waters by 1985."

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