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Toxins and Genotoxins in the Niagara River Watershed as Reflected by Chironomid Diversity and Frequency of Labial Plate Deformities

by

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ABSTRACT

Because some benthic invertebrates are sensitive to mutagens and carcinogens, a few ecologists have attempted to use them to signal the presence of genotoxins in aquatic sediments

Chironomids from each of 15 sample sites in three rivers of the Niagara River Watershed were sampled and divided into two groups: those with ligulas and those with labial plates. The latter group of chironomids were classified as either normal (no deformities in their labial plates), slightly deformed (slight assymetries due to teeth which were missing or chipped") or grossly deformed (those with extra teeth, fused teeth, crossed teeth or large gaps between their teeth). Among the 995 chironomids taken from the 154 Ekman grab samples, 699 possessed labial plates and 24% of these (171) displayed gross deformities in the structure of their labial plate. Most of the chironomids displaying gross deformities came from areas in the Niagara River Watershed where sediments are contaminated with mutagenic and/or carcinogenic substances.

The highest frequency of chironomid labial plate deformities occurred at the B.F.Goodrich Company's discharge pipe. In 1986, 33 kg of vinyl chloride, (C_2H_3Cl), was released into the Welland River at this site (MOE 1987). Vinyl chloride is an extremely powerful mutagen and human carcinogen and is suspected of causing the high frequency (47%) of gross chironomid labial plate deformities observed at this site.

The second highest frequency of chironomids with gross labial plate deformities occurred in the heavily industrialized section of the Buffalo River in Buffalo, New York. Thirty-five percent of the chironomids which possesed labial plates displayed these deformities as compared to 9% at the"control" site.

It was concluded that the frequency of chironomid labial plate deformities provides researchers with a useful index for evaluating sediments which are contaminated with mutagenic or carcinogenic substances.

INTRODUCTION

The whole future of the human race is held in the genes of those living today. According to R. Bertell (1988), the rate of genetic damage in humans has doubled since 1945. Much of this has been attributed to genetic damage from exposure to toxic waste (Ibid). Of the more than 48,000 chemicals listed by the EPA, next to nothing is known about the toxic effects of nearly 80% and less than 1,000 have been tested for acute effects. Even fewer of these chemicals have been tested for chronic effects such as those causing cancer, reproductive or mutagenic effects. It is for this reason that research work with signal species or indicator organisms is so desperately needed.

Elevated frequencies of chironomid labial plate deformities have been correlated with the presence of genotoxic pesticides in lake sediments (Hamilton and Saether 1974), heavy metal carcinogens such as cadmium and chromium (Wiederholm 1984), sediments contaminated by coal tars (Cushman 1984) sediments contaminated with radioactive material (Warwick et al 1987) and sediments contaminated with vinyl chlorides (Lan 1988). It is reported (Hare and Carter, 1976) that natural populations of chironomids in areas such as Georgian Bay which are relatively unimpacted by manmade genotoxic chemicals display very low frequencies of labial plate deformities (0-3%).

The massive mortality of chironomid and other macroinvertebrate larvae following the Sandoz pollution incident in the Rhine River in 1986 revived interest in the use of morphological anomalies as biological indicators of water quality (van Urk and Kerkum 1987).

Deformities of Benthic Invertebrates Exposed to Mutagens

Sato et al. (1983) using the Ames test found that some sediments which they removed from the Niagara River and its tributaries were mutagenic. It was the purpose of this study to follow up on the research of Sato et al. (1983) by carrying out further studies on the genotoxicity of the sediments of the Niagara River Watershed by using the frequency of chironomid labial plate deformities as an indication of the presence of sediments contaminated with genotoxic agents.

The term "genotoxin" is used here to refer to carcinogens which undergo chemical reactions with DNA, (i.e. DNA damaging agents, Barrett 1987). Chemical carcinogens have been classified by Weisberg and Williams (1981) as either genotoxic or epigenetic but the distinction implies exclusivity where none exists (Barrett 1987). It was concluded by a working group of the International Agency for Research on Cancer (1983) that no classification of chemicals according to mechanism could be completely exhaustive or definitive. Furthermore, many chemical carcinogens operate via a combination of mechanisms depending on the target cells. "For example, some carcinogens are complete carcinogens in one tissue, promoters in another, and initiators in another. Classification of chemicals into a single category may be misleading and hinder our understanding of the complex problem of chemical carcinogens" (Barrett 1987). We conluded that to attempt to distinguish between the mechanisms of chemical carcinogens using only data associated with the relative frequency of chironomid labial plate deformities was unwarranted.

Chironomid larvae are among the most widely distributed benthic invertebrates in freshwater. In addition, their larvae represent a sensitive stage in their life cycle (Roback, 1978). Research on the frequency of deformities of chironomid larvae in polluted freshwater led to the use of deformities of mouth parts, antennae and chironomid body wall thickness for the detection of genotoxic contaminants (Hamilton and Saether, 1971; Wiederholm, 1984; Warwick et al., 1987).

The mouthparts of chironomid larvae are normally fairly symmetrical. Deformed specimens are characterized by their asymmetrical labial plates and mandibular structures. Unusual thickenings of the chironomid larval body wall were also considered as a deformity by Hamilton and Saether (1971). It was suggested that different types of deformities may be caused by different types of pollutants (Hamilton and Saether, 1971). This susceptibility to different types of pollutants seems to differ among the various chironomid species. Some species are far more sensitive to carcinogens and mutagens than others (Wiederholm, 1984; Warwick et al., 1987).

Mechanisms of Genotoxin Deformity Induction

The mechanisms of deformity induction include gene mutations, interference with transcription and translation, disruption of cell division, and metabolic disturbance (Weis and Weis, 1987). Mutagenic or genotoxic compounds cause deformities in animals by disrupting genes (Metcalfe and Sonstegard, 1985). Genotoxic substances which are discharged into water systems accumulate in the associated sediments which comprise the habitats for many benthic invertebrate taxa (Buikeman and Herricks, 1978; Lafont, 1984; Wetzel, 1983). Although the absolute concentration of genotoxic pollutants may be very low in water, sediment bioconcentration and food chain bioaccumulation serve to magnify their concentration (Buikema and Herricks, 1978; Tarkpea et al., 1985).

Objectives of this Study

The first part of the study was aimed at collecting approximately 1,000 chironomids from areas within the Niagara River Watershed. Sites with known histories of contaminants were chosen. These data were then used to construct a data-base which included the observed frequency of deformities in chironomid labial plates The purpose of this data-base was to determine whether it was possible to infer the presence of genotoxic materials in sediments from a study of the frequency of deformities in chironomid labial plates.

Kaiser and Combe (1983) described a number of types of volatile organic compounds which were present in the industrial portions of the Welland River. Lan (1988) noted that at least 3 compounds identified by Kaiser and Combe were

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genotoxic. In addition, nickel and chromium, both genotoxic heavy metals, were found at concentrations about 2 orders of magnitude above background levels downstream of Atlas Steels Ltd. (Brindle, unpublished WTF 1987 Report) and another genotoxic substance, vinyl chloride, was also described (MOE 1987) for the Welland River. Genotoxic pesticides such as "Roundup" and Atrazine were also reported for the Welland River watershed area.

These observations prompted studies of the genotoxicity of Welland River water (Veltri and Lan, 1987) using the Ames test to measure mutagenicity. In addition, Welland River sediment samples were analyzed using the SOS Chromosome test (Lan 1988).

The second part of this study assembled another data-base on the density (no. per m^2), generic richness and diversity of chironomids at each of the 15 study sites. The purpose of this second data-base was to determine whether it would be possible to infer the presence of toxic materials in river sediments from the abundance, diversity and generic richness of chironomids.

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Site Descriptions

The Welland River has been studied since the 1960's (e.g. Johnson, 1964), and was emphasized in this study because of its status as a provincially significant wetland area (MNR 1984). The Welland River flows east through the City of Welland to the Niagara River (Fig. 1). Upstream of the City of Welland, the river is mainly influenced by agricultural runoff. Within and downstream of the City of Welland, the major discharges to the river are from industrial and domestic sources (Steele, 1981; Dickman et al., 1983).

Welland River at Evan St., Welland

The Evan Street "Control" receives most of its water from Lake Erie via the Welland Ship Canal. The remainder comes from the agricultural areas drained by the upper Welland River Watershed. The "control" site was located in the city of Welland (Fig. 2) about 0.4 km upstream of the Atlas Steels' discharge pipe and about

2 km upstream of the City of Welland's Sewage Treatment Plant. A total of 27 Ekman dredges were collected here during August and September of 1988 (13th of August , and the 13th and 15th of September). Samples were taken at a distance of about one meter from shore and at a depth between 0.5-1.0 meters. Sediments were composed primarily of light reddish brown clay and small stones. Algae and submerged macrophytes were also present. Samples included a number of molluscs, oligochaetes, insect larvae, and water mites. The most abundant invertebrate group were the chironomids. Some oil was visible on the surface of the water at the time that the Ekman samples were taken in mid-September.

Welland River at Beaver Creek

The confluence of Beaver Creek and the Welland River (Fig. 3) is located about 2 km east of Wellandport. A total of 13 Ekman dredges were taken at this location on the 15th, 19th and 29th of July and on August 23rd, 1988. In most dredges, chironomids were the most abundant group, followed by oligocheates, isopods, amphipods and water mites. The samples were all collected within a 2 meter radius of each other and were located less than 2 meters from the shore in 0.5 - 1.0m of water. The sediments were composed of mud, and laced with cattail (*Typha*) roots, and water millfoil (*Myriophyllum*) stems. Bark fragments and the Canada water weed (*Elodea)* were also found in some samples.

Pond Inlet at Brock University

The Pond Inlet (Fig. 4) receives its chlorinated "makeup" water from the Decew Water Filtration Plant. This shallow pond is an artificial environment that is maintained in constant circulation during daylight hours. Twenty-five Ekman dredges were collected at 9 sites chosen at random from the pond (Figure 10). Dredges were taken at this location on the 27th, 29th and 30th of June, and on the 1st and 9th of September, 1988. The depth of the water ranged from less than 0.5m (at sites A, B, C, and G) to over 1.0m at site G. Oligochaetes (Milbrink 1983) were the most abundant group at all sites except site G, where chironomids were more abundant. Crayfish were found at sites B and C, and leeches at sites C, F and H. Damsel fly larvae, and other insect larvae were also present. Sediments were composed of clay (sites A, E, F and I), clay and sand (sites B and C), as well as clay and stones (sites D, G and H). Filamentous green algae was abundant at sites F and I, and present at lower densities at sites A, B, H, and I. Also present was decomposing willow (*Salix)* foliage (sites A, B and C), and cattail roots and stems (sites B, C, H and I).

Welland River at the Richelieu Club, Welland

The Richelieu Club (Fig. 5) borders the Welland River immediately downstream of the Welland Sewage Treatment Plant. About 100 meters of cattail dominated marsh occur along the shore of the river at this point. Sediments were

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clay-rich and a heavy Bunker 'C' type oil was very abundant in the sediments at this site. Fifteen Ekman dredge samples were removed from in front of the cattail fringe. Oligochaetes were considerably more abundant than chironomids at this site. A number of small pelecypods were also observed in the Ekman samples from this location.

B.F. Goodrich Company

The B.F. Goodrich discharge pipe which flows under Chippewa Creek Road, empties into a short (Ca.100m long stream) which discharges into the Welland River about 10 km northeast of Welland, and 4 km west of the Conrail and Montrose Bridges (Fig. 6). Nine Ekman dredges were collected on 13 August 1988 within 1.0m of the shore and at a depth of approximately 0.5m. Oligochaetes were the dominant genus at this site, followed by chironomids. The sediments were composed of a fine black clay mixed with decomposing organic matter. In some places, fungi and/or filamentous green algae were attached to the surface of the clay. In addition, 18 other Ekman samples (9 in 1986 and 9 in 1987) were taken from this site and analyzed by Lan (1988).

Welland River at The Montrose and Conrail Bridges

The Conrail Railway Bridge is located close to the Q.E.W. next to the Montrose Bridge (Fig. 7). The station is about 7 km west of the confluence of the Welland and Niagara Rivers. Three Ekmans were taken on July 6th, 1988 at a depth of 1.5-2.0 meters. Chironomids were the dominant taxa at this site, while oligochaetes, leeches, amphipods and thread worms were also observed. The sediments were composed primarily of mud, leaves, and other decaying vegetation.

Chippawa Creek

The water at this site comes entirely from the Niagara River. The site was located in the Village of Chippawa, near 4083 Front Street, slightly downstream of the site of a toxic coal tar cleanup area (Fig. 8). No samples were taken directly from the cleanup site near Norton Abrasives' outfall because the sediments had been dredged out in early 1988 and the resulting excavated area filled in with gravel and rocks. Nine Ekman dredges were collected immediately downstream of the cleanup site on July 4th, 1988 at a point 3 m from shore and at a depth of 0.6 m. Chironomids and oligochaetes were abundant while clams, dragonfly nymphs, water mites and flatworms were also fairly common. The sediments were composed of decomposing leaves and algae with an underlying layer of muddy sand.

The Buffalo River

The Buffalo River (Fig. 9) flows through the western (industrialized) portion of the city of Buffalo, New York. Replicated Ekman dredges were collected at five

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stations in the lower Buffalo River. Oligochaetes were extremely abundant, supplanting all other genera. At Station 613, which was located 61,300 feet from the mouth of the Buffalo River, a clay layer was observed, with an overlying layer of decomposing vegetation, sand and small fragments of shale. The sediment composition was similar to that observed at the New York Central Bridge, and at Station 759. Station 710 was also similar, but submerged aquatic vegetation (e.g. *Elodea canadensis* and *Potamogeton robensii)* was found there in some abundance. Pea clams were also observed at Station 710. At Station 751, the sediments were composed of a brown clay layer intermixed with black deposits of organic matter. Station numbers refer to the Corps of Engineers' designations as distance in feet x 100 from the confluence of the Buffalo River with Lake Erie and the Niagara River. Samples were taken near the center of the river at sample depths ranging from 4 to 6 m.

Atlas Specialty Steels

This site (Fig. 5) was chosen because of its known source of heavy metals (MOE 1987). Although 9 Ekman dredges were removed from this site and carefully sieved for benthic invertebrates, none were found. Presumably, chironomids were unable to tolerate the elevated heavy metal concentrations in the sediments at this site.

Cyanamid Chemical Co.

The ammonia-rich waters and chromium-rich sediments produced by the Cyanamid Canada Co. (Fig. 6) enter Thompson's Creek which flows into the Welland River (MOE 1987). Nine Ekman samples taken from Thompsons Creek near the Cyanamid discharge point source. No benthic invertebrates were found in any of the samples. As a result, a second set of 9 Ekman samples were taken some 2 km downstream near the confluence of Thompsons Creek with the Welland River (Fig. 6).

Ford Glass Co.

Ford Glass was sampled because it discharges organic solvents into the Welland River (MOE 1987). Most of the benthic invertebrates at this site were sludge worms (aquatic oligochaetes such as *Limnodrilus*.). Nine Ekman samples were taken from this site at a distance of 1 to 2 m from shore and a depth of 0.25 to 0.5 m. A dense stand of cattails (*Typha*) formed a fringe at the edge of the water where and the Ekman samples were taken from in fronmt of this fringe.

METHODS

Procedures

The Removal of Sediment Samples

An Ekman Dredge was used to remove sediment samples at each station. The dredge was lowered onto the surface of the sediment and a mesenger was used to trigger it to close. The Ekman Dredge measured 15.3 cm x 15.3 cm. and penetrated the mud to a depth which was dependent on the type of sediment and the pressure with which the dredge was inserted. Typically, the depth of penetration was 4 cm (+ or - 1 cm) for a mud and clay substrate of the type found in the Welland and Buffalo Rivers.

To collect enough chironomid larvae for statistical analysis, at least 3 replicate Ekman samples were collected from each site. Where chironomids were scarce, up to 27 Ekman samples were collected in order to gather a minimum of 30 individual chironomids per site. These samples and those taken at each of the other study sites are stored at Brock University and are available on request.

The dredged sediments were transferred to a special bucket equipped with a 0.75 mm. mesh sieve at its base. Each sieved sample was placed in a vial or plastic bag and labelled by location number. The samples were then transported to the lab for additional sorting, which was completed within 24 hours from the time that the samples were taken.

Sorting

In the lab, each sample was placed again in the sieve plate bucket and thoroughly rinsed with tap water. The resieved sample was then spread out on a large white enamel tray and covered with about 1 cm. of tap water so that the specimens could be easily observed and separated. The specimens were removed with forceps and placed in a 7% formalin solution (Pimental, 1967). Two vials were used: one for chironomids and one for all other invertebrates. Chironomids were identified to the generic level (some to species) based on (Wiederholm, 1983).

Sample Preservation

Once the samples were sorted they were transferred to coded vials which contained a 5% formalin solution (50 ml. of 10% formalin, 50 ml. of distilled water). After 24 hours the chironomids were transferred to a glycerine solution (20 ml. of glycerine and 80 ml. of 95% ethanol) (Pennak, 1953).

Mounting Labial Plates and their Evaluation

The chironomid head capsules were separated from their bodies to permit better viewing of their labial plates. The labial plate (Fig. 11) was then evaluated for the presence of deformities and categorized as either 'normal' (Fig. 11A), 'slightly deformed' (Fig. 11B), or 'grossly deformed' (Fig. 11C).

A 'slight deformity' in the labial plate of a chironomid was characterized by partially fused teeth, blunt or chipped teeth, moderate irregularities in the shape or size of teeth, missing teeth (with appropriate gaps remaining) and gaps that displayed slight asymmetries.

A 'gross deformity' in the labial plate of a chironomid was characterized by fused teeth, crossed teeth, extra teeth, numerous missing teeth (suggesting a weak labial plate), and teeth of an extremely bizarre shape or size.

Results and Discussion

Measuring Genotoxicity

Evan St.

Chironomids from each of the eleven sample sites were divided into two groups: those with and those without labial plates. Among the 163 chironomids taken from the 27 Ekman grab samples which were removed from this site, 56 chironomids possessed ligulas (all of which were members of the genus *Procladius*). Because it was difficult to distinguish deformities in the chironomids with ligulas and because the frequency of abnormalities in chironomids with ligulas did not vary appreciably between sites, only chironomids possessing labial plates were evaluated in this study These data are summarized as "ligula corrected totals" (Tables 1 to 8).

The MOE (1984) indicated that the levels of contaminants in the water of the Welland Ship Canal were very low. This same water is the primary source of drinking water for most of the people in Regional Niagara. The majority of the water reaching the Evan St. site comes from Lake Erie via the Welland Ship Canal (MOE 1984). For this reason the Evan St. location was treated as a "control" site.

Hare and Carter (1976) examined 73 individuals of *Chironomus* (s.s.) *cucini* from a station in Georgian Bay located about 3 km from Parry Sound. According to sediment analyses performed by the M.O.E. this site is one of the least contaminated in the Great Lakes. Only one of the 73 chironomids examined by Hare and Carter was deformed (1.4%).

In the Niagara River Watershed, nine per cent of the 107 chironomids with labial plates displayed gross deformities. This was one of the lowest deformity levels found in the Niagara Region. In a study of Lake Erie by Hamilton and Saether (1971), it was noted that deformed chironomid larvae were generally restricted to locations near known sources of industrial pollution.

The density of chironomids at this site (258 m^{-2}) was not significantly lower than the mean (451 m^{-2}). It was suspected that the absence of toxic discharges at this site resulted in a normal population of chironomid predators such as dragon fly nymphs and beetle larvae as well as a variety of fish.

Both species richness (20 taxa) and species diversity (H = 3.5) were higher at the Evan St. site than at any other of the 15 study sites. Species diversity and species richness were used to characterize community structure (Cairns et al., 1972; Hart, 1974).

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Beaver Creek

The Beaver Creek site was chosen to represent an agricultural portion of the Niagara River watershed. In 1987, the dominant chironomids at this site were *Chironomus* and *Procladius*. In 1988 *Procladius* all but disappeared and *Glyptotendipes* took its place (Table 2).

Species diversity (H = 2.81) and species richness (13 taxa) were high. Only Pond inlet and the control site had higher diversity and species richnes (Figs. 13 & 14).

According to discussions that we had with local farmers in this area, substantial quantities of Atratol 80W which contains 75% Atrazine + 5% Prometron was used in this region on corn crops. Atrazine is a suspected carcinogen (Sax,1984, p328). In addition to Atrazine, a number of other agricultural pesticides are applied each year to the crops in this area.

The level of gross deformities here was 19% (29 of the 150 chironomids with labial plates displayed gross deformities). This was the highest among any of the sites in the non-industrialized parts of the Welland River (Table 2). Hamilton and Saether (1971) reported that aberrant chironomid mouth parts, might be caused by pollutants from agricultural sources.

Pond Inlet

The dominant chironomids in Brock University's Pond Inlet were *Chironomus* and *Cladotanytarsus* (Table 3). Thirteen percent of the 106 chironomids with labial plates which were examined from this site displayed gross deformities (28% displayed only minor labial plate deformities).

The average density of chironomids (193 m^{-2}) in Pond Inlet was substantially lower than the mean (451 m^{-2}). Chironomids were particularly "patchy" at this site and for this reason we carried out a more detailed study of their spatial distribution (Fig. 10) in order to determine the nature of this patchiness. We concluded that the spatial heterogeneity of the habitats in this small pond (e.g., rock, sand, clay and macrophytes) was a major contributing factor to both the high level of chironomid spatial heterogeneity and the high chironomid species diversity (H = 2.98) and species richness (13 taxa).

Chironomid labial plate deformities in Pond Inlet (13%) were significantly higher ($p < 0.05$) than the Evan St. Control Site level of 9%. A herbicide termed "Roundup" was first applied to Pond Inlet to kill cattails in the summer of 1985 and last applied in the fall of 1986. Each of the 3 applications contained about 85 g of active ingredient.

According to the "Crop Protection Handbook" the active ingredient in Roundup is an isopropylamine salt of glyphosate. Glyphosate is N phosphono methyl glycine, which is used at 41% of full strength as a broad spectrum herbicide. About 5% of the active ingredients in Roundup are water soluble at normal summer temperatures in this area. It is recommended that Roundup should not be used near water because of its adverse impact on many aquatic invertebrates and fish (Crop Protection Handbook, p1134).

Richelieu Club

At the Richelieu Club, (Table 4) just downstream from the Welland Sewage treatment plant (Fig. 5) the labial plate deformity rate (8%) was not significantly different from that observed at the control site (9%). However, unlike the control site, 82 of the 95 chironomids from this site belonged to only one taxon, *Phaenopsectra flavipes*, a pollution tolerant species. Species diversity (H = 0.68) and species richness (4 taxa) were among the lowest observed at any of the 15 study sites (Table 9).

In Lytle Creek, U.S.A., an aquatic invertebrate community survey (Gaufin et al., 1952), revealed that upstream of the Lytle Creek sewage treatment plant's sewage outfall, significantly higher species richness occurred than at the downstream site, and with distance downstream the species richness increased. This was consistent with the observations of Cairns et al., (1972) and Cushman, (1984), who noted that species diversity increased as toxicity levels fell as a function of distance downstream.

Chironomid density (270 m^{-2}) was substantially lower at the Richelieu Club than the mean for the Welland River (451 m^{-2}). This was interpreted as the result of toxic discharges and not chironomid predation. The sediments at this site were contaminated with a bunker 'C' type of heavy oil. Even though some petroleum refinery effluents (Metcalfe et al., 1985) and some crude oils (Vandermeulen et al. 1985) are both toxic and genotoxic, the absence of elevated frequencies of labial plate deformities at this site suggests that genotoxic components were not present at significant concentrations.

B. F. Goodrich

The highest level of gross chironomid labial plate deformities found in the Niagara River Watershed (47%) occurred at this site. This was the case in both 1986, 1987 and 1988 (Table 5). *Tanypus* was the dominant chironomid over the three years that we sampled at this site. Chironomid density (801 m^{-2}) was nearly twice the level of the mean but generic richness (6 taxa) and diversity (H = 0.32) were both low.

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According to the MOE Report on industrial direct discharges in Ontario (MOE 1987) the B.F. Goodrich Co. discharged 32.85 kg of vinyl chloride into the Welland River in 1986. Vinyl chloride (C_2H_3Cl) is an extremely powerful mutagen and human carcinogen (Sax, 1984; Connell and Miller 1984). Vinyl chloride, which is relatively insoluble in water, would be rapidly adsorbed by organics within the sediments near the B.F.Goodrich point source.

Conrail and Montrose Bridge Site

The Conrail and Montrose Bridge site was about 4 km downstream of B. F. Goodrich, and 3 km downstream of Cyanamid (Fig 1). The site was selected because it was in the Welland River recovery zone as indicated by the higher aquatic plant distribution pattern described for the lower Welland River (Dickman et al. 1983).

The dominant chironomid at this site was *Chironomus plumosus* group followed by *Polypedilum*. Eight genera were observed in the three sets of three Ekman samples taken from this location. The gross deformity rate (9%) was only slightly above the levels recorded at the control site (Evan St.).

The density of chironomids (2,548 m^{-2}) was an order of magnitude higher here than at most of the other study sites (Table 6). A few pollution tolerant species such as *Chironomus* and *Polypedilum* were extremely abundant at this site.

Low competition and predation rates and high nutrients (food levels) were probably the reason for this high density. Cyanamid's toxic ammonia levels at this site (MOE 1987) were low enough to permit some of the more tolerant chironomid taxa such as those noted above, to develop extremely high population densities. We can only speculate that the absence of normal competitors such as sludge worms, might be due to chromium levels which were higher than background at this site (Dickman 1988). Piscivores which normally feed on chironomids may have been held in check at this site by toxic ammonia (Steele 1981).

Chippawa Creek

The Chippawa Creek site was designated in 1986 by the M.O.E. for a "cleanup" of its coal tar contaminated sediments. At the time that the site was sampled, (summer and fall of 1988), the majority of these coal tars had been removed from the river. However, chironomids living downstream at our sampling sites would have been exposed to the coal tars during most of their development. We hope to take additional samples from this site in 1989 to determine whether the frequency of

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labial plate deformities has declined as a result of the MOE sponsored cleanup.

The coal tar residue was discovered in 1985 by local residents living immediately downstream of one of the Norton Abrasives Company's discharge pipes. Samples of the river sediments which were taken immediately downstream of the coal tar contaminated area contained chironomids with a 14% frequency of gross chironomid labial plate deformities. *Chironomus* and *Cricotopus* were the dominant genera at this site (Table 7). The chironomid density (204 m^{-2}), generic richness (S=5) and diversity (H=1.6) were all relatively low. Experimental pond studies by Cushman indicated that pollution by a synthetic, coal tar-derived oil was correlated with a high frequency of labial plate deformities in *Chironomus decorus* living in the contaminated sediments of his experimental ponds (Cushman, 1984).

Buffalo River

This site was chosen because the Buffalo River was designated by the International Joint Commission as one of 42 sites requiring a Remedial Action Plan (RAP).

The Buffalo River was sampled at 5 sites. Station 759 near the Park St. Bridge was located 75,900 feet from the confluence of the Buffalo River with the Niagara River. Station 759 was dominated by large quantities of oligochaetes (12,350 m^{-2}). At station 751 near the Buffalo Color Co. oligochaete density increased to 22,750 m^{-2} and at station 710 near the Conrail Bridge, tubificid densities dropped to 1,170 m^{-2} and pea clams (*Pisidium*) reached densities of 1,170 m^{-2} Closer to the Niagara River (Stations 679 and 613) the oxygen levels of the water at the mud water interface declined (Litten 1987) and oligochaetes again became more abundant (15,000 m^{-2} and 18,850 m^{-2} respectively).

The chironomids at these 5 sites (Table 8) were predominantly *Procladius* cf. *bellus* with a few individuals of *Chironomus plumosus* group, *Cladopelma* sp. and *Glyptotendipes* sp. The gross deformity rate (35%) was the second highest in the Niagara Peninsula. Chironomid density (88 m^{-2}) was low as it was at Atlas, Ford and Cyanamid. Total generic richness (S=5) was also low as was diversity (H=0.52).

The high density of sludge worms (tubificids) which we observed in the lower reaches of the Buffalo River and the low densities of all other benthic invertebrates including chironomids, was interpreted as indicative of an environment which was polluted with excessive amounts of decomposing organic matter (Cairns 1978; Hayes 1984).

The chironomids which we found in the lower Buffalo River displayed an unusually high frequency of labial plate deformities. There were a total of 61 chironomids found at the 5 sample sites in the lower Buffalo River and 14 of these possessed labial plates. The gross deformity rate for these 14 individuals was 35% (Table 8). In contrast, the mean frequency of chironomid labial plate deformities from the 10 Welland River study sites was 24% (Table 9). This was significantly lower than that observed in the Buffalo River. Litten found napthalene, hexachlorocyclohexane, heptachlor epoxide, PCB's and PAH's as well as a variety of heavy metals including mercury, zinc and lead in the sediments of the Buffalo River (Litten 1987).

Cyanamid Chemical Co.

None of the nine Ekman samples taken from Thompson's Creek near the Cyanamid discharge had any chironomids. The ammonia-rich waters and chromium-rich sediments at this site were probably responsible for the absence of chironomids. The only site in the Welland River with a chironomid density similar to Cyanamid was the Atlas Steels Co. where the heavy metal content of the sediments was so high that in 9 Ekman samples, no chironomids were found.

During 1986, Cyanamid Canada Inc. discharged 78 kg per day of toxic ammonia into the Welland River (MOE 1987). During 1986, they also discharged 832 kg of chromium (2.28 kg day^{-1}) into the Welland River via Thompson's Creek. Thompsons Creek has a mean flow of 32,400 m^3 day^{-1} (Ibid).

Because we couldn't find any chironomids near the Cyanamid discharge site, we moved downstream approximately 2 km to a point near the confluence of Thompson's Creek and the Welland River. The nine additional Ekman samples taken from this downstream site contained an average of 3.78 chironomids per sample: (nine individuals of *Chironomus plumosus* group (9), *Clinotanypus (1)*, *Cricotopus bicinctus* (1) *Natarsia (11)*, *Paramerina (1)*, *Polypedilum* (1), *Pseudochironomus (1)*, and *Tanypus* sp. (9) (Lan 1988). Only 8% of the chironomids with labial plates at this site displayed any gross deformities (Table 9).

Chironomid density (57 m^{-2}) was extremely low. No sludge worms were able to survive in the Cyanamid effluent as tubificid worms are relatively intolerant of heavy metals such as chromium (Brinkhurst & Cook 1980).

Atlas Specialty Steels

The frequency of chironomid deformities at Atlas could not be calculated because the chironomids were apparently unable to tolerate the

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elevated heavy metal concentrations in these sediments. Data for both Cyanamid and Atlas have been previously reported (Lan 1988).

Atlas Specialty Steels Co. in Welland discharges 30,000 m^3 day^{-1} into the Welland River. Elevated levels of nickel, chromium, lead, zinc, copper, cobalt and iron in these discharges results in sediment contamination at and downstream of their discharge pipe, the Atlas-Mansfield storm sewer.. The area downstream of this discharge was occupied by sediments contaminated with nickel (2,900), lead (2,400), zinc (2,200) and chromium (2,100) mg g-1 dry weight of sediment (Brindle, in Dickman et al. 1988).

In 1986, the Atlas Specialty Steels Co. released 31 kg of cadmium and 5,694 kg of chromium into the Welland River (MOE 1987). Both of these heavy metals are known to be mutagenic and carcinogenic (Sax 1984). It was for this reason that samples were taken from near the Atlas discharge in order to determine their impact on the frequency of chironomid labial plate deformities. Unfortunately, no chironomids or oligochaetes were able to survive in the heavily contaminated sediments immediately downstream of the Atlas discharge. In 1989 we plan to sample the river at 500m intervals downstream of Atlas to determine benthic invertebrate densities as a function of distance downstream of this industry. Changes in the frequency of chironomid labial plate deformities will also be noted.

Studies of heavy metals such as Hg, Zn, Cd, Ni, Pb, Cu and Cr in Sweden indicated that heavy metal contaminated lakes, displayed a much higher percentage of deformed chironomids than did unpolluted lakes (Wiederholm, 1984).

Ford Glass Co.

The Ford Motor Co. discharges 8,554 m^3 of effluent to the Welland River every day. This discharge includes 3.2 kg day^{-1} (1,168 kg per year) of phosphorus and 24.1 kg day^{-1} (8,797 kg per yr) of soxlet extractable solvents (MOE 1987).

Only 10 chironomids were observed in the nine Ekman dredge samples removed from the Ford Glass discharge area in the Welland River and only one of these displayed gross deformities of its labial plate. Additional samples are needed to permit any conclusions about the frequency of labial plate deformities at this location.

Generic richness (3) and diversity (0.66) were among the lowest in the Welland River (Table 9). Three chironomid taxa were observed; *Procladius* (12 m-2), *Polypedilum* (36 m-2) and *Tanypus* (5 m-2).

Most of the benthic invertebrates at this site were sludge worms (aquatic oligochaetes such as *Limnodrilus*). Competition from sludge worms such as *Limnodrilus* may have resulted in the low density (47 m^{-2}) and low diversity of chironomids which we observed at this site.

Measures of generic richness

Each of the 5 sites in the Buffalo River and 10 sites in the Welland and Niagara Rivers were ranked on the basis of 1) the diversity and generic richness of chironomids (Figs. 13 and 14), 2) density of chironomids (Fig. 15), and 3) relative frequencies of chironomid labial plate deformities (Fig. 16).

By comparing the species pattern of chironomids in normal (control areas) with that of polluted areas, it was concluded that three factors interactively contributed to species diversity and generic richness:

1. Spatial heterogeneity (e.g. Pond Inlet had three types of habitats, rocks, mud and aquatic plants). This variety of habitats was correlated with the high chironomid diversity and generic richness in this small pond.
2. Sites where oligochaete densities were high (e.g. 3 of the 5 Buffalo River stations) typically revealed low chironomid diversity and abundance.
3. Sites where chironomid predation was suspected (e.g. the Evan St. "control" site) displayed low chironomid density and moderate diversity.
4. Sites where sediments were contaminated with heavy metals (e.g. Atlas Steels) or other contaminants such as those associated with the Welland Sewage Treatment Plant and Ford Glass, displayed low chironomid diversity and density.

Not only did the chironomid communities change in diversity, generic richness and density at the 15 sampling sites but a shift in the dominant species was frequently noted. It is possible that those dominant species associated with a particular type of discharge may prove useful in characterizing a suite of factors associated with that discharge (Buikeman and Herricks, 1978). In our study, pollution tolerant chironomid genera were found to dominate at particular sites in the study area (e.g. *Procladius* cf. *bellis* was particularly common at locations where dissolved oxygen was low and heavy metal concentrations were high. *Phaenopsectra flavipes* was associated with water discharged by the Welland sewage treatment plant, and *Polypedilum* was associated with the discharge area of the Ford Glass Co.

Changes in species composition and density in benthic invertebrate communities can be related to the level of toxic materials entering the environment (Hart and Fuller, 1974; Buikeman and Herricks, 1978; Wiederholm, 1984). Chironomid species diversity and species richness in the Niagara River Watershed were closely correlated (Fig.12, R^2 = 0.87).

In general, as the level of sediment contamination increases, a reduction in the complexity of the chironomid community is observed as the abundance of a few species generally increases (Cairns et al., 1972; Hart, 1974).

CONCLUSIONS

1. Forty seven percent of grossly deformed chironomids occurred immediately downstream of the discharge pipe of the B. F. Goodrich Company. This company discharged 33 kg of vinyl chloride, (C_2H_3Cl), into the Welland River in 1986. Vinyl chloride, an extremely powerful mutagen and human carcinogen, was suspected of inducing the chironomid labial plate deformities observed at this site.

2. Thirty five percent of the chironomids at the 5 (pooled) stations in the lower Buffalo River displayed grossly deformed labial plates. Litten (1987) found napthalene, hexachlorocyclohexane, heptachlor epoxide, PCB's and PAH's as well as a variety of heavy metals including mercury, zinc and lead in the sediments of the lower Buffalo River.

3. Nineteen percent of the Beaver Creek chironomids displayed gross labial plate deformities. This was the highest level among non-industrialized regions (i.e. agricultural areas) of the Niagara River Watershed. It was speculated that the presence of pesticides containing mutagenic agents such as Atrazine was the reason for the elevated frequency of labial plate deformities in this area.

4. Thirteen percent of the 113 chironomids examined from 9 sites in Pond Inlet displayed gross deformities. This was higher than expected and may have been associated with the presence of chlorinated makeup water and "Roundup" which was used in 1986 and 1987 by Brock University at extremely low concentrations to control aquatic plant growth in this pond.

5. Upstream of the industrialized section of the Welland River but downstream of agricultural areas, at the Evan St. "control" site, the frequency of chironomid labial plate deformities was 9%.

It was reported by Hare and Carter, (1976) that natural populations of chironomids in areas such as Georgian Bay, which are relatively unimpacted by manmade chemicals, display very low frequencies of chironomid labial plate deformities (0-3%).

It is our conclusion that sites contaminated with genotoxins will result in chironomids having a high frequency of gross labial plate deformities. Sites with low or negligible levels of contaminants will be associated with high chironomid diversity and species richness and low frequencies of chironomid labial plate deformities. Thus, the frequency of chironomid labial plate deformities provides a useful index for evaluating sediments which are contaminated with mutagenic or carcinogenic substances. Chironomid diversity was affected by predation, competition and habitat diversity in addition to sediment and water toxicity. Thus only

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when the former are known, can chironomid diversity be used to infer the relative level of sediment toxicity.

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Table Captions

Table 1.

Table 1

Control Site: Welland River at Evan Street (Welland)
Results for All (27) Ekman Dredges Combined

Chironomid Genera	Number of normal Chironomids	(%)	# of slightly deformed Chironomids	(%)	# of grossly deformed Chironomids	(%)	Total # of Ind.	Chironomid Density (No/m^2)
Allopsectrocladius	1	(100%)	0	(0%)	0	(0%)	1	
Axarus	0	(0%)	1	(100%)	0	(0%)	1	
Chironomus	0	(0%)	1	(100%)	0	(0%)	1	
Chryptochironomus	3	(37%)	4	(50%)	1	(13%)	8	
Cladopelma	0	(0%)	2	(67%)	1	(33%)	3	
Cricotopus	8	(67%)	3	(25%)	1	(8%)	12	
Dicrotendipes	6	(84%)	1	(14%)	0	(0%)	7	
Glyptotendipes	0	(0%)	1	(50%)	1	(50%)	2	
Harnischia	0	(0%)	1	(100%)	0	(0%)	1	
Mesopsectrocladius	2	(67%)	1	(33%)	0	(0%)	3	
Microtendipes	1	(100%)	0	(0%)	0	(0%)	1	
Parachironomus	1	(100%)	0	(0%)	0	(0%)	1	
Phaenopsectra	9	(26%)	21	(62%)	4	(12%)	34	
Polypedilum	5	(38%)	6	(46%)	2	(15%)	13	
Procladius (Ligula only)	45	(80%)	10	(18%)	1	(2%)	56	
Psectrocladius	2	(100%)	0	(0%)	0	(0%)	2	
Pseudochironomus	11	(79%)	3	(21%)	0	(0%)	14	
Rheotanytarsus	1	(100%)	0	(0%)	0	(0%)	1	
Stictochironomus	1	(100%)	0	(0%)	0	(0%)	1	
Tanytarsus	0	(0%)	1	(100%)	0	(0%)	1	
Ligula corrected totals	51	(47%)	46	(42%)	10	(9%)	107	169
Totals	96	(59%)	56	(34%)	11	(7%)	163	258

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TABLE 2

Confluence of the Welland River and Beaver Creek
Results for all (13) Replicates Combined

Chironomid Genera	Number of normal Chironomids	(%)	# of slightly deformed Chironomids	(%)	# of grossly deformed Chironomids	(%)	Total # of Ind.	Chironomid Density (No/m2)
Ablabesmyia	1	(100%)	0	(0%)	0	(0%)	1	
Chironomus	18	(28%)	30	(47%)	16	(25%)	64	
Cladopelma	2	(50%)	2	(50%)	0	(0%)	4	
Cryptochironomus	6	(55%)	4	(36%)	1	(9%)	11	
Dicrotendipes	6	(75%)	2	(25%)	0	(0%)	8	
Einfeldia	1	(50%)	0	(0%)	1	(50%)	2	
Endochironomus	4	(50%)	4	(50%)	0	(0%)	8	
Glyptotendipes	8	(36%)	7	(32%)	7	(32%)	22	
Lauterborniella	1	(20%)	3	(60%)	1	(20%)	5	
Microtendipes	0	(0%)	1	(100%)	0	(0%)	1	
Polypedilum(Lan 86)	1	(100%)	0	(0%)	0	(0%)	1	
Procladius (Ligula only)	19	(90%)	2	(10%)	0	(0%)	21	
P. richardsonii (Lan 86)	32	(100%)	0	(0%)	0	(0%)	32	
Tanytarsus (Lan 86)	3	(15%)	14	(70%)	3	(15%)	20	
Tanypus (Ligula only)	3	(75%)	1	(25%)	0	(0%)	4	
Ligula corrected totals	54	(32%)	67	(45%)	29	(19%)	150	357
Totals	108	(52%)	70	(34%)	29	(14%)	207	493

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TABLE 3

Pond Inlet at Brock University
Results for all (25) Replicates Combined

Chironomid Genera	Number of normal Chironomids	(%)	# of slightly deformed Chironomids	(%)	# of grossly deformed Chironomids	(%)	Total # of Ind.	Chironomid Density (No/m^2)
Chironomus	14	(45%)	2	(39%)	5	(16%)	31	
Cladopelma	10	(63)	6	(37%)	0	(0%)	16	
Cladotanytarsus	20	(74%)	6	(22%)	1	(4%)	27	
Cryptochironomus	0	(0%)	1	(33%)	2	(67%)	3	
Endochironomus	1	(33%)	1	(33%)	1	(33%)	3	
Glyptotendipes	1	(50%)	1	(50%)	0	(0%)	2	
Microchironomus	0	(0%)	0	(0%)	1	(100%)	1	
Paratanytarsus	1	(50%)	1	(50%)	0	(0%)	2	
Polypedilum	2	(67%)	1	(33%)	0	(0%)	3	
Procladius (Ligula only)	3	(60%)	1	(20%)	1	(20%)	5	
Stictochironomus	11	(69%)	2	(13%)	3	(18%)	16	
Tanypus (Ligula only)	1	(50%)	0	(0%)	1	(50%)	2	
Tanytarsus	1	(50%)	0	(0%)	1	(50%)	2	
Ligula corrected totals	61	(58%)	31	(29%)	14	(13%)	106	181
Totals	65	(58%)	32	(28%)	16	(14%)	113	193

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Table 4

Welland River at the Richelieu Club (Welland)
Results for All (15) Ekman Dredges Combined

Chironomid Genera	Number of normal Chironomids	(%)	# of slightly deformed Chironomids	(%)	# of grossly deformed Chironomids	(%)	Total # of Ind.	Chironomid Density (No./m^2)
Cricotopus	0	(0%)	1	(100%)	0	(0%)	1	
Phaenopsectra	45	(55%)	30	(37%)	7	(8%)	82	
Procladius (Ligula only)	6	(55%)	5	(45%)	0	(0%)	11	
Psectrocladius	1	(100%)	0	(0%)	0	(0%)	1	
Ligula corrected totals	46	(55%)	31	(38%)	7	(8%)	84	240
Totals	52	(55%)	36	(38%)	7	(7%)	95	270

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TABLE 5

B. F. Goodrich Discharge Stream
Results for all (9) Replicates Combined

Chironomid Genera	Number of normal Chironomids	(%)	# of slightly deformed Chironomids	(%)	# of grossly deformed Chironomids	(%)	Total # of Ind.	Chironomid Density (No/m^2)
Ablabesmyia (Lan 86 D1)	0	(0%)	0	(0%)	2	(0%)	2	
Chironomus (Lan 86 D1)	2	(6%)	15	(48%)	14	(6%)	31	
Procladius (Ligula only)	0	(0%)	1	(100%)	0	(0%)	1	
Psectrotanypus	1	(50%)	1	(50%)	0	(0%)	2	
Pseudochironomus (Lan 86)	0	(0%)	0	(0%)	1	(100%)	1	
Tanypus (Ligula only) 188)	23	(33%)	23	(38%)	15	(29%)	61	
Tanypus (Lan 86 D1)	45	(92%)	0	(0%)	4	(8%)	49	
Tanypus (Lan 86 D2)	21	(95%)	0	(0%)	1	(5%)	22	
Ligula corrected totals	3	(8%)	16	(44%)	17	(47%)	36	171
Totals	92	(54%)	40	(24%)	37	(22%)	169	801

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Table 6

Welland River at the Conrail Bridge
Results for All (3) Ekman Dredges Combined

Chironomid Genera	Number of normal Chironomids	(%)	# of slightly deformed Chironomids	(%)	# of grossly deformed Chironomids	(%)	Total # of Ind.	Chironomid Density ($No./m^2$)
Chironomus	52	(48.%)	45	(42%)	10	(9%)	107	
Cricotopus	8	(57%)	6	(43%)	0	(0%)	14	
Monopsectrocladius	3	(100%)	0	(0%)	0	(0%)	3	
Paratendipes	0	(0%)	1	(100%)	0	(0%)	1	
Polypedilum	13	(41%)	14	(44%)	5	(16%)	32	
Procladius (Ligula only)	5	(63%)	3	(37%)	0	(0%)	8	
Tanypus (Ligula only)	4	(36%)	6	(55%)	1	(9%)	11	
Tanytarsus	1	(33%)	2	(66%)	0	(0%)	3	
Ligula corrected totals	77	(48%)	68	(43%)	15	(9%)	160	2277
Totals	86	(48%)	77	(43%)	16	(9%)	179	2548

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TABLE 7

Chippawa Creek, Chippawa
Results for All (9) Replicates Combined

Chironomid Genera	Number of normal Chironomids	(%)	# of slightly deformed Chironomids	(%)	# of grossly deformed Chironomids	(%)	Total # of Ind.	Chironomid Density (No/m^2)
Chironomus	13	(54%)	10	(42%)	1	(4%)	24	
Cricotopus	3	(25%)	4	(33%)	5	(42%)	12	
Nanocladius	2	(40%)	3	(60%)	0	(0%)	5	
Rheotanytarsus	1	(100%)	0	(0%)	0	(0%)	1	
Tanytarsus (Ligula only)	0	(0%)	1	(100%)	0	(0%)	1	
Ligula corrected totals	19	(44%)	17	(42%)	6	(14%)	42	199
Totals	19	(43%)	18	(42%)	6	(14%)	43	204

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TABLE 8

Buffalo River, Buffalo, New York
Results for all (30) Ekman Dredges Combined

Chironomid Genera	Number of normal Chironomids	(%)	# of Slightly deformed Chironomids	(%)	# of Grossly deformed Chironomids	(%)	Total # of Ind.	Chironomid Density (No/m^2)
Chironomus	2	(67%)	2	(0%)	2	(33%)	6	
Cladopelma	1	(25%)	2	(50%)	1	(25%)	4	
Glyptotendipes	0	(0%)	0	(0%)	1	(100%)	1	
Procladius (Ligula only)	47	(100%)	0	(0%)	0	(0%)	47	
Psectrotanypus	1	(33%)	1	(33%)	1	(33%)	3	
Ligula corrected totals	4	29%	5	35%	5	35%	14	20
Totals	51	(84%)	5	(8%)	5	(8%)	61	88

Table 9 (Summary Table)

Results for all (155) Ekman Dredges

Location	No. Counted Counted	# Ekman Reps.	Density #/m.Sq.	% Abnormalities	Diversity (H)	Richness (S)	(rank)	#/Ekman
Pond Inlet	113	25	193	13%	2.98	13	2	4.52
Richelieu Club	95	15	270	8%	0.68	4	9	6.33
B.F.Goodrich	169	9	801	47%	0.32	6	5	18.78
Minurcase and Conrail	179	9	2,548	9%	1.04	5	8	59.67
Chippewa Creek	43	9	204	14%	1.60	5	6	4.77
Buffalo River	61	30	88	35%	0.52	5	8	2.03
Cyanamid	34	9	161	8%	1.66	8	4	3.78
Ford Glass	11	9	53	8%	0.66	3	10	1.22
Beaver Creek	150	13	493	19%	2.81	13	3	11.54
Atlas Steels	0	9	0	0	0	0	11	0
Evan St. (Control Site)	163	27	258	9%	3.5	20	1	6.04
Totals	995	154	4959	171	16.33	81		116.11
Means	90.5	14	451	15.5	1.48	7.36		10.55

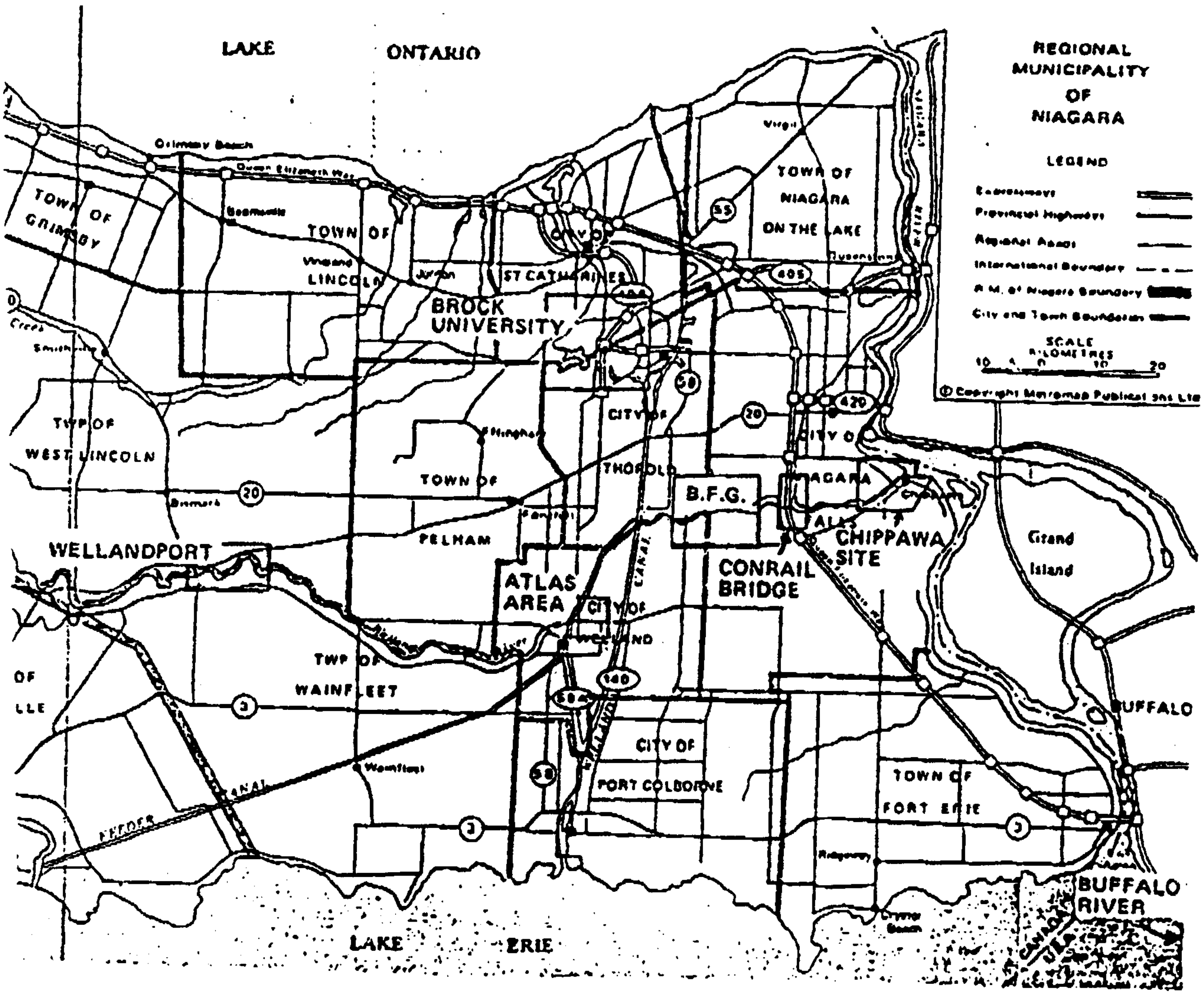

Figure 1: The six sample station sites in the Niagara Peninsula study region.

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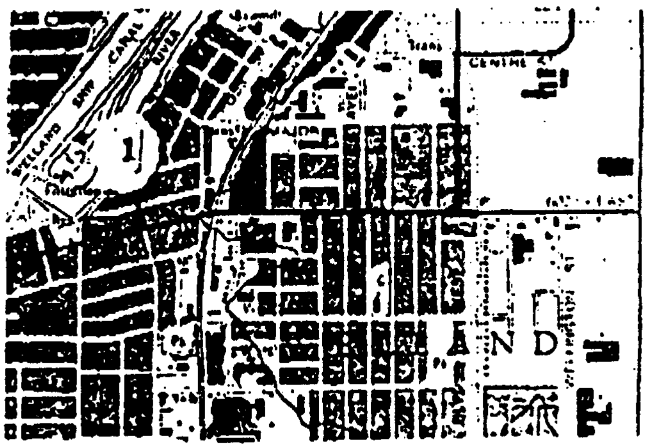

Figure 2: Station 1--the "Control" site at Evan Street, Welland; upstream of all industrial discharges.

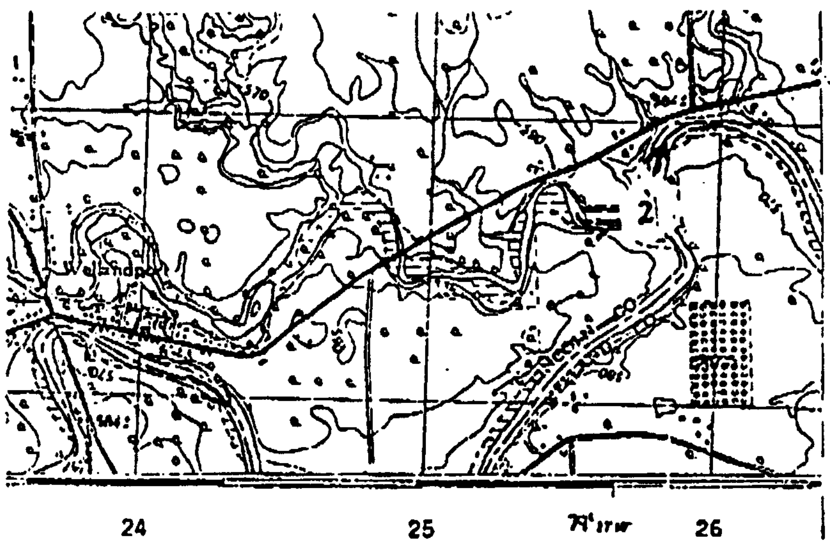

Figure 3: Station 2--located in the agricultural part of the Welland River near Wellandport.

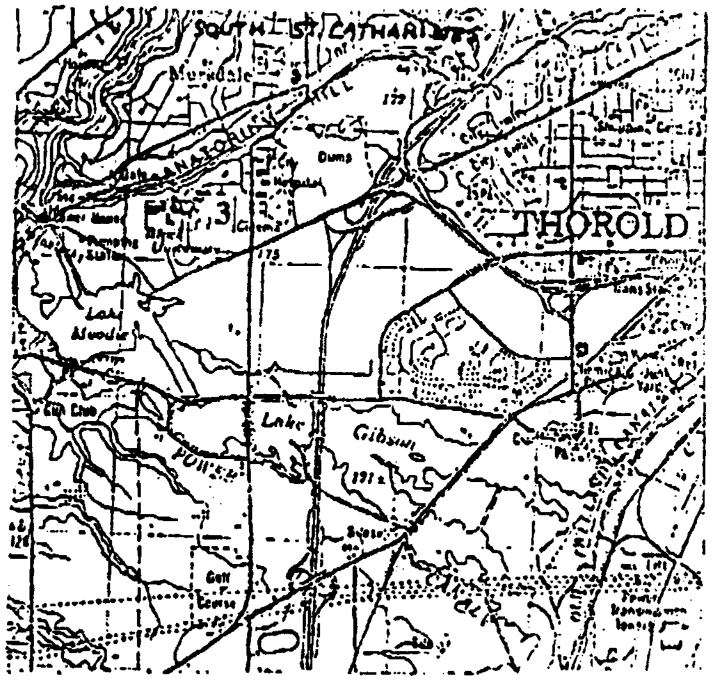

Figure 4: Station 3--located at the Pond Inlet at Brock University, and chosen to test the impact of the broad spectrum herbicide "Roundup", which contains 2,4-D as the active ingredient.

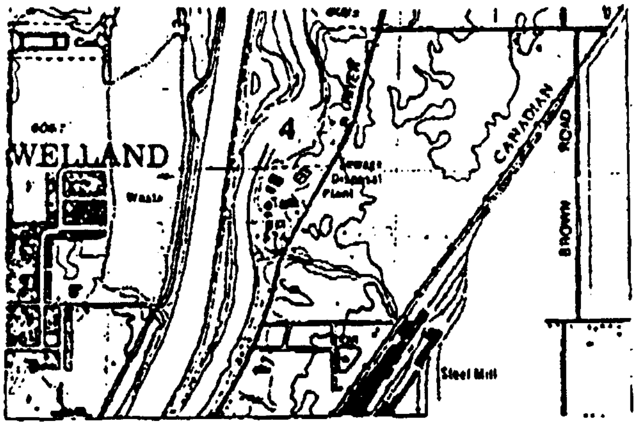

Figure 5: Station 4--located on the Welland River near the Richelieu Club, downstream of the Welland Sewage Treatment Plant.

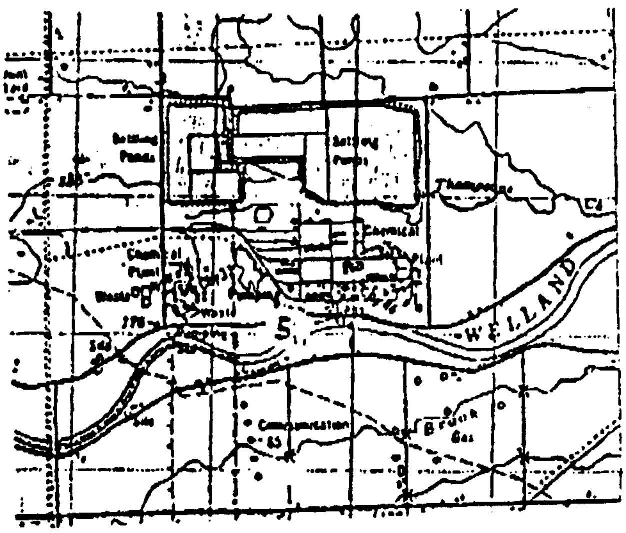

Figure 6: Station 5 included three sampling stations; two from the discharge site of the B.F. Goodrich Co., which is slightly downstream (to the east) of the pumping station; and one at the end of the B.F. Goodrich discharge creek at its confluence with the Welland River.

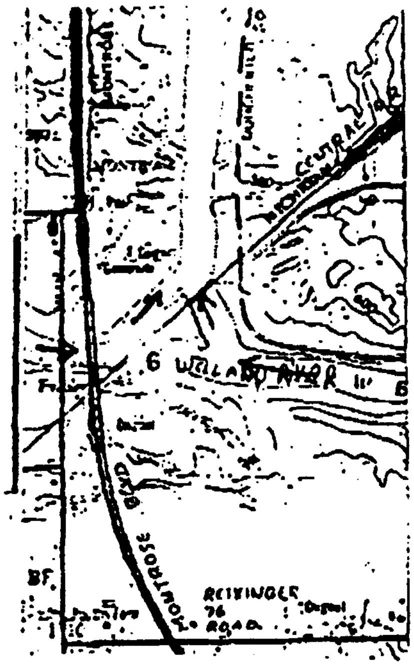

Figure 7: Station 6--located at the Conrail railway bridge, this site was chosen as an example of an industrial area recovery zone.

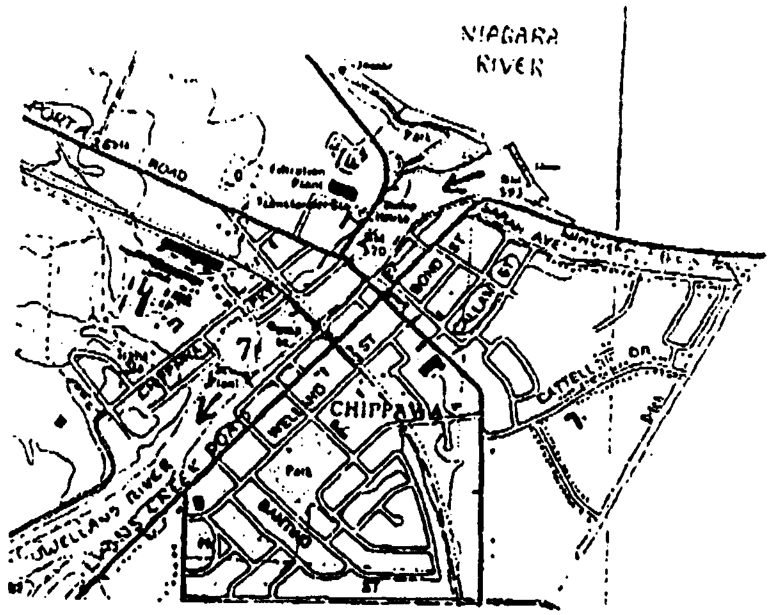

Figure 8: Station 7--located near Front Street, Chippawa; this site was chosen from the Niagara River near a toxic waste clean-up zone.

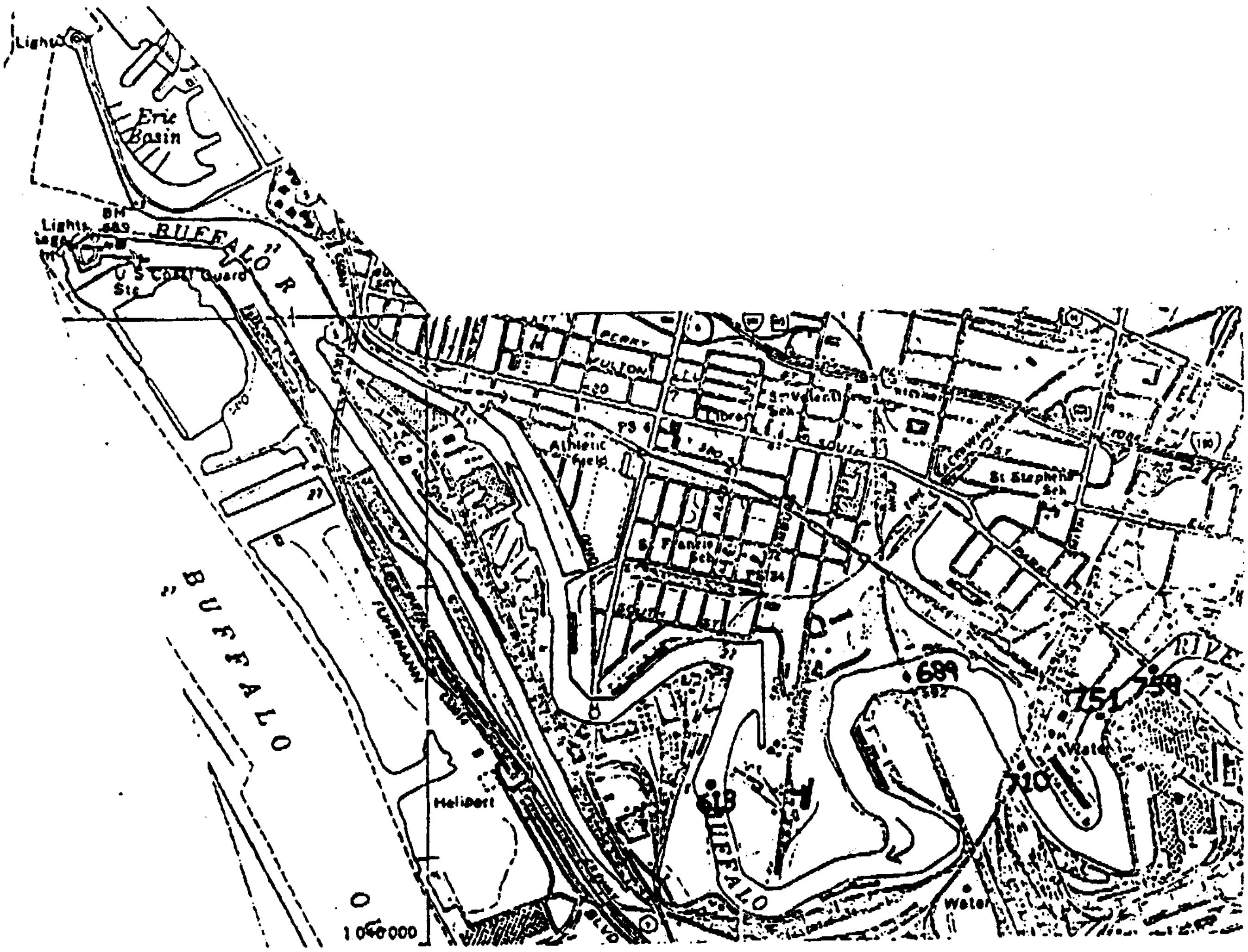

Figure 9. Stations 613 - 759 were collectively referred to as station 8. The station numbers represent the distance in feet from the mouth of the Buffalo River.

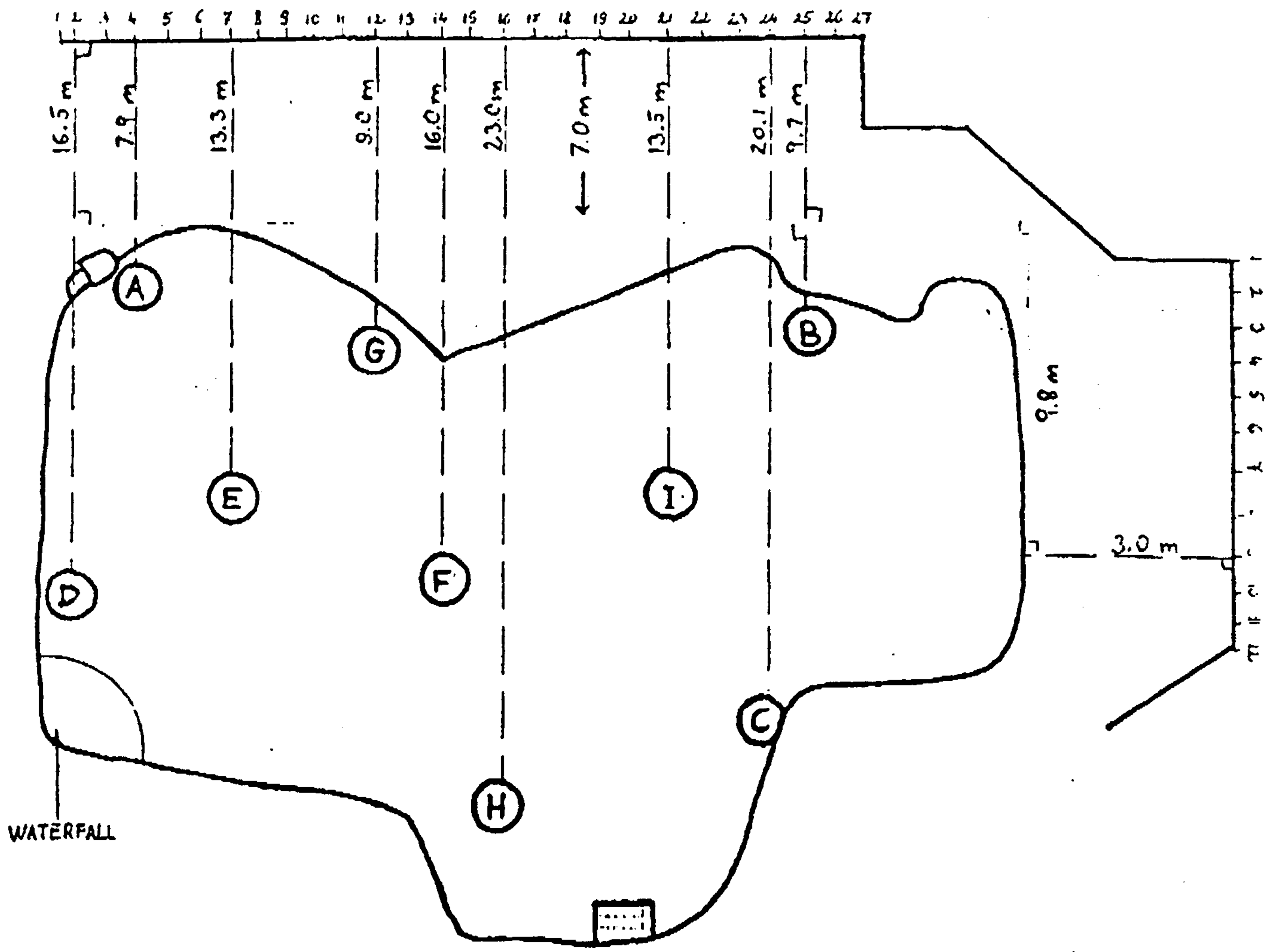

Figure 10: Map of the Pond Inlet (Showing sites A-I) The coordinates of the sampling sites were determined by measuring the distance from the cafeteria's window frames (27 total--numbered at the top of the sketch). Because these were located exactly 1 meter apart it was possible to approximate y-coordinates by establishing right angles. A rope was used to measure the x-coordinates. For example, Site 'F' was located perpendicular to second window frame to the left, at a distance of approximately 15.6 m.

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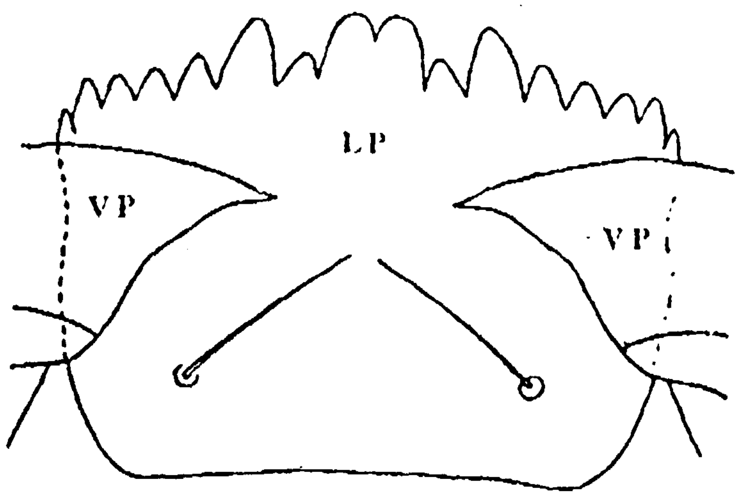
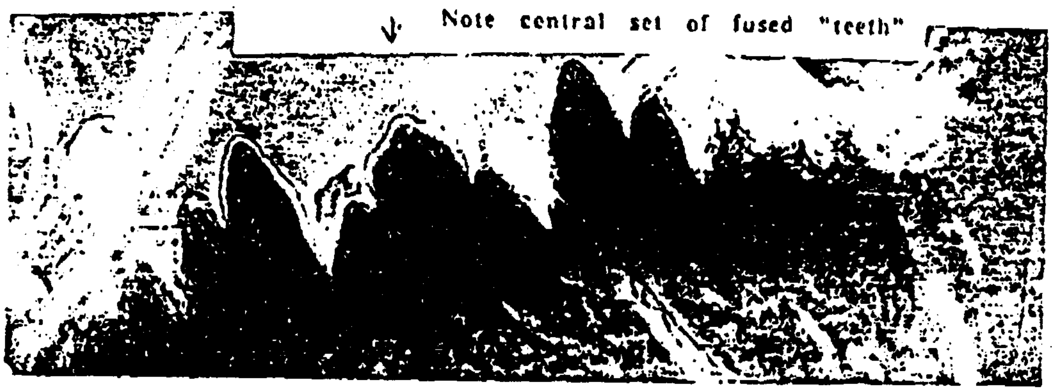
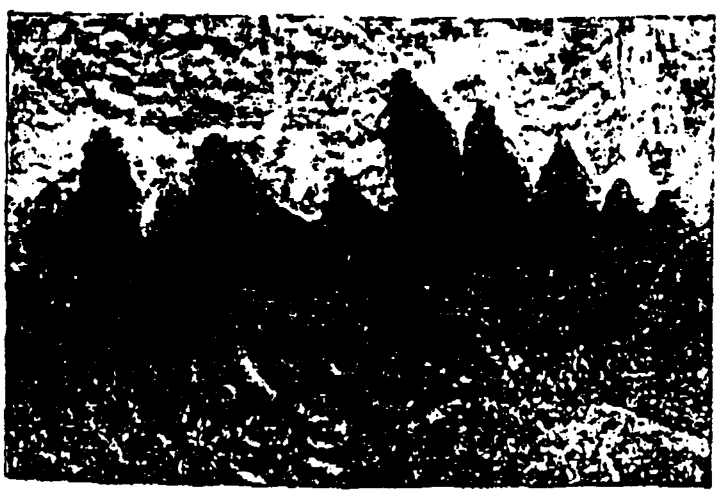
Figure 11 A Chironomid labial plate (LP) with mentum and ventromental plate (VP) (After Wiederholm 1983).



11 B Chironomus plumosus group, slightly deformed labial plate X 480



11 C Chironomus plumosus group, grossly deformed labial plate X 400



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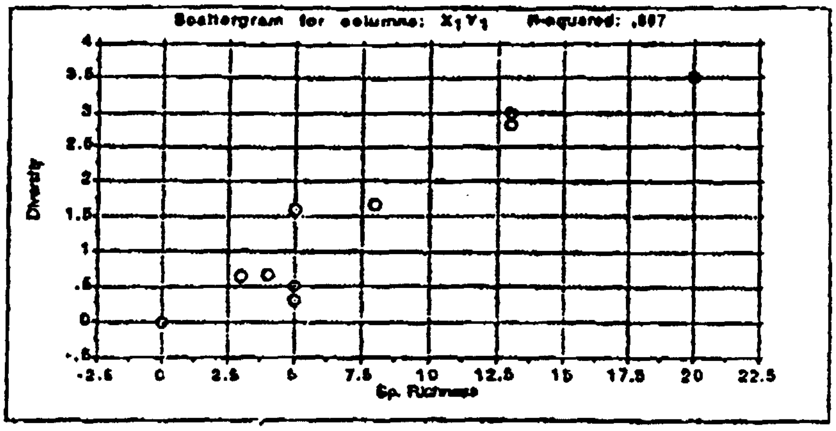
Scattergram for columns: X1 Y1
R-squared:
Diversity
4
3.5
3
2.5
2
1.5
1
.5
0
-.5
-2.5
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
Sp. Richness

Figure 12

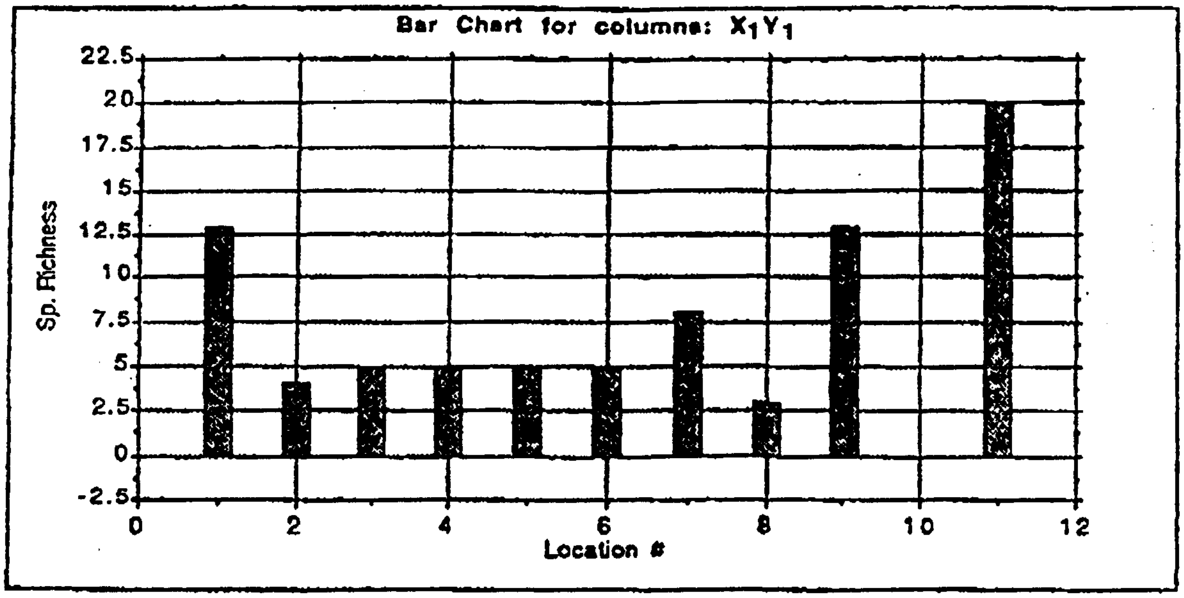

Figure 13

Location No. 1. Pond Inlet, 2. Richelieu Club, 3. B.F. Goodrich, 4. Montrose and Conrail Bridges, 5. Chippewa Creek, 6. Buffalo River (all 5 sites pooled), 7. Cyanamid, 8. Ford Glass, 9. Beaver Creek, 10. Atlas Steels and 11. Evan St."Control" Site

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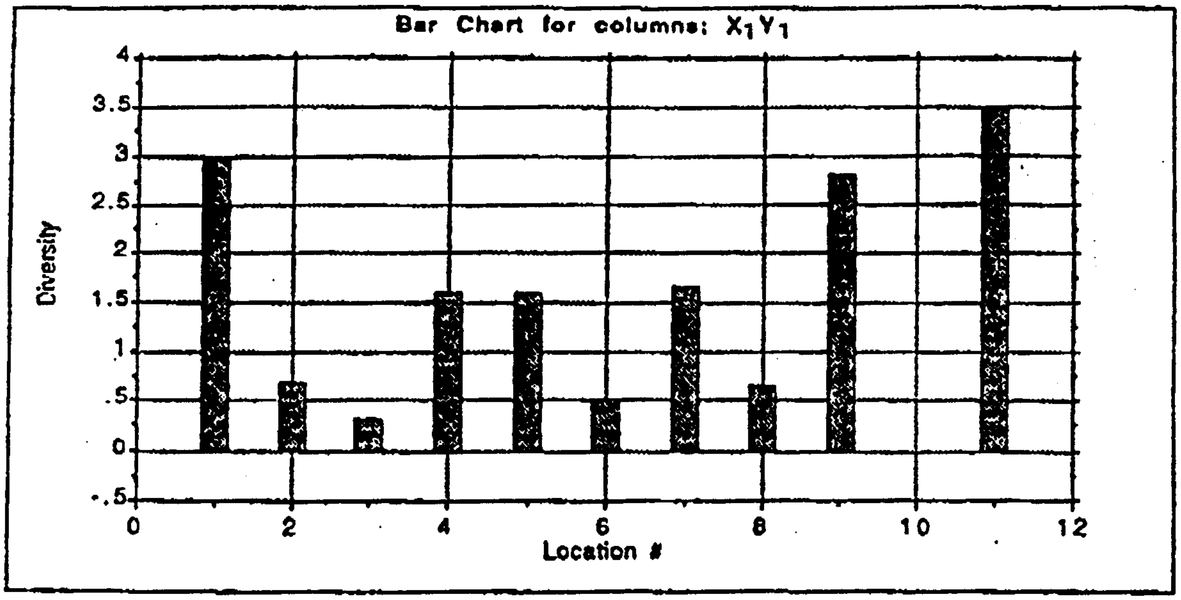

FIGURE 14

Location No. 1. Pond Inlet, 2. Richelieu Club, 3. B.F. Goodrich, 4. Montrose and Conrail Bridges, 5. Chippewa Creek, 6. Buffalo River (all 5 sites pooled), 7. Cyanamid, 8. Ford Glass, 9. Beaver Creek, 10. Atlas Steels and 11. Evan St."Control" Site

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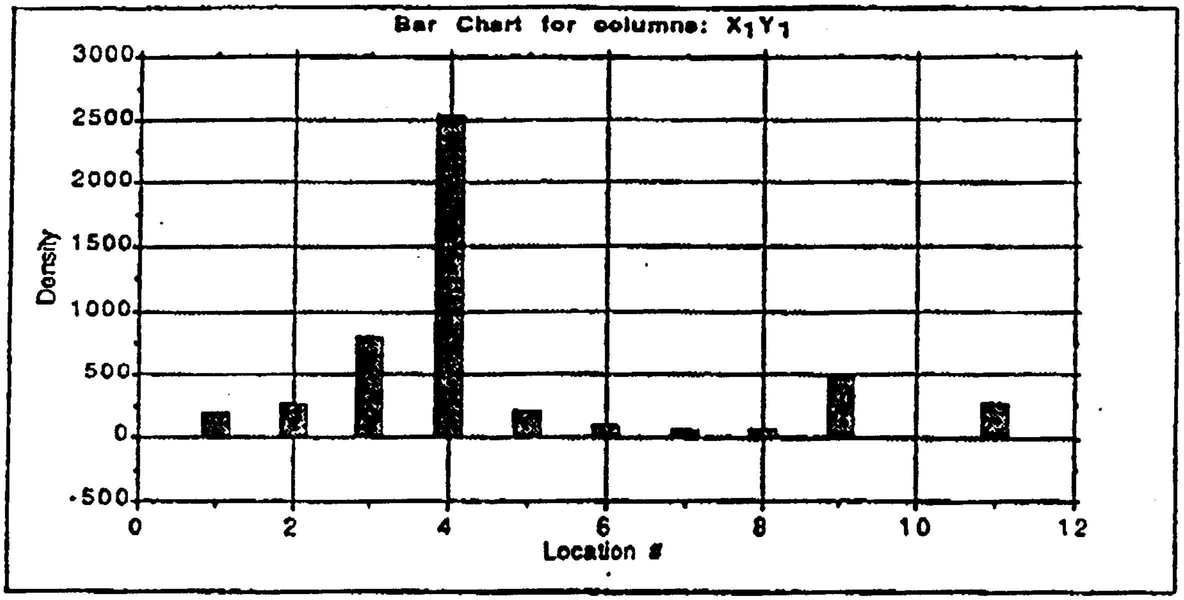

Figure 15

Location No. 1. Pond Inlet, 2. Richelieu Club, 3. B.F. Goodrich, 4. Montrose and Conrail Bridges, 5. Chippewa Creek, 6. Buffalo River (all 5 sites pooled), 7. Cyanamid, 8. Ford Glass, 9. Beaver Creek, 10. Atlas Steels and 11. Evan St."Control" Site

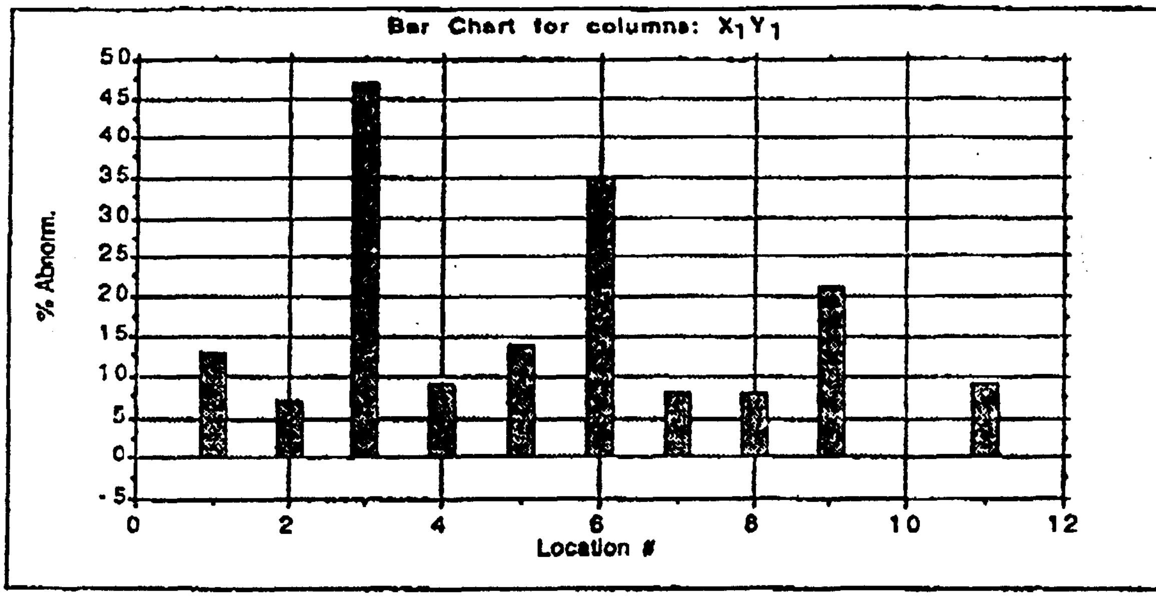

FIGURE 16

Location No. 1. Pond Inlet, 2. Richelieu Club, 3. B.F. Goodrich, 4. Montrose and Conrail Bridges, 5. Chippewa Creek, 6. Buffalo River (all 5 sites pooled), 7. Cyanamid, 8. Ford Glass, 9. Beaver Creek, 10. Atlas Steels and 11. Evan St."Control" Site

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