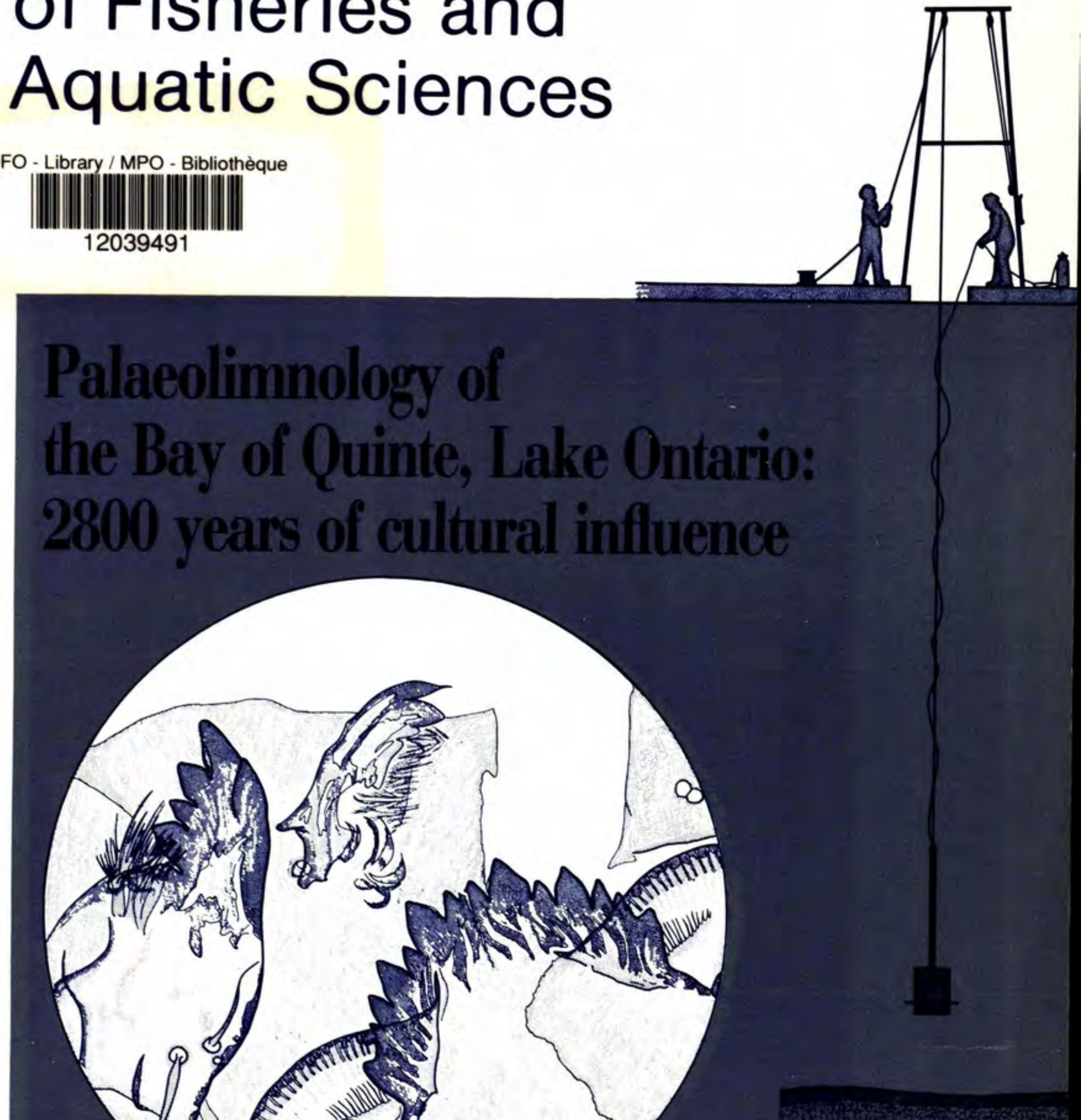
Canadian Bulletin of Fisheries and Aquatic Sciences

Palaeolimnology of the Bay of Quinte, Lake Ontario: 2800 years of cultural influence



W. F. Warwick

BULLETIN 206
Ottawa 1980

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Palaeolimnology of the Bay of Quinte, Lake Ontario: 2800 years of cultural influence

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DEPARTMENT OF FISHERIES AND OCEANS
Ottawa 1980

The *Canadian Bulletins of Fisheries and Aquatic Sciences* (formerly *Bulletins of the Fisheries Research Board of Canada*) are designed to interpret current knowledge in scientific fields pertinent to Canadian fisheries and aquatic environments. Recent numbers in this series are listed at the back of this Bulletin.

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Department of Fisheries and Oceans
Scientific Information and Publications Branch
Ottawa, Canada
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The significant aspect of human action is man's total impact on ecological systems, not the particular contributions that arise from specific pollutants. Interaction among pollutants is more often present than absent. Furthermore the total effect of a large number of minor pollutants may be as great as that of one major pollutant. Thus, the total pollution burden may be impossible to estimate except by direct observation of its overall effect on ecosystems.

Anon 1970: 119

ABSTRACT

Warwick, W. F. 1980. Palaeolimnology of the Bay of Quinte, Lake Ontario: 2800 years of cultural influence. Can. Bull. Fish. Aquat. Sci. 206: 117 p.

Three sediment cores from the Bay of Quinte, each about 2 meters long, were taken in March 1972 through the ice in 22.3 meters of water, with a modified Mackereth corer at a site 3 kilometers down channel from Glenora, Ontario. The chronology of the core sediments was established by four chronological techniques — *Ambrosia* pollen, lead-210, carbon-14, and an Erosion Index (a new technique for fingerprinting core sediments) — so that stratigraphic parameters could be correlated with historical events. Historical changes in the quality and quantity of the sediments were defined by grain-size measurements, ignition analyses, and chemical–geological data. Changes in productivity in the water column and the quality of organic materials in the sediments were traced through carbon, nitrogen, phosphorus, and ignition analyses.

Analysis of the fossil chironomid succession demonstrates that man, especially European man, has had, and is having, a profound impact on the Bay of Quinte. Primitive cultures such as the Hopewell who thrived some 2000 years ago, and the Iroquois who occupied the area between 1000 and 1650 A.D., clearly had a measurable effect on the processes influencing the aquatic environment of the bay. However, their impact was minor compared to that imposed by the development of European culture. The chironomid fauna has undergone profound changes since the arrival of European colonists. For 2000 years prior to their arrival, the fauna remained remarkably stable and was characteristic of relatively undisturbed oligotrophic conditions. With the arrival of the French and British, the chironomid community responded to the initial colonization by developing a progressively more eutrophic fauna, paralleling the increased productivity of the bay from increased nutrient inputs. However, the chironomid community reverted to a more oligotrophic fauna when large-scale deforestation in the watershed introduced massive amounts of erosion materials into the bay. The resulting unstable bottom conditions and the dilution and burial of organic food led to the development of an imbalanced oligotrophic fauna, characterized by *Micropsectra* spp., which was maintained in spite of the continued increase in productivity in the water column. The inhibitory effect of the mineral sediments formulated in the expression:

$$\text{TROPHY}_{\substack{\text{faunal}\\ \text{indices}}} = \text{TROPHY}_{\substack{\text{productivity}\\ \text{indices}}} - \text{mineral sediment accumulation}$$

continued as long as the rate of sediment accumulation remained rapid, but, once the rate began to decline, the suppressed effects of continued eutrophication proceeded with increasing rapidity. The transition from the imbalanced oligotrophic fauna to the depleted *Chironomus–Procladius* fauna tolerant of present-day eutrophic conditions was so rapid that the intervening *Phaenopsectra* community was unable to develop to proportions normally found in mesotrophic lakes. The increased incidence of deformed larvae in the most recent sediments indicates industrial and/or agricultural contaminants are present in the aquatic environment, and adds a new dimension to the list of insults man has inflicted on the bay.

Key words: Chironomidae, eutrophication, sedimentation, contamination, deformities, palaeolimnology

RÉSUMÉ

WARWICK, W. F. 1980. Palaeolimnology of the Bay of Quinte, Lake Ontario: 2800 years of cultural influence. Can. Bull. Fish. Aquat. Sci. 206: 117 p.

Un carottier de Mackereth modifié a été utilisé pour prélever trois carottes de sédiment, d'environ 2 mètres de long chacune, à travers la glace dans 22,3 mètres d'eau en mars 1972, dans la baie de Quinte à un endroit situé à 3 kilomètres en aval de Glenora, en Ontario. La chronologie des sédiments dans les carottes a été établie d'après quatre méthodes : pollens d'*Ambrosia*, plomb-210, carbone-14 et indice d'érosion (technique nouvelle d'identification des sédiments d'une carotte). De cette façon, il a été possible d'établir la corrélation entre paramètres stratigraphiques et événements historiques. Les changements historiques de qualité et de quantité de sédiments ont été définis par des mesures de la grosseur des grains, analyses par incandescence et données chimiques–biologiques. Les changements de productivité dans la colonne d'eau et la qualité des matières organiques dans les sédiments ont été suivis par dosages du carbone, de l'azote et du phosphore, et analyses par incandescence.

L'analyse de la succession des chironomides fossiles démontre que l'homme, en particulier l'Européen, exerça dans le passé et exerce encore une profonde influence sur la baie de Quinte. Les cultures primitives, telles celle de Hopewell qui florissait il y a quelques 2 000 ans et celle des Iroquois qui occupèrent la région de 1000 à 1650 A.D., eurent un effet clairement mesurable sur les processus affectant l'environnement aquatique de la baie. Leur influence était cependant mineure comparée à celle de la culture européenne. Depuis l'arrivée des colons européens, la faune des chironomides a subi de profonds changements. Dans les 2 000 ans qui précédèrent l'arrivée de ces derniers, la faune demeura remarquablement stable, offrant les caractéristiques de conditions oligotrophes relativement peu dérangées. Avec l'arrivée des Français et des Britanniques, la réaction de la communauté des chironomides au début de la colonisation fut d'évoluer en une faune progressivement plus eutrophe, en même temps que croissait la productivité de la baie par suite d'apports accrus de nutriments. Par ailleurs, la communauté des chironomides retourna à des conditions plus oligotrophes au moment où une déforestation à grande échelle du bassin hydrographique versa dans la baie de vastes quantités de matériaux d'érosion. Les conditions du fond instables et la dilution et l'ensevelissement de la nourriture organique qui en résultèrent contribuèrent à instaurer une faune oligotrophe déséquilibrée, caractérisée par *Microspectra* spp., qui se maintint en dépit d'une augmentation constante de productivité dans la colonne d'eau. L'effet inhibiteur des sédiments minéraux formulé par l'expression :

$$\underset{\substack{\text{indices}\\ \text{fauniques}}}{\text{TROPHIE}} = \underset{\substack{\text{indices de}\\ \text{productivité}}}{\text{TROPHIE}} - \text{accumulation des sédiments minéraux}$$

se fit sentir aussi longtemps que l'accumulation des sédiments se poursuivit à un taux rapide. Mais une fois que ce dernier commença à décliner, les effets répressifs d'une eutrophisation continue se firent sentir avec une rapidité accrue. La transition entre une faune oligotrophe déséquilibrée et une faune pauvre en *Chironomus* et *Procladius* capable de tolérer les conditions eutrophes présentes fut tellement rapide que la communauté intermédiaire de *Phaenospectra* ne put s'établir en des proportions normalement rencontrées dans les lacs mésotrophes. L'occurrence accrue de larves difformes dans les sédiments les plus récents indique qu'il y a dans l'environnement aquatique des pollutions industrielles et/ou agricoles, ce qui donne une dimension nouvelle aux méfaits de l'homme dans la baie.

1. INTRODUCTION

1.1 Overview

The Bay of Quinte, a prominent bay on the Canadian shore of Lake Ontario, is a major recreational area in southern Ontario, and in the past was the site of a major portion of the Lake Ontario commercial fishery. The area around the lower part of the bay was one of the earliest areas in Upper Canada to be colonized by European settlers. The history of this early colonization and the course of its progress leading to modern society is reasonably well documented.

In recent years, there has been increasing evidence that water quality and catches of desirable commercial fish species are declining. Although these changes have not been historically well documented, present limnological conditions are reasonably well known (Johnson 1970). In 1972 a multidisciplinary study, Project Quinte, was initiated to evaluate present limnological conditions in the bay, and to monitor future effects of major remedial measures undertaken to improve conditions in the aquatic environment.

For this Bulletin three sediment cores each about 2 m long were taken at a site 3 km down channel from the Glenora Fisheries Station, Glenora, Ont. The cores were analyzed by palaeolimnological techniques, to assess the degree to which lake processes have been affected by cultural activities within the watershed of the Bay of Quinte.

The impact of cultural development on a body of water involves direct introduction of materials to the aquatic environment, and indirect introduction of materials as a result of the modification of the terrestrial environment of the watershed. The direct effects are often more closely correlated with the numerical growth of populations, whereas the indirect effects are more often influenced by the type, extent, and duration of human activities. Increase in human population in a watershed typically stimulates biological production in lakes through the introduction of nutrient materials. Modifications to the terrestrial environment also introduce nutrients through leaching processes, but the major impact is often exerted through the erosion and sedimentation of terrestrial mineral sediments and other materials of nonaquatic origin. The complex interaction between these effects influences changes in the sedimentary regime and trophic condition of the aquatic environment which, in turn, are reflected in the yearly increment to the bottom sediments.

The interrelationship of these major processes in the Bay of Quinte and its watershed is summarized in Fig. 1. The bay receives direct input of waste materials from the human population in the watershed while forestry, agriculture, and other land-disturbing practices increase the input of materials as a result of erosion and leaching processes. These inputs combine to affect sedimentation and eutrophication processes in the bay and these, in turn, result in changes in the biological community.

The overall objective of this Bulletin is to assess the impact of man on the bay and its watershed, and to semiquantitatively estimate the relative importance of the various impact processes. The approach was to make a detailed comparison of the information in the historical record with the information gleaned from the sedimentary record.

Palaeolimnology was defined by Delorme (1972: 1) as the study of fresh waters of the past, especially of lakes and ponds. In its broadest sense it deals with all physical, chemical, meteorological, and biological conditions pertaining to such a body of water. Palaeolimnological methods allow the incorporation of long time scales into an analysis from which conclusions may be drawn regarding the sequence of change and the rates of change in the evolution of a lake and its watershed. The Glenora site in the Bay of Quinte represented an ideal location to test the limits of the methodology as most of the principal variables could be verified.

The Chironomidae (Diptera), a family of nonbiting midges, were chosen as the prime biological index for this study, because the family is large and members occupy virtually every type and condition of aquatic habitat. The extraordinary ecological range and sensitivity of the Chironomidae make it possible to interpret changes in aquatic environments with a high degree of resolution. The composition and relative abun-

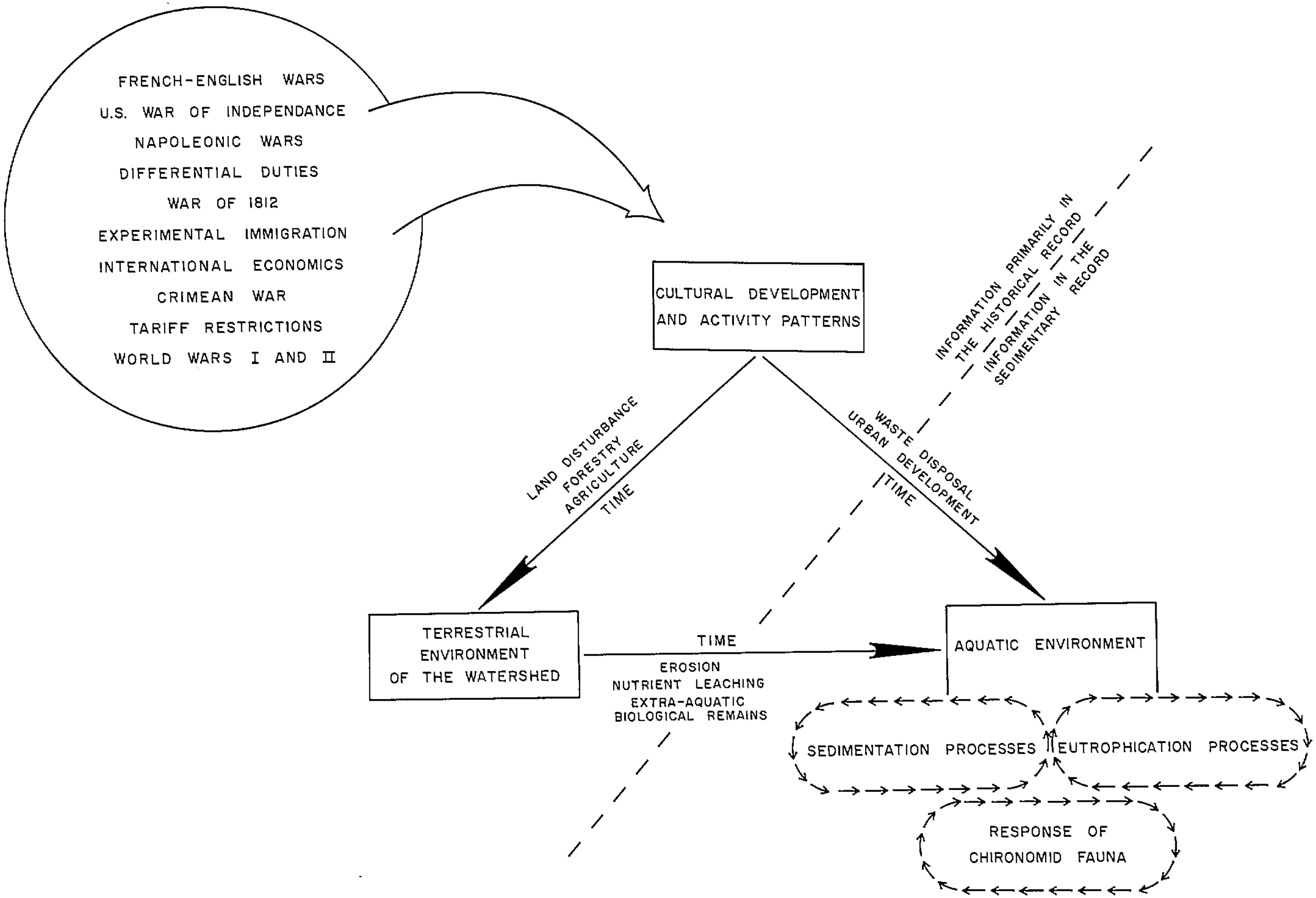

FIG. 1. Schematic summary of the major processes influencing the Bay of Quinte and surrounding watershed.

dance of the indigenous chironomid fauna change in response to changes in oxygen supply, food availability, temperature, and sedimentation regime. In turn, these changes are reflected in the yearly increment of chironomid remains, primarily the chitinous head capsules of the larvae, to the sediments.

Usefulness of the chironomid fauna in classifying the trophic state of lakes has generally been related to their specific difference in tolerance to low oxygen concentrations. The basic works of Thienemann (1913: 245; 1915: 22; 1922: 642; 1931: 70) and later Brundin (1949: 878; 1956: 192; 1958: 289) defined the trophic status of lakes according to the species of chironomids living in the profundal zone. Brundin (1958: 291) predicted that the lake-type system developed in Europe using chironomid communities as indicators of trophic status would have worldwide validity. Most recently, Sæther (1975b: 3130) developed a comparable lake-type system based on North American fauna. The two systems are outlined below:

	Europe (Brundin 1949, 1956)		North America (Sæther 1975b)
Harmonic lakes			
I	*Heterotrissocladius subpilosus* — lakes	I	*Heterotrissocladius oliveri* — lakes
II	*Tanytarsus lugens* — lakes (with *Heterotrissocladius grimshawi* or *H. scutellatus*)	II	*Tanytarsus* sp. ? — lakes (with *Monodiamesa tuberculata* and *Heterotrissocladius changi*)
II/III	*Stictochironomus rosenschoeldi* — lakes	II/III	*Chironomus atritibia* and *Phaenopsectra coracina* — lakes
IIIa	*Chironomus anthracinus* — lakes	IIIa	*Chironomus decorus* — lakes
IIIb	*Chironomus plumosus* — lakes	IIIb	*Chironomus plumosus* — lakes
Disharmonic (Dystrophic) lakes			
IV	*Chironomus tenuistylus* — lakes (with *Zalutschia zalutschicola*)	IV	*Chironomus* sp. ? — lakes (with *Zalutschia zalutschicola*)

Lundbeck (1936: 294–296) theorized that throughout its life history a lake would pass through the same succession of chironomid communities as normal lake-type succession proceeded.

Initially, the principal objectives of this Bulletin were to determine if significant changes had occurred in the succession of chironomid remains in the core sediments, in terms of lake-type succession, and to determine whether these changes were associated with changes in the trophic status of the Bay of Quinte. More specifically, (1) were the changes in the chironomid community structure connected with the development of European culture in the immediate area around the bay, (2) did chironomid succession in the sediments follow the same orderly sequence of events as the classical succession from oligotrophy to eutrophy, (3) was the time scale of the sequence of succession accelerated by culturally induced eutrophication, and, if so, (4) did the acceleration obliterate evidence of some stages in the succession, (5) was the influence of pollutants exerted on the chironomid communities indirectly through depletion of oxygen, or was the influence more direct, and (6) was the effect of cultural eutrophication reversible? As the study progressed it became apparent that these objectives were overly simplistic and that the sedimentary record contained a great deal more information than required to meet the original objectives. Important relationships that emerged as the study progressed were: (1) other earlier cultures, especially Hopewellian and Iroquoian, also influenced conditions in the bay and its watershed, (2) activities in the more distant parts of the watershed were discernible in the sedimentary record, as well as those in the more immediate vicinity of the bay, and (3) the rate and type of sedimentation had a major direct effect on the chironomid fauna that in many cases was more important than the effects of changes in trophic conditions in the bay.

As indicated in Fig. 1, the information required was primarily in two sources, the historical record and the sedimentary record. The principal lines of investigation are summarized in Table 1. Historical information in the written record was first correlated with the sedimentary record, to establish a detailed chronology of the sediments at different levels in the core. Once this was done, a variety of physical measurements on the sediments provided information on sedimentation processes, while chemical analyses and fossil analyses provided the basis for assessment of trophic

TABLE 1. Summary of procedures adopted to assess impact of the major factors influencing aquatic environment of the Bay of Quinte.

Study aspect	Analytical approach	Purpose of information
Historical chronology	Documentary	Historical enumeration of population growth and development Historical account of population activity patterns influencing the terrestrial and aquatic environments
Sedimentary chronology	*Ambrosia* pollen Cesium-137 Lead-210 Carbon-14 Erosion Index	Establishment of the geochronology of sediment stratigraphy
Sedimentation	Textural parameters	Assessment of the characteristics of the sediment depositional environment
	Sediment accumulation	Quantification of sediment accumulation; a measure of gross sediment stratigraphy
	Sediment density Mineral content Sediment porosity Water content	Measurement of bulk sediment and sediment compaction characteristics
Eutrophication	Total carbon Organic carbon Organic matter Inorganic carbon Total nitrogen Total phosphorus	Assessment of changes in trophic status using sediment chemical parameters as indices of cultural eutrophication
	Chironomidae fauna	Assessment of changes in trophic status using biological indices

conditions at the time the sediments were deposited. Once these pieces in the puzzle were defined, it was possible to unravel and assess some of the more important impacts of man on this bay and its watershed.

Man, especially European man, has had, and is having, a profound impact on the Bay of Quinte and its watershed. Detailed documentation of the magnitude of these impacts is probably one of the more significant results of this study. Prehistoric cultures such as the Hopewellian culture, which thrived some 2000 yr ago, and the Iroquoian culture, which occupied the area from around 1000 to 1650 A.D., clearly influenced processes in the watershed and bay; however, their impact on the aquatic fauna was minor compared to what has occurred since the arrival of European settlers. The aquatic fauna, as represented by the chironomid fossils, underwent a profound adjustment during the past 300 yr. For the 2000 yr prior to the arrival of Europeans, the fauna remained remarkably stable and was characteristic of relatively undisturbed oligotrophic conditions. In contrast, the present fauna consists only of forms that are tolerant of eutrophic conditions. Another disturbing aspect is that the incidence of severely deformed fossil remains increased markedly in the most recent sediments. Although the cause of these deformities has not been confirmed, the evidence indicates that such deformities usually occur where toxic contaminants are present in the environment.

In general, the response of the chironomid fauna followed the accepted theories of faunal response to eutrophication; however, in this case the sedimentation processes compounded and at times overshadowed the impact of eutrophication. A review of previous work further indicates that the direct effects of sedimentation processes on the chironomid fauna may be of more general significance than previously suspected.

As the study progressed it became apparent that all palaeolimnological techniques were not equally applicable. By necessity, a major part of the study consisted of a detailed evaluation of palaeolimnological techniques, both individually and in combination. No single technique was sufficiently accurate and all encompassing to draw definite conclusions; however, when used in combination, they did provide a powerful, high-resolution method of assessing the long-term impact of man on a lake–watershed ecosystem.

1.2 The Study Area

1.2.1 MORPHOMETRY AND PHYSIOGRAPHY OF THE BAY OF QUINTE

The Bay of Quinte, located on the northeastern shore of Lake Ontario between the mainland and Prince Edward County peninsula (Fig. 2), is a complex, Z-shaped bay, 86 km long from the eastern entrance of Murray Canal to Point Pleasant (Indian Point). The inner arm of the bay, 48 km long, consists of a series of connected basins ranging in depth from 3.7 to 7.6 m and varying in width from 0.6 to 4.5 km. The middle arm, designated Long Reach, is 16 km long, ranges in depth from 5.8 to 17 m, and varies in width from 0.8 to 5.6 km. The outer arm of the bay, designated Adolphus Reach, is 22 km long, ranges in depth from 17 to 52 m, and varies in width from 0.8 to 3.2 km. An additional arm, Hay Bay, extends 16 km eastward from the middle arm, ranges in depth from 1.7 to 7 m, and varies in width from 0.8 to 3 km. The outer end of the Bay of Quinte exits into Lake Ontario by two passages at either end of Amherst Island. The western passage, designated Upper Gap, is 3 km wide and 25 m maximum depth, whereas the eastern passage, designated Lower Gap, is 3 km wide and 33 m deep. The total surface area of the Bay of Quinte is 254 km^2.

Most of the drainage into the Bay of Quinte comes from the north shore of the inner arm by way of four rivers (Fig. 3). Of these, the Trent River is the most important, draining 12,600 km^2. The Moira River drains 2700 km^2 and the Salmon and Napanee rivers collectively drain 1660 km^2. A number of smaller creeks lead into the bay, but their drainage area is limited. The total area of the Bay of Quinte watershed is 18,200 km^2.

Headwaters of the main rivers draining into the Bay of Quinte arise in the Precambrian Shield, but traverse limestone and clay plains over much of their course. The soils overlying the limestone base are very shallow; in large areas of the Napanee River plain, soils are only a few centimeters deep (Chapman and Putnam 1951: 229). However, soils of the clay plains of the lower Trent watershed are considerably deeper and more extensive.

Prince Edward County, which forms one shore of the Bay of Quinte, is a flat plateau of Ordovician limestone tilting into Lake Ontario from northeast to southwest. Cliffs on the uplift side rise to 52 m in the Picton–Glenora area and shield Picton Bay, Adolphus Reach, and parts of Long Reach from the prevailing southwesterly winds. The southwesterly shoreline of Prince Edward County slopes gently into Lake Ontario.

1.2.2. HISTORY OF THE BAY OF QUINTE REGION

The Bay of Quinte has strongly influenced the development of primitive and modern civilizations in southern Ontario. Since early man became aware of its existence, the terminus of the Bay of Quinte and the Trent River system has been a vital crossroad for waterborne traffic. Travelers from the eastern end of Lake Ontario, who used the sheltered waters of the bay to avoid treacherous shoals off the south shore of Quinte's Isle, could continue along the north shore of Lake Ontario by portaging at Ancient Carrying Place or, alternatively, pass into the interior to Georgian Bay and the upper Great Lakes via the major waterway of the Trent system. Besides the facility the Trent system afforded for easy travel to the interior, the area through which it passed was highly desirable for agricultural purposes. The fertile southern plains were well suited for development of the agricultural methods of primitive societies and, later, their more modern counterparts. The more northerly shield areas, also easily accessible by the Trent system, provided valuable hunting and fishing grounds. The facility of movement and suitability of the area made the Bay of Quinte region a natural setting for the development of primitive, and then more modern, societies.

1.2.2.1 Cultural periods — Within the time frame of interest, three aboriginal and two European cultures were resident in the area (Warwick unpublished data). The earliest, the Hopewell culture, flourished some 2000 yr ago. An extensive culture that traded widely throughout North America, the Hopewell were responsible for the extensive earthen figures, believed to be of religious significance, in the immediate area of Rice Lake, Ont. After the Hopewell culture, the area was inhabited by small numbers of nomadic Algonkian. A considerably more primitive people, the Algonkian were eventually displaced by the culturally more-advanced Iroquois. Developed in stages of increasing sophistication between 1000 and 1650 A.D., the Iroquois culture in southern Ontario ultimately evolved into the historic Huron, Petun, Neutral, and Erie tribes. Estimates by French priests place the total population of the four tribes at 60,000 in mid-17th century. An advanced semisedentary culture with a highly organized functional system of society, religion, and government, the southern Ontario Iroquois were destroyed or dispersed in 1649–50 by tribes, also of Iroquoian origin, from the south side of Lake Ontario.

French presence in the Bay of Quinte area was closely governed by the ebb and flow of war-

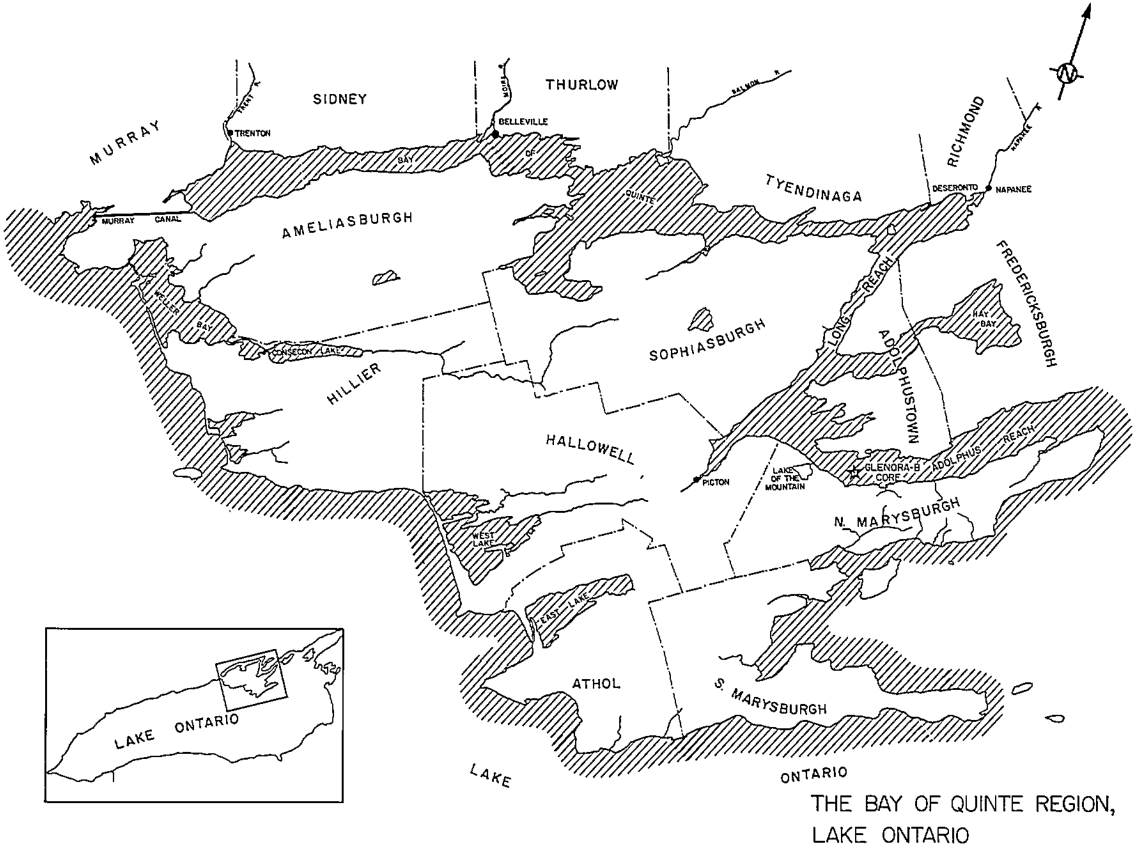

FIG. 2. The Bay of Quinte region, indicating the Glenora core site.

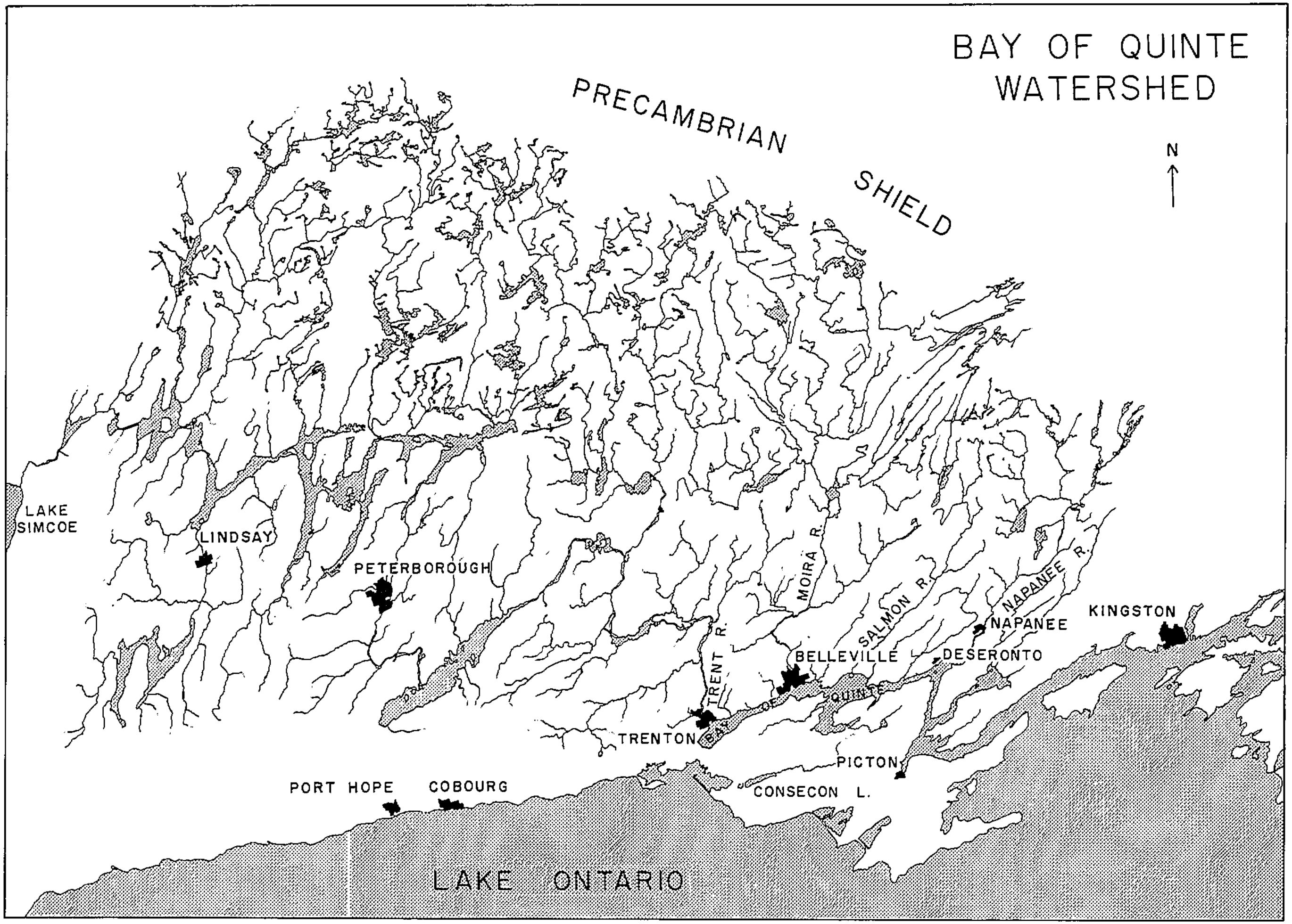

FIG. 3. The Bay of Quinte watershed including major population centers.

fare to gain control of the lower Great Lakes region. Their tenure falls into three distinct periods: the period between 1669 (when the Sulpician Mission was built on Quinte's Isle) and 1682 (when it was finally abandoned); the period of uneasy peace in the first half of the 18th century (when desultory fur-trading activity was conducted), and the period of intense military activity just prior to the fall of Fort Frontenac in 1758 and, ultimately, the French regime in Canada 2 yr later. At no time in their tenure were the French resident in the area in large numbers.

British colonization began dramatically in 1784, with the arrival of 1814 United Empire Loyalists in the area immediately around the lower end of the Bay of Quinte. Growth of the Adolphustown colony was slow initially, but population rose steadily after the War of 1812, increased rapidly after 1838, and reached a maximum in the 1860s. A population decline phase followed that lasted until the turn of the 20th century. The revitalization in population growth since that time has been closely linked with the shift from a rural, agrarian society to an urban, industrialized society.

1.2.2.2 Agricultural practices — Agriculture was practiced extensively by the Hopewell and Iroquois cultures. The Iroquois in particular depended heavily on the cultivation of maize, beans, and squash as their primary food source and their large populations dictated the clearing of extensive acreages of agricultural land for support. The required land was cleared by felling trees, piling brush around the stumps, and burning them. The land-clearing process had to be repeated frequently because native-type agriculture quickly exhausted the soil.

The French did not engage extensively in agriculture in the Bay of Quinte area. The Sulpician Mission cleared land for planting corn, wheat, pot-herbs, and watermelon in an attempt to become as self-sufficient as possible, but the mission's limited tenure precluded any serious agricultural development.

Agricultural activity in the British colonies developed slowly while only primitive land-clearing methods like those used by the Iroquois were available, but proceeded much more rapidly as cleared land became available in the wake of large-scale lumbering operations. The fact that a large proportion of the land cleared by an unbridled lumber industry was unsuitable for agriculture in the first place, coupled with the poor agricultural practices of the early farmer, led to the rapid exhaustion of the soils. This, in turn, proved responsible in large measure for the dramatic decline in population after the 1860s as the land was progressively abandoned. The realization that, in spite of improved methods, soils of much of the area remain unsuited to agriculture has probably been a contributing factor leading to urbanization of the area in recent years.

1.2.2.3 Forestry practices — Development of the trade in forest products proceeded in five distinct phases (Warwick unpublished data). The initial land-clearing activities of the early settlers produced large quantities of high quality ash that were marketed for a variety of uses and provided many settlers with their first cash crop. The square timber trade, an industry of the first magnitude, was initiated by an oak shortage in the Royal Navy in 1804–05, followed by a drastic shortage in all naval timber in 1808–09 when Napoleon's Continental System closed the Baltic Sea. Denied access to traditional sources of timber, the existence of the Royal Navy, and ultimately Great Britain's ability to resist Napoleon, were threatened. The British parliament reacted by instituting a system of Differential Duties that made it economically feasible to ship Canadian timber products to Great Britain. The square timber trade was created virtually overnight and lasted well beyond 1846 when the last of the duties was finally rescinded. The American lumber trade, an offshoot of the square timber trade, developed slowly after 1835 as American markets opened up, but was transformed in 1851 when large American firms were allowed into Canada to harvest timber for the first time. These firms crossed over Lake Ontario, rapidly stripped the entire area of southern Ontario of its finest pine stands, then crossed into Michigan in the 1860s. The vast, desolated, stump-filled regions left behind attested to the ruthlessness of the trade. In the wake of large lumber firms, small Canadian manufacturing firms sprang up. A trade in manufactured wood products was fostered which first supplemented, then supplanted the lumber industry, as stocks of timber suitable for lumber declined. The pulp and paper industry began in 1892 after lumber grade timber stocks were exhausted. Based on stocks of smaller timber and second growth, activity in the pulp and paper industry in the area lasted until the 1950s.

1.2.3. Evidence of Recent Cultural Eutrophication

Interest in the changing limnological conditions in the Bay of Quinte is a recent phenomenon. According to McCombie (1967: 37), the alarming decline in the catches of lake whitefish and walleye triggered concern that the Bay of Quinte may have become eutrophic to the point where it was no longer suitable for game and commercial fish species. By the early 1950s, fishermen in the Bay of Quinte began to complain of gillnets fouled by algal slimes. Hurley and Christie (1977: 1851) stated that the bay has been subjected to cultural eutrophication in increasing degrees since the 1950s. However, these authors stated that the role of changing limnological conditions in alterations to fish communities in the Bay of Quinte was difficult to quantify, and maintained that no absolute causal relationships between eutrophication and changing fish species could be inferred. Christie (1973: 48) documented the chronology of successional changes in the fish communities of the bay and Lake Ontario.

Evidence of accelerated cultural eutrophication in the Bay of Quinte has been apparent only from the mid-1940s, when Tucker (1948: 380) carried out the first examination of the phytoplankton population at a deepwater station in Adolphus Reach off Prinyer Cove (near the tip of Point Pleasant). He found that Bay of Quinte waters contained the same major suite of plankters as Lake Erie. McCombie (1967: 39) examined the phytoplankton communities at stations in the inner, middle, and outer arms of the bay. He demonstrated that a definite trophic gradient existed in the bay; phytoplankton concentrations in the inner bay were about 10 times greater than those in the middle bay and 100 times greater than those in the outer bay at its mouth. However, McCombie stated that, although his 1963 and 1964 data suggested an increase in phytoplankton concentrations when compared to Tucker's 1945 data, the evidence was inconclusive. Hurley and Christie (1977: 1852) presented data that show the phytoplankton population is dominated by blue-green algae and diatoms, and that average concentrations of these have consistently and substantially increased since 1945.

Hurley and Christie (1977: 1851) stated that aquatic macrophytes were more abundant and more widely distributed in the bay in the 1880s than they are now (Macoun 1888, quoted by Hurley and Christie). Macrophyte distribution has become even more restricted to small inlets and creek mouths since 1959. At present, the only common species is the Eurasian milfoil, *Myriophyllum spicatum* (Bristow et al. 1977: 467). According to Hurley and Christie, increased primary production reduced water transparency, which resulted in reductions of aquatic macrophytes and the transition to either emergent types or those that begin growth early in the year before light penetration becomes critical.

Johnson (1970: 76) and Johnson and Brinkhurst (1971a: 1683; 1971b: 1699; 1971c: 1715) carried out a detailed and comprehensive study of the benthic macroinvertebrate communities of the Bay of Quinte. On the basis of critical community analysis, they divided the bay into three discrete communities: the inner–middle bay, Adolphus Reach–Prince Edward Bay, and deepwater Lake Ontario. The macroinvertebrate fauna in the Bay of Quinte was homogenous between Trenton and Picton Bay (with some departure noted at the latter location). The second community occurred below Glenora and extended into Prince Edward Bay. The deepwater Lake Ontario community represented a distinct community type. Some semblance to the first, or inner–middle bay community type, was detected in upper Adolphus Reach, whereas the community of lower Adolphus Reach had many characteristics in common with the deepwater Lake Ontario community. Johnson (1970: 76), cautioned, however, that the second community type should not be considered transitional between the first and third, because it contained numerous species not found in the other community types.

Of greatest interest to the present study is the point of junction between the first community type, typified by a distinct chironomid association characteristic of eutrophic conditions, and the second community type, typified by an association of sphaeriids, oligochaetes, chironomids, and crustaceans characteristic of mesotrophic conditions. The two distinct communities, the inner–middle and the outer, were joined by a transitional zone extending from Thompson Point to Allen Point. Johnson (1970: 23, 77, fig. 10) established one of his four major sampling stations, the Glenora station, in the middle of this transitional zone. The cores for the present study were taken from this location.

A brief survey of the dominant types in the macroinvertebrate community defined by Johnson (1970: app. B, tables 5–8) include: *Chironomus attenuatus* group (probably including *C. anthracinus* and *C. attenuatus), C. plumosus, C. atritibia, Procladius denticulatus* group (probably including *P. denticulatus* and *P. freemani), Tanytarsus* sp. *C.* (not figured), *Tubifex tubifex, Potamothrix bavaricus, Limnodrilus hoffmeisteri, Pisidium casertanum, P. henslowanum, Asellus militaris, Gammarus fasciatus, Pontoporeia affinus,* and *Valvata piscinalis*. Johnson (1970: 43) recorded the lowest oxygen concentrations at depth (3.1 mg·l^{-1}) in September before fall overturn began. Similar conditions persisted through 1972, 1973, and 1974 (D. A. Hurley personal communication). From sedimentation trap studies

Johnson (1970: 45) calculated that the Glenora sediments received 1.48 g solids$\cdot m^{-2}\cdot day^{-1}$. Of this, 0.42 g (28%) was organic matter. The calculated sedimentation rate was 0.504 $mm\cdot yr^{-1}$. The mean diversity index for the benthic macroinvertebrate community was 3.14 with a range of 2.59–3.66.

2. METHODS

2.1 Coring Operations

Three cores were taken through the ice at Johnson's (1970) Glenora station, approximately 2960 m down channel from the Glenora Fisheries Station. Core site coordinates were 44°02.6′ N, 77°01.2′ W. Position references by sextant are recorded counterclockwise in Table 2 and shown in Fig. 4.

The three cores taken at the site were spaced in an equilateral triangle, 11 m to the side. Ice cover was 66 cm. Average water depth was 22.3 m.

Cores were taken with a modified Mackereth (1969) short core sampler redesigned to take a core 2 m in length and 7.30 cm in diameter. A 20.32-cm horizontally flanged skirt was attached midway on the anchor chamber, and sufficient polystyrene floats were attached to the top of the corer to attain just slightly negative buoyancy. Both latter modifications were incorporated to prevent undue displacement of the loose surficial sediments at the core site by the weight of the corer.

The modified Mackereth corer was lowered through the ice from a high-lift tripod to a predetermined depth (5 m above the bottom sediments), then inched down until the bottom was reached, to prevent hydraulic shock disturbance to the fragile surficial sediments from the large anchor chamber of the instrument (Brinkhurst 1967: 1; Flannagan 1970: 1696; Davis 1974: 467). High-pressure air was bled very slowly into the corer to minimize sediment distortion on barrel penetration. The retrieved cores were capped and transported vertically to the Glenora Fisheries Station for sectioning. Extreme care was taken not to disrupt the fragile upper sediment surface layers during transportation. All cores were color described (Appendix 1) and sectioned within 24 h of retrieval.

The cores were sectioned at 1-cm intervals. Sectioning proceeded in two phases. The watery surficial sediments were extruded upward into a retaining collar the same diameter as the core barrel. A fine brass shim knife was then passed between the retaining collar and the core barrel to sever the section. This procedure was used until the sediments became sufficiently compact (6 cm deep) to obviate the need for the retaining collar. Succeeding sections were extruded free, the outer smear zone carefully removed, and the section severed with the knife. Each sample was independently sealed in a plastic bag.

2.2 Core Chronology

The three cores were first compared to establish whether they were representative of the sedimentary record at the core site, and to select the best core for more detailed analysis. The three methods used were: (1) color comparison of the core stratigraphy (Appendix 1), (2) comparison of the depth of the *Ambrosia* (ragweed) pollen rise in the three cores, and (3) comparison of the depths of occurrence of a band of ferromanganese micronodules.

TABLE 2. Position references by sextant for Glenora core site (17/3/72).

Position reference	Reference description	Degrees (line of sight)
1	280-ft main chimney of Portland Cement Co. Ltd. (directly up channel toward Picton, Ont.; highest projecting structure in plant complex)	
		14°26′
2	Church steeple (denomination unknown) at Lake-on-the-Mountain, Ont.	
		94°32′
3	West roof peak of residence due south of core site	
		195°29′
4	West roof peak of prominent old barn on north shore	
		55°33′
1	as above	

Five chronological techniques (Table 3) were used to establish the chronology of the Glenora-B

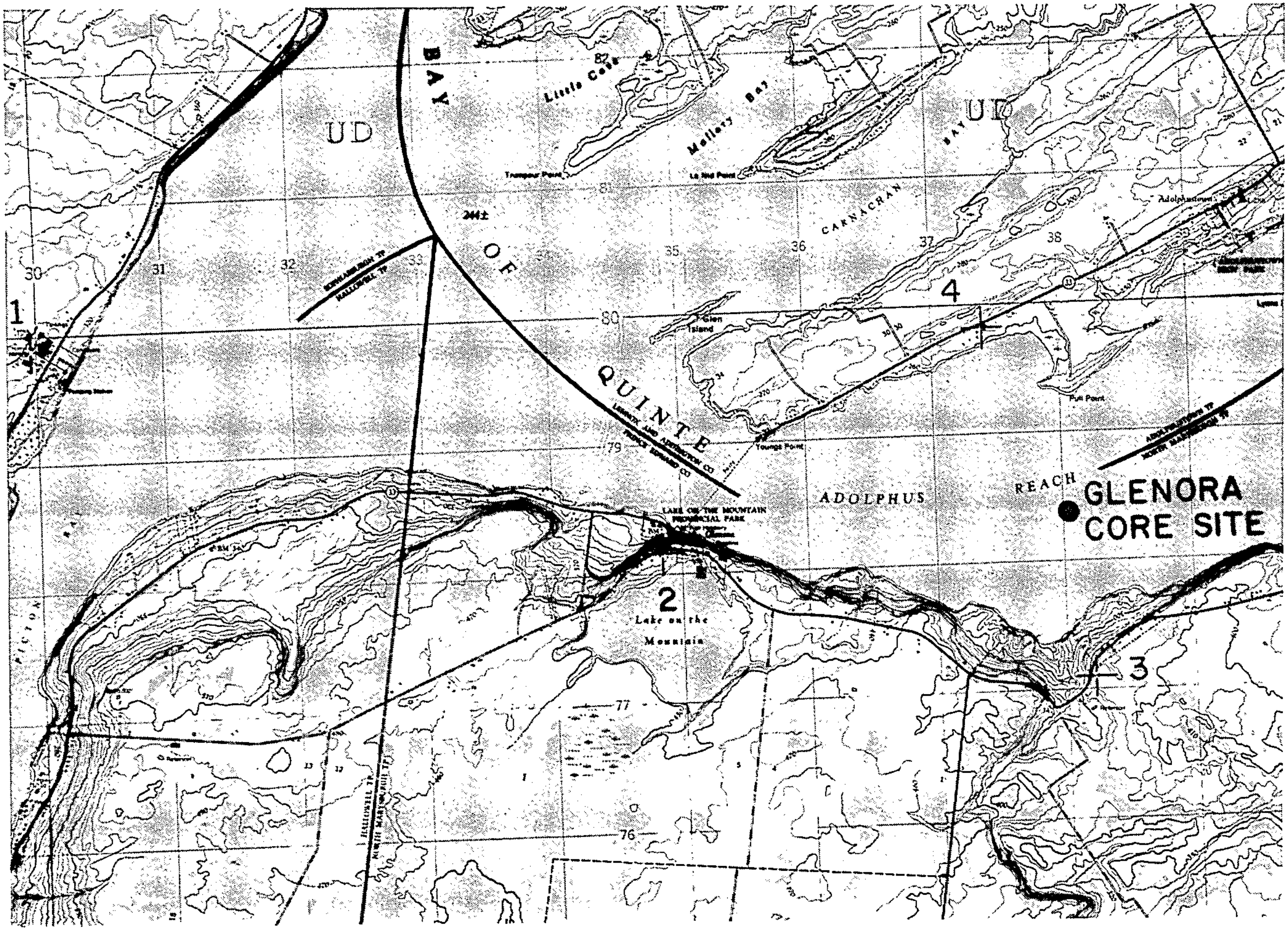

FIG. 4. Topographic map of the Glenora-B core site including sextant reference points. Sextant reference points are labeled counterclockwise.

core sediments (Appendix 1). The *Ambrosia* pollen rise, which was established at 1849 ± 5 yr by McAndrews and Boyko (1972: 1–2) for southern Ontario, was located in the core. This reference point was used to center the age scale developed from the measurement of lead-210 in the sediments. An Erosion Index based on physical sediment data was then used in conjunction with historical documents, to verify the sequence of dates established by the first two techniques, and to extend the chronology beyond the technical limits of the lead-210 method. The older sediments were dated by centering the age scale determined by carbon-14 measurement on the sequence established from the other methods. The process is iterative and in the final analysis all relevant data, whether historical, biological, chemical, or physical, were used and compared to establish the core chronology as precisely as the methodology would allow.

Because *Ambrosia* prefers disturbed soils exposed to sunlight and rendered unstable through erosion processes (Boyko unpublished data), the presence of *Ambrosia* pollen in lake sediments is interpreted as an indication of the physical disturbance of soils within the area. Bassett and Terasmae (1962: 148) and McAndrews (1972: 223) similarly related the sudden rise in *Ambrosia* pollen concentrations in recent lake sediments in southern Ontario to settlement by Europeans, removal of trees in favor of large agricultural development, and the resultant provision of numerous disturbed habitats.

The use of cesium-137, a fallout by-product of nuclear weapon detonations, as a chronological tool stems from the sequence of its deposition from the atmosphere into the sediments. The initial deposition in the sediments is correlated with the detection of significant amounts of cesium-137 in the atmosphere for the first time in 1954 (Pennington et al. 1973: 324; Hubbard and Striffler 1973: 1440). Atmospheric fallout increased to a distinct peak in 1959, but maximum fallout was recorded in 1963 during the 1961–64 weapons testing period (Schreiber et al. 1968: 57; Ritchie et al. 1973: 254; Pennington 1973: 368; Robbins and Edgington 1975: 298). Cesium-137 fallout reached a minimum in 1967–68 during the moratorium on testing, but has increased again in recent years with the resumption in nuclear weapons testing (Hardy 1971: app. C; 62–69). Detection of this deposition pattern in the sediments can theoretically provide a valuable index to the chronology of the most recent sediments.

Lead-210, a member of the uranium-238 radioactive decay series with a half-life of 22.26 yr, enters the sedimentary cycle through a series of natural events. Radon-222, a radioactive gas and precursor of lead-210, diffuses out of the earth's crust after formation from its parent, radium-226. Radon-222 decays in the atmosphere through a series of short-lived intermediate nuclides and is

TABLE 3. Summary of significance and applicability of chronological methods used to date Glenora-B core sediments.

Chronological method	Theoretical significance	Significance and applicability to present study
Ambrosia pollen	Indicator of land disturbance, primarily post-European; no time limit	Historic sequence of land disturbance and land abandonment in the watershed; stratigraphic marker in core correlation
Cesium-137	Nuclear detonation fallout product beginning in 1952; peak input to sediments in 1959 and 1963–64	Limited chronological value; subject to diffusion under certain conditions
Lead-210	Natural U-238 isotope with constant atmospheric input; useful for time periods in the order of a century	Very accurate chronological tool if the anomalous zone in the surface sediments can be avoided; otherwise usefulness severely restricted
Carbon-14	Natural carbon isotope incorporated in normal photosynthesis	Reasonably accurate in older sediments, but must be used with great care in most recent sediments
Erosion Index	Indicator of periods of land disturbance; no time limit; measure of fine sediment stratigraphy	Very sensitive monitor of periods of land disturbance by human activity, even at considerable distances. Verification index for chronologies established by other methods; requires extensive knowledge of human activity patterns for use

removed as lead-210 by natural atmospheric precipitation. The measurement of lead-210 has been shown by a number of authors (Goldberg 1962: 123; Krishnaswamy et al. 1971: 407; Koide et al. 1972: 442; 1973: 1186) to be a useful time clock for geological processes with time spans in the order of a century.

The use of carbon-14, a natural radioactive isotope produced by cosmic ray activation of nitrogen in the atmosphere, is based on changes in the C^{14}:C^{12} ratio in materials of primary biological origin. The isotope and the normal carbon atom are incorporated in plant photosynthetic processes in near-constant proportion. As the materials age, however, the C^{14}:C^{12} ratio alters as a result of the decay of the isotope. The carbon-14 method is useful in aging detrital organic materials incorporated into the sediments tens of thousands of years ago.

The Erosion Index is based on the physical measurement of sediment grain size and is defined as the fraction of clay-sized material finer than 10.50 ϕ[1] divided by the total clay-sized fraction ($>$ 8.5 ϕ). The index was developed on the premise that, in the sedimentary record, one of the earliest manifestations of the presence of man would be fine mineral sediment material introduced into the aquatic environment, in contrast to the coarser silt-size materials produced in the water column through normal metabolic processes and deposited in the sediments. In comparison with the radio–chronological techniques, there should be no time limit on its usefulness because it is a physical process.

2.3 Physical Characterization of Sediments

Techniques selected for the physical characterization of the sediments are summarized in Table 4. Taken together, the techniques (Appendix 1) provide information about (1) hydraulic conditions controlling the deposition and accumulation of sediments at the core site, (2) type, source of origin, and distance the sediments were transported in the hydraulic medium, (3) changes in the physical and chemical properties of the sediments, and (4) amount and intensity of the accumulation of sedimentary material.

The use of grain size analysis, the physical measurement of constituent sediment grains, and their quantification (expressed as percent) into half phi-size categories, stems from the knowledge that the composition and texture of a sediment are inherited from its source material and modified by the agents of transportation and mechanisms of deposition. Grain size analysis not only measures changes in the physical characteristics of sediments, but also provides vital information on the hydraulic energy at the deposition site. This information is necessary in assessing suitability of the site for the stable accumulation of sediments and provides insight into the sensitivity to be expected in the sedimentary record.

The Erosion Index is also based on the physical measurement of sediment grain size. As a textural parameter, the sensitivity of the index to chronological events provides a reasonably accurate estimate of the type and source of origin of sedimentary material accumulating at any given time, and the distance between the source and deposition site. This, in turn, allows an estimate of the efficiency of the hydraulic sorting that the sediment material has been subjected to during transportation to the deposition site.

Moment measures, also based on the physical measurement of sediment grain size, may be regarded as a set of interrelated statistical parameters whose variations provide an insight into changes in the physical characteristics of the sediments, the distance sediments have been carried to the deposition site, and depositional characteristics of the sedimentary environment.

Water content, the volume of water contained per unit volume of fresh sediment, provides an index of sediment compactness by measuring the porosity or spatial volume between sediment particles. Because water content or porosity is directly related to the type and composition of sedimentary material, and depth and weight of the overlying sediments contributing compressive stress to the sediment profile, the measure provides an insight into these factors as well. Theoretically, a knowledge of the rate of sediment compaction can be useful in correcting sediment age profiles compressed by accumulating overburden pressure.

Sediment density, the weight of dry sediment per unit volume of fresh sediment, provides a measure of the bulk characteristics of sediments, including both organic and inorganic fractions. Sediment density is directly related to sediment type and composition, and is modified by the effects of material breakdown and compaction forces. Theoretically, sediment density data can be useful in correcting sediment age profiles in a manner similar to that employing water content.

The calculation of sediment accumulation, the product of sedimentation rate times sediment density, provides a direct measure of the impact of

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[1] The phi notation is defined as $\phi = -\log_2$ of the diameter in millimeters (Inman 1952: 126).

TABLE 4. Summary of significance and applicability of sediment measurements used to characterize Glenora-B core sediments

Sediment measurements	Theoretical significance	Significance and applicability to present study
Grain-size analysis	Measure of physical characteristics of sediments	Sensitive measure of changes in sediment physical characteristics; coarse ferromanganese micronodule/sand grain horizon provides important secondary stratigraphic marker
	Indicator of hydraulic conditions at core site	Sensitive indicator of suitability of core site hydraulic conditions for unbiased sediment accumulation
Erosion Index	Measure of fine sediment stratigraphy; indicator of periods of land disturbance	Sensitive; provides reliable estimate of source and distance of origin of erosion products entering deposition cycle at core site through relationship with chronological sequences and human activities
Moment measures	Measures of depositional characteristics at core site	Sensitive measure of hydraulic energy at core site, sensitivity primarily a function of mean grain size; index of distance of origin of erosion materials depositing at the core site
Water content	Index of sediment compaction	Measure of compactness or porosity of sediments; measure of water holding properties of different types of accumulating sediments
Sediment density	Measure of bulk sediment, both organic and inorganic	Gross measure of sediment qualitative changes; inversely related to water content measures
Sediment accumulation	Measure of gross sediment stratigraphy	Indicator of intensity of disturbance in watershed
Mineral content	Measure of inorganic sediment fraction	Crude measure of qualitative changes in sediment composition
Loss on combustion	Measure of total calcium and magnesium carbonate carbon in sediments; by LOC method	Limited value
Carbon (inorganic)	Measure of total calcium and magnesium carbonate carbon in sediments; by GSP	Accurate measure of carbonate carbon in sediments; measure of sediment qualitative changes
LOC:GSP	Not previously established	Crude measure of sediment clay content

erosion processes on the aquatic environment. The measure is a direct function of the intensity of the disturbance introducing sedimentary material to the aquatic system, and the distance the disturbance occurs away from the deposition site. Therefore, the measurement of sediment accumulation can serve as an indicator of the intensity of watershed disturbance if, as in the present study, the distance factor can be deduced from chronological and fine sediment stratigraphy data.

Mineral content, an ignition measure of the weight of dry mineral sediment per unit volume of fresh sediment, provides a direct measure of the inorganic sediment fraction. This measure is useful in defining changes in sediment composition and assessing the influence of the mineral component on the mobility of chemical elements and the responses of the biological community.

The carbonate carbon fraction was measured by two methods. Loss on combustion (LOC)[2], defined as the percentage weight loss at 950–1000°C (termed additional loss on ignition by Frey 1960: 687) was used initially as it is considered a reasonable measure of carbonate carbon, either calcium or magnesium, in sediments where the clay mineral fraction is small (Mueller 1964: 14; DeCosta 1968: 401). In sediments con-

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[2] The term loss on combustion (LOC) has purposely been used to avoid the plethora of terms assigned to this index in the literature. Although perhaps not technically accurate, it is sufficiently distinct to avoid confusion with loss on ignition determined at 550°C.

taining a significant clay fraction, however, the measure is exaggerated by the loss of water of hydration from the clay mineral fraction. Therefore, inorganic carbon, C_I, was additionally measured by Stainton's (1973: 1441) gas stripping procedure (GSP), to compensate for the known presence of significant amounts of clay minerals in the Bay of Quinte sediments. The relationship between LOC and inorganic carbon (GSP), which reflects the exaggeration effect of the loss of water of hydration under these circumstances, provides a crude measure of sediment clay content. The measurement of carbonate carbon provides a measure of qualitative change in the sediments.

2.4 Chemical Characterization of Sediments

The parameters that were measured (Appendix 1) to characterize the chemistry of the sediments are summarized in Table 5. The primary objective of the chemical characterization was to provide an index to changes in the trophic status of the Bay of Quinte as a result of cultural eutrophication. The parameters measured were to provide (1) a measure of aquatic productivity through the organic material balance in the sediments, and (2) a measure of the quality of the sediments with regard to the nutritional value of organic materials available as food to benthic communities.

The organic content was determined by two methods to provide a measure of aquatic productivity. Loss on ignition at 550°C is understood by a number of authors (Allgeier et al. 1932: 449; Twenhofel and Broughton 1939: 235; Hansen 1959: 40; Frey 1960: 687; Goulden 1964a: 3; Deevey 1969: 58) to be a reasonably accurate expression of organic matter content in sediments. However, Deevey (1955: 300) and Mackereth (1966: 172) expressed grave reservations about the accuracy of the method in sediments where clay

TABLE 5. Summary of significance and applicability of chemical parameters used to characterize Glenora-B core sediments.

Chemical parameter	Theoretical significance	Significance and applicability to present study
Carbon (total)	Measure of aquatic productivity; index of cultural eutrophication: by CHN analyzer	Limited characterization value; concentrations variably influenced by mineral sediment dilution
Carbon (inorganic)	Measure of carbonate carbon, both calcium and magnesium, in sediments; by GSP	Accurate measure of carbonate carbon in sediments; measure of sediment qualitative changes
Carbon (organic)	Measure of aquatic productivity; index of cultural eutrophication; by C_T–C_I	Limited characterization value; concentrations variably influenced by mineral sediment dilution
Organic matter	Measure of aquatic productivity; index of cultural eutrophication; by LOI	Limited characterization value; concentrations variably influenced by mineral sediment dilution
Organic matter: organic carbon	Not previously established	Index of nutritional quality of carbonaceous materials in sediments
Nitrogen (total)	Measure of aquatic productivity; index of cultural eutrophication	Limited characterization value; concentrations variably influenced by mineral sediment dilution
Phosphorus (total)	Measure of aquatic productivity; index of cultural eutrophication	Limited characterization value; concentrations variably influenced by mineral sediment dilution; subject to element migration
C_O:N_T	Measure of aquatic productivity; index of cultural eutrophication	Excellent characterization of changes in aquatic productivity
N_T:P_T	Index of nutritional quality of sediment organic material	Doubtful value
C_O:P_T	Index of nutritional quality of sediment organic material	Doubtful value
Ferromanganese micronodules	Indicative of certain limnological conditions; origin unknown	Valuable indicator of profundal oligotrophic environments poor in humus, but rich in oxygen

mineral concentrations were high. To compensate for the known presence of clay minerals in the Bay of Quinte sediments, organic carbon (C_O) was measured by measuring total carbon (C_T) by the CHN analyzer method and subtracting inorganic carbon (C_I) measured by GSP. Although the quantification of either organic matter or organic carbon proved only of limited value in the assessment of trophic change, the relationship between the two measures, organic matter:organic carbon, provided a valuable index of the nutritional quality of carbonaceous materials held in the sediments.

Nitrogen and phosphorus, important elements in algal physiology, were measured with the idea that, as productivity in the water column increased, the amount of the elements sedimented in planktonic detritus would increase, and thus provide a measure of aquatic productivity.

The ratio between organic carbon and total nitrogen was computed as a measure of aquatic productivity. The link between the carbon to nitrogen ratio and eutrophication through definitive algal communities is the basis for use of the ratio as a measure of aquatic productivity. The ratio C:N is characteristic for different types of algal communities and these communities are known to follow a definite succession in the course of eutrophication. As the algal community adjusts to changing aquatic conditions, the adjustments are recorded in the sediments in the ratio of carbon to nitrogen of organic detritus sedimented in planktonic remains.

The ratios of total nitrogen and organic carbon to total phosphorus were computed to provide an index of the nutritional quality of the organic materials in the sediments. Although there are little data on these ratios in the literature against which to compare the results, their value appears doubtful because of the apparent mobility of phosphorus in some sediments.

The ferromanganese micronodules were analyzed chemically to confirm their identity. Although their exact origin is not known, they have been found to be a valuable indicator of oligotrophic profundal environments poor in humus and rich in oxygen (Brundin 1949: 859).

2.5 Biological Characterization

2.5.1 OVERVIEW OF FAUNA–PRODUCTIVITY RELATIONSHIPS

Remains of the Chironomidae communities were analyzed (Appendix 1) to provide a biological index of the changes in aquatic productivity initiated by cultural eutrophication. Although the usefulness of the Chironomidae as indicators of trophic status has generally been attributed to their specific tolerance to oxygen concentrations at the mud–water interface, the availability of food is also involved. According to Brundin (1949: 655), although "... it is the oxygen factor that excludes the species which are characteristic of oligotrophic lakes from eutrophic lakes, it is the food factor that keeps the species characteristic of eutrophic lakes from developing more strongly in oligotrophic lakes." The relative influence of each factor on development of the chironomid community is difficult to assess, because the two factors are interrelated. In oligotrophic lakes, food availability is clearly the most likely governing factor; however, as the supply of organic material to the sediments increases as productivity increases, oxygen concentrations are progressively reduced to the point where they eventually become limiting and only those species most tolerant to low oxygen availability can survive. The relationship of the chironomid community to productivity through these two interrelated factors, which operate throughout the trophic spectrum, makes the structure of the chironomid community a particularly valuable index of trophic status.

2.5.2 GENERAL TAXONOMIC CONSIDERATIONS

Literature on the Chironomidae is voluminous, but diffusely spread throughout a large number of publications; there is no single source for taxonomic reference. Systematics primarily follow Hamilton et al. (1969), and morphological terminology for the larval head capsules follows Sæther (1971). The identification of chironomid remains recovered from sediments is difficult, because specimens in the majority of cases lack the diagnostic characters used in classical taxonomic treatments.

A number of methods were used to cope with these difficulties and to aid in the identification of individual specimens. Reconstruction methods, particularly for specimens with fractured mentum, were profitably used to detail original configurations. In cases where various diagnostic features (such as the fragile labral setae or antennal segments) were distributed among a number of specimens, a composite picture of the type was carefully compiled on which to base the identification. Every effort was expended to minimize the possibility of introducing irrelevant material into the composites.

In some cases, new features hitherto unmentioned in classical taxonomic literature were used to separate specimens. For example, the genus

Cricotopus van der Wulp was separated from the similar *Orthocladius* van der Wulp on the basis of the point of juncture of the ventromentum with the dorsomentum. Those specimens in which the two parts of the mentum joined at the base of the second lateral teeth were placed in the genus *Cricotopus*, and those joining at the base of the first lateral teeth were assigned to *Orthocladius*. Although some modification to this rule was necessary to conform to descriptions of obvious species in the literature, far from negating its value, this distinctive feature may prove of considerable value in future reevaluations of species assigned to the two genera.

Measurement techniques were widely employed to supplement diagnostic characters. Measurements accurate to one quarter graduation of the ocular micrometer were attained by superimposing a secondary grid on the specimen image and the micrometer scale via the drawing tube. Measurements of the width of teeth and their ratios to one another proved valuable, particularly in separating the species of *Cricotopus* on the basis of Hirvenoja (1973). Application of the technique to the Tanytarsini looks promising, but time constraints and the lack of any comparable data in the literature have limited effective development and use of the technique at this time.

The degree of certainty involved in any specific identification is reflected in the nomenclature used in the lists of taxa found in the course of study. Where diagnostic characters and/or ecological preferences have fitted published or unpublished descriptions, species names have been given with a reasonable degree of certainty. The names of specimens whose diagnostic characters were lacking, or overlapped characters of other species, are prefaced by terms that indicate the degree of certainty involved. In a number of cases identifications are restricted to generic names, but, fortunately, only a few types remain where generic identifications are in doubt. A considerable number of very good taxa have been separated that do not key out in the classical taxonomic literature and probably represent new, undescribed species. These taxa have tentatively been associated with genera to which they appear taxonomically related. Finally there remain those specimens, primarily belonging to the Tanytarsini, that can only be separated into groups. These, unfortunately, may have only limited interpretive value.

2.5.3 NUMERICAL ANALYSIS

2.5.3.1 The rating system — A rating system was adopted to counter the bias in the summation of data that would have arisen if fragments of individuals and intact individuals were treated equally. The system is simple: a specimen in which the mentum was intact is rated as one individual whereas a specimen in which only a portion of the mentum was found is rated as one half.

2.5.3.2 Relative frequencies and confidence intervals — All relative frequencies are based on the rated total of the fauna of all major Chironomidae groupings. Ninety-five percent confidence intervals were calculated at group level, using the method of Mosimann (1965: 643) formulated by the equation

$$\rho_{(0.95\ \mathrm{limit})} = \frac{\hat{\rho} + [(1.96)^2/(2n)] \pm (1.96)\sqrt{[\rho(1-\rho)/n] + [(1.96)^2/(4n^2)]}}{1 + [(1.96)^2/n]}$$

where ρ denotes a point estimate of the true proportion, $\hat{\rho}$ the proportion x/n of a particular taxon, where x is a number of specimens of taxon, X, encountered in a total of n specimens. All confidence intervals were for counts inside the basic sum.

2.5.3.3. Population comparisons — Relationship of the number of species and numbers of individuals of each species was evaluated by the Shannon-Wiener information function

$$H(S) = c\left\{\log_{10} N - \frac{1}{N}\sum_{\mathrm{r}=1}^{s} n_r \log_{10} n_r\right\}$$

where n_r = number of individuals in the r^{th} species, N = total number of individuals, S = total number of species, and $c = 3.321928$ (MacArthur and MacArthur 1961: 594; Southwood 1966: 347). The equitability measure, ϵ, was calculated after Lloyd and Ghelardi (1964: 220). Both $H(S)$ and ϵ were calculated for each of the major chironomid groupings, as well as the total chironomid fauna found at each interval sampled.

Jaccard's (1912), Kulezynski's (1928), and Sørenson's (1948) indices (collectively referred to as coefficients of community) were computed along with the percentage similarity of community as outlined in Southwood (1966: 332). Kendall's (1962: 6) "tau" coefficient was computed after the method outlined by Ghent (1963: 569). In the calculation of uncorrected tau, referred to as τ_a by Kendall (1962), missing species were regarded as present at zero frequency and assigned the last rank, whereas tied ranks were assigned the midrank in a series of ties. Although not as conservative as dropping missing species from both ranks, the assignment of these species to the last rank has ecological validity according to Ghent (1963: 570), in that a species' absence from a community may be regarded as ". . . the result of competitive selection operating against its survival in a particular habitat." On the other hand, the decision to leave tau uncorrected for ties introduces an element of conservatism by incorporating a penalty for a lack of sampling precision, on the premise that tied ranks should not appear in an adequately sampled community (Ghent 1963: 572).

2.5.4 Live Chironomidae Sampling

The live Chironomidae fauna at the Glenora core site was sampled to provide a reliable census of the 1972 chironomid community and to provide a comparison with the surface fossil community. Some differences are to be expected. Population estimates based on the chironomid fossil remains recovered from the surface sediments necessarily involve an average fauna representative of the suite of years encompassed by the surface-most 1 cm of sediment. Considerable variation may also be introduced into such an estimate because of the initial difficulties inherent in sampling the watery surficial sediments, and because of the limited amount of replicate material available for analysis.

Samples of the live Chironomidae fauna were taken through the ice after the coring operation was completed. Four replicate samples were taken from each of the three core sites with a deep 232.3-cm^2. Ekman dredge, sieved through a 200-μ sieve bag, and the residue stored in water in clean glass jars. The samples were sorted live in the laboratory under a stereomicroscope and permanent microscope slides made of the Chironomidae specimens.

3. STRATIGRAPHIC ASPECTS OF GLENORA SEDIMENTS

3.1 Correlation Between Cores

3.1.1 GROSS COLOR STRATIGRAPHY

Wet sediments of the Glenora cores were singularly featureless in appearance. The zone of surface-oxidized sediments (Fig. 5) was reasonably well defined by color, but the two zones of discriminant color in the older sediments were variably separated by transition zones of mottled appearance, with color characteristics of the zones on either side.

Sediments of the Glenora-B core when dry (Table 6) demonstrated a higher degree of color variability than when wet. The upper sediments were basically olive-gray and lower sediments grayish brown to dark grayish brown. The two basic color zones were separated by a reasonably distinct band of sediment between 40 and 43 cm, that varied in color from pale olive to olive as a result of ferromanganese micronodules in the horizon.

3.1.2. STRATIGRAPHIC MARKER COMPARISONS

The *Ambrosia* pollen profile and ferromanganese micronodule horizon provide convenient markers for comparative purposes. The *Ambrosia* profile (Fig. 5) is most consistent in detail. The *Ambrosia* pollen rise occurs at exactly the same levels in cores B and C and only 1 cm higher in core D. The break in the *Ambrosia* pollen profile in the B and C cores at 36.5 cm and in D core at 35.5 cm has been identified as the result of a heavy influx of clay material from a historical event in the watershed. The mineral material effectively diluted the pollen record and caused the apparent discontinuity in the *Ambrosia* profile. The ferromanganese micronodule horizons are not as consistent in detail; the horizons in the B and C cores are narrow and sharply defined, but their maximum distributions appeared at 40.5 and 36.5 cm, respectively. The micronodule horizon in the D core is broader, less sharply defined, bimodal, and extends through the levels of the horizons in the other two cores. As their exact mechanism of formation is not known, the ferromanganese micronodule horizons may not be considered as reliable a marker as the *Ambrosia* profiles; nevertheless, their presence does provide supplementary evidence for comparing the three cores. These two features indicate that the cores are representative of sediment deposits in the immediate vicinity of the Glenora core site, and that no blatant disruption of the sediments has occured that would compromise interpretation of the stratigraphic sequences.

3.2 Core Chronology

The chronology of the visibly featureless Glenora-B core sediments was established by integrating the *Ambrosia* pollen stratigraphy, lead-210 profile, Erosion Index, and carbon-14 measurements (Fig. 6). The *Ambrosia* pollen rise at 37.5 cm (tentatively dated at 1849 ± 5 yr on the basis of the date established for the *Ambrosia* rise in southern Ontario by McAndrews and Boyko (1972: 1–2)) provided a reliable focal point around which to begin collocating results of the other techniques. The chronological scale, developed from the measurement of lead-210, was then centered on the *Ambrosia* rise and the dates were calculated for each interval median between 13.5 and 46.5 cm. The *Ambrosia*–lead-210 scale was then applied to the Erosion Index and, on the basis of an interpretation of historical and physical data, the date of the Ambrosia rise was readjusted by 3 yr. The readjustment placed the *Ambrosia* rise in the Glenora-B core at 1852, an adjustment well within McAndrews and Boyko's accuracy limits. The time period demarcated by the lead-210 scale lay be-

TABLE 6. Dry sediment color stratigraphy of the Glenora-B core. (Munsell soil color 5Y 5/2 to 5Y 4.5/2, olive gray; 5Y 5/3, olive; 5Y 5.5/3, pale olive to olive; 5Y 6/3, pale olive; 2.5Y 5/2, grayish brown; 2.5Y 4.5/2, grayish to dark grayish brown; 2.5Y 4/2, dark grayish brown)

Interval (*cm*)	Color	Interval (*cm*)	Color
0–23	5Y 5/2	59–64	2.5Y 4.5/2
23–26	5Y 4.5/2	64–66	2.5Y 5/2
26–28	5Y 5/2	66–68	2.5Y 4.5/2
28–40	5Y 5/3	68–70	2.5Y 5/2
40–41	5Y 5.5/3	70–147	2.5Y 4/2
41–42	5Y 6/3	147–161	2.5Y 4.5/2
42–43	5Y 5/3	161–164	2.5Y 5/2
43–59	2.5Y 5/2		

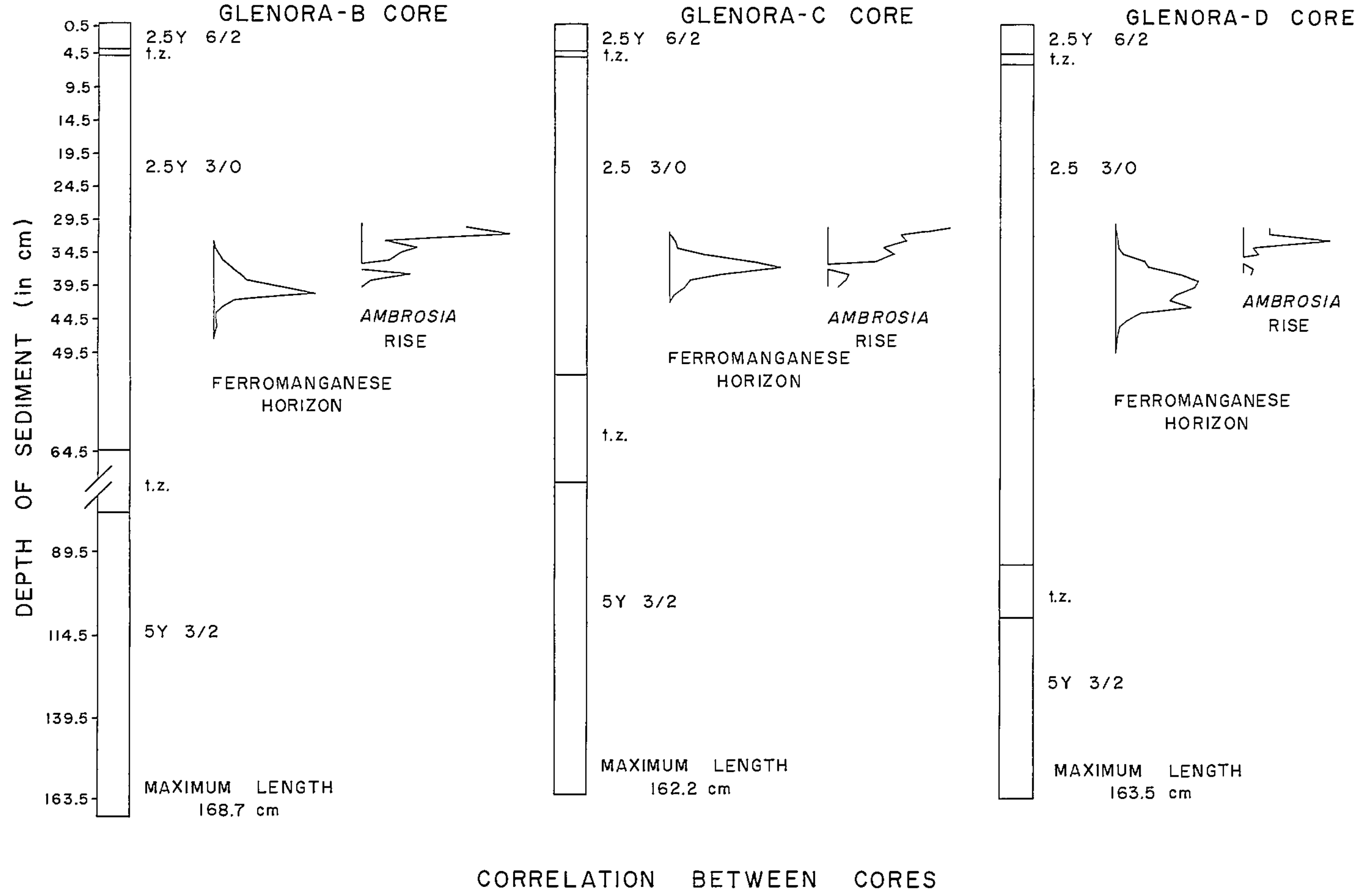

FIG. 5. Comparison of wet sediment color, ferromanganese microndule horizon, and the *Ambrosia* pollen rise in the Glenora cores. Wet Munsell soil color 2.5Y 6/2 = light brownish gray, 2.5Y 3/0 = very dark gray, 5Y 3/2 = dark olive gray. The abbreviation t.z. refers to the transition zones.

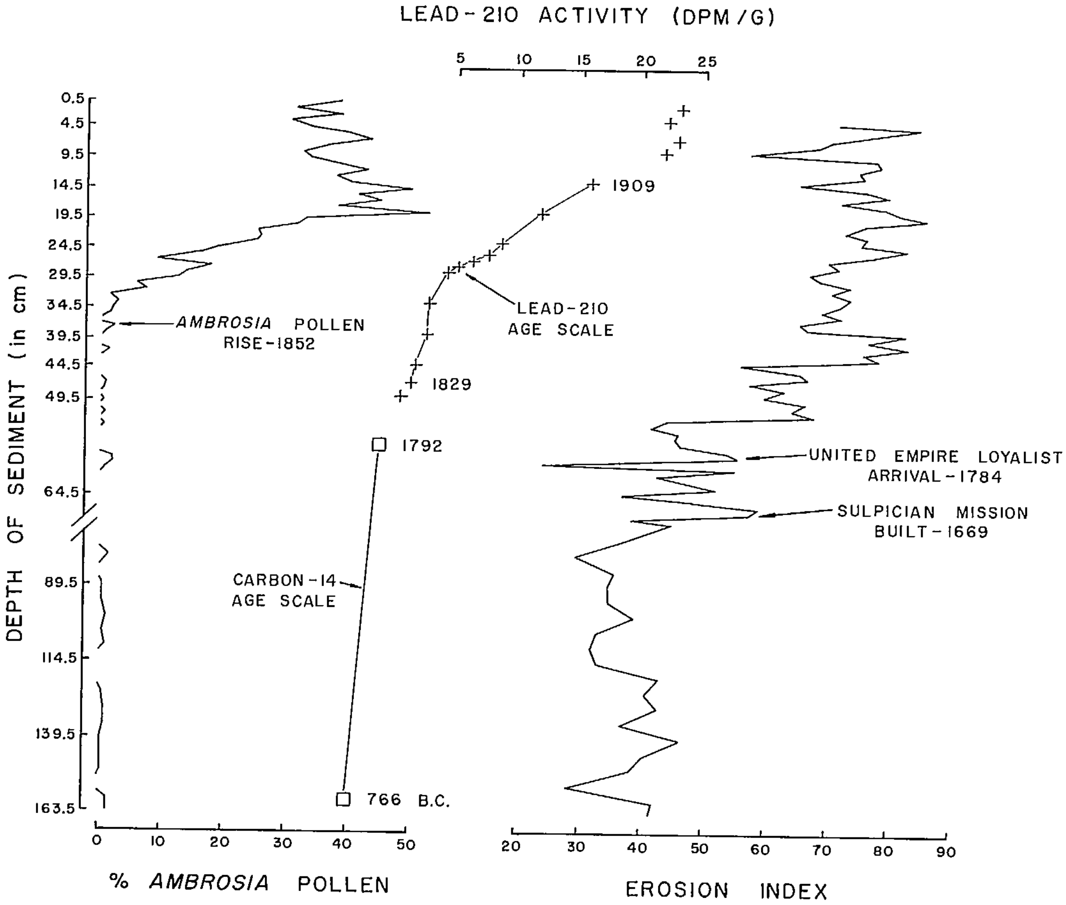

FIG. 6. Summary of data used to establish the chronology of the Glenora-B core sediments.

tween 1829 and 1909 in the corrected chronology.

The chronology was then extended past the limits of the lead-210 scale by isolating and identifying historical markers in the Erosion Index. The sharp rise in the Erosion Index at 58.5 cm was attributed to the arrival of the United Empire Loyalists in the immediate vicinity in 1784. A second sharp rise in the Erosion Index at 67.5 cm was interpreted as evidence of activity in the area during the building of the Sulpician Mission which began in 1669. These two prominent, easily identifiable markers were then used to calculate the age sequences between 1669 and 1829.

Sediments from the older parts of the core were then dated from carbon-14 data. The age of the carbon-14 measurement made at 56.5 cm was first corrected to 1792 from the age scale developed from the previous methods. The difference between the measured and actual ages was then used to calculate an error factor to correct the carbon-14 measurement at 159.5 cm, from which a date of 766 B.C. was computed. The intervening age sequences between this date and 1669 were then calculated.

At the top of the core, age sequences from 1909 to the present were calculated on the basis of an average sedimentation rate between 13.5 cm and the surface sediments. The chronology established for the Glenora-B core sediments, including dates of special significance (underlined), is presented in Table 7.

A number of decisions made in the use of the chronology data warrant explanation. The *Ambrosia* pollen peak at 37.5 was accepted as the beginning of the *Ambrosia* rise, even though not contiguous with the greater part of the *Ambrosia* profile. An analysis of the historical pattern of the Erosion Index and other sedimentary parameters shows that the break in the *Ambrosia* profile was caused by dilution of the pollen record through the intensive accumulation of mineral sediment, and the *Ambrosia* at 37.5 cm belong to the same yearly increment to the sediments as that at 35.5 cm (Warwick unpublished data).

The four lead-210 values that define the anomalous zone on the uppermost 8 or 9 cm of the core were not included in the development of the lead-210 chronology scale. The anomalous zone is described as an interval of nearly constant lead-210 activity of variable thickness in the surficial sediments or, alternatively, as a zone where the lead-210 activity is lower than would be expected on the basis of the profile determined lower in the core (Edgington and Robbins 1976: 174). Although the significance of the zone is not known, the lead-210 values from the zone represent an apparent rapid increase in the rate of sedimentation that is inconsistent with the facts derived from other sources (Warwick unpublished data). Therefore, these spurious results preclude starting the lead-210 scale from the surface sediments and necessitate centering the scale from the historical sediment layers on some other well-identified marker, such as the *Ambrosia* pollen rise. The last lead-210 measurement was not included in the scale because the measurement approached the technical limits of the lead-210 method. The possibility of a large inherent error factor cautioned its use.

Five carbon-14 measurements were made in the study, but only two were used in the development of the chronology (Warwick unpublished data). When compared against the age scale developed through other methods and verified from the historical record, error factors computed for the carbon-14 age of a shell of the bivalve *Elliptio complanata* Sol. (collected in the Bay of Quinte in 1901 and measured as a control) and the carbon-14 ages of the sediment organic material from 33.5 and 56.5 cm steadily improved as the actual age of the material *decreased*. This indicated that, not only had the accuracy of the carbon-14 measurements not remained constant throughout the chronologized period, but *had actually improved.* Because this unexpected departure from the usual trend was probably linked to man's involvement in the bay (Warwick unpublished data), only the carbon-14 measurement from 56.5 cm was used in the chronology. This measurement was made on material least influenced by the activities of European colonization, and accumulated under conditions more likely similar to those prevailing when sediments in the older portions of the core were deposited.

TABLE 7. Detailed chronology of Glenora-B core sediments.

Level	Year	Level	Year
0.0	1972	47.5	1825
0.5	1969	48.5	1822
1.5	1965	49.5	1818
2.5	1960	50.5	1814
3.5	1956	51.5	1811
4.5	1951	52.5	1807
5.5	1946	53.5	1803
6.5	1942	54.5	1799
7.5	1937	55.5	1795
8.5	1932	56.5	1792
9.5	1928	57.5	1788
10.5	1923	58.5	1784
11.5	1919	59.5	1771
12.5	1914	60.5	1758
13.5	1909	61.5	1746
14.5	1907	62.5	1733
15.5	1905	63.5	1720
16.5	1903	64.5	1707
17.5	1901	65.5	1695
18.5	1899	66.5	1682
19.5	1897	67.5	1669
20.5	1896	68.5	1650
21.5	1894	69.5	1617
22.5	1892	72.0	1550
23.5	1890	74.5	1484
24.5	1888	77.7	1400
25.5	1886	79.5	1352
26.5	1879	81.4	1300
27.5	1873	84.5	1219
28.5	1867	89.5	1087
29.5	1864	92.8	1000
30.5	1861	94.5	954
31.5	1858	99.5	822
32.5	1855	104.5	689
33.5	1853	109.5	557
34.5	1853	114.5	424
35.5	1852	119.5	292
36.5	1852	124.5	159
37.5	1852	129.5	27 A.D.
38.5	1851	131.5	27 B.C.
39.5	1849	134.5	106
40.5	1846	139.5	238
41.5	1843	144.5	371
42.5	1841	149.5	503
43.5	1838	154.5	636
44.5	1835	159.5	766
45.5	1832	163.5	874
46.5	1829		

The two radiocarbon ages in the oldest sediments were inverted. The age measured at 159.5 cm was accepted for chronological purposes because sediment chemical and physical parameters indicated that characteristics of the depositional environment at this interval were more like those at 56.5 cm (the interval from which the age correction factor was determined) than those at 114.5 cm. Comparison of *Ambrosia* profile ages determined in this study with the carbon-14 age-dated *Ambrosia* pollen profile by Bassett and Terasmae (1962: 147) confirm this decision.

Cesium-137 data were not used in the development of the Glenora-B core chronology. The age sequence implied by the cesium-137 profile was clearly at variance with the detailed chronology developed by the other methods, and verified from historical accounts (Warwick unpublished data). The data demonstrate that in sediments like those found at Glenora, cesium-137 is subject to diffusion as hypothesized by Lerman (1973: 938).

3.3 Sedimentary Parameters

3.3.1 SEDIMENTARY REGIME

3.3.1.1. Grain size distribution — Grain size measurements establish that the two major sediment populations in the Glenora-B core matrix were primarily silt-size and clay-size materials. Vertical distributions of the two main components (Fig. 7) show that a fundamental shift from a silt-dominated to a clay-dominated sediment occurred between the older sediments (below 70 cm) and more recent sediments. A breakdown of the clay-size fraction (in summarized form, Fig. 8) indicates that the shift in dominance was primarily due to the addition of very fine (> 10.50 ϕ) clay-size materials. A. G. Wikjord (personal communication) placed the fine materials in the smectic montmorillonite family of clays by thermogravimetric and X-ray diffraction methods. Confirmation for the identification comes from Thomas et al. (1972: 73). They reported that abundant montmorillonite sediments were found only in the Kingston Basin, whereas sediments throughout the remainder of Lake Ontario were primarily illite, with lesser amounts of chlorite and kaolinite. The montmorillonite clay material, which probably came from the clay plains of the Trent and Napanee River valleys, undoubtedly was borne by the currents of the Bay of Quinte to the Glenora site and then to the Kingston Basin of Lake Ontario via the Lower Gap. Distributions of two minor populations of fine grain-size quartz particles and ferromanganese micronodules are also shown lying in close proximity to one another in Fig. 8.

The accumulation of fine clay-size materials in the more recent sediments indicates that hydraulic energy at the core site is very low. The transition in particle-size dominance in the older core sediments reflects a changing source of sediment material, rather than a change in hydraulic energy conditions. The low hydraulic energy environment of the site makes it ideal for sensitive accumulation of even the finest sediments.

Fine grain-size quartz particle and ferromanganese micronodule horizons serve as convenient markers for correlating the cores. The former are believed to be of aeolian origin, whereas the latter are thought to be of biological or chemical origin (Warwick unpublished data).

3.3.1.2 The Erosion Index — The Erosion Index provides a means of identifying periods of environmental perturbation in the watershed (Fig. 9). Periods of intense human activity are generally defined by increases in the Erosion Index. This feature is aptly illustrated by the marked increases in the Erosion Index as a result of intense activity in the watershed associated with the building of the Sulpician Mission in 1669, the arrival of the United Empire Loyalists in 1784, the beginning of the timber trade in response to naval timber shortages in the Royal Navy during the period 1808–11, and the opening of the back townships concomitant with the last phase of heavy voluntary immigration into British North America during 1838–41. Conversely, periods typified by a pronounced absence of human activity in the watershed are defined by decreases in the Erosion Index. The sharp declines in the index marking the Abandonment Stage between the end of the French Regime and the arrival of the United Empire Loyalists (1771), and the inactivity in the forest products industries during the Great Depression (1932), illustrate the effects of inactivity in the watershed on the Erosion Index. In this way, the index has proven highly reliable in verifying the accuracy of the chronology established for the sedimentary sequences (Warwick unpublished data). Because the Erosion Index accentuates the proportion of the finest particles in the clay size range, its accuracy is, in no small measure, a direct function of the sensitivity of the low hydraulic energy environment of the core site for the accumulation of fine mineral sediments.

The Erosion Index also shows, through its strong correlation with chronological events, that the shift from predominantly silt-size sediments to progressively finer clay-size sediments (shown in grain size analysis) is a function of the progressive development of the watershed (Warwick unpublished data). As people penetrated further into the watershed from the Bay of Quinte, their activities introduced erosion materials which came from areas of different soils, and were subjected to progressively greater degrees of hydraulic sorting. Today, with watershed develop-

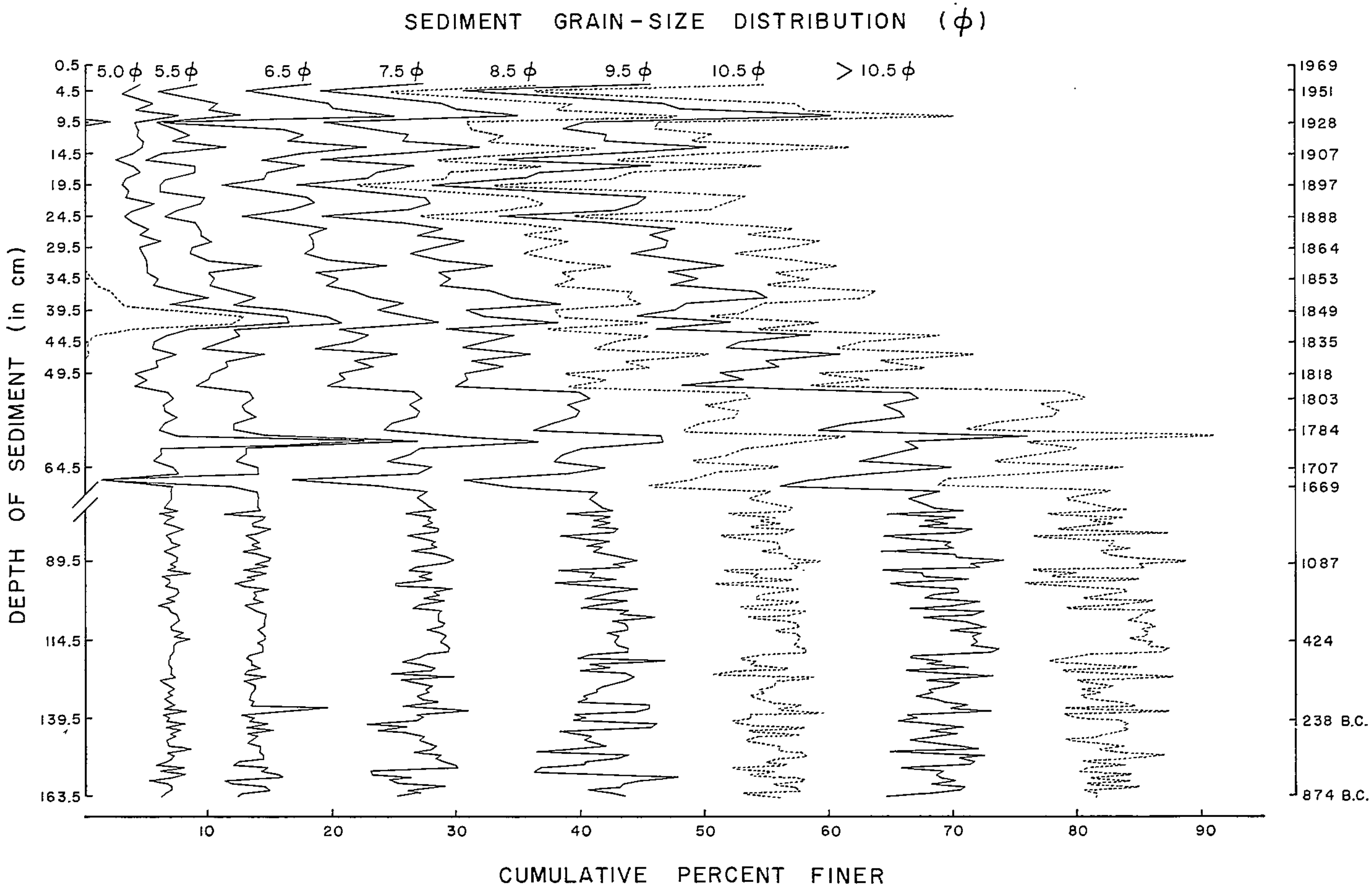

FIG. 7. Grain size distribution in the Glenora-B core as a function of sediment depth. The dashed profiles delineate the <4.0 ø, 8.5 ø, and >10.50 ø size range boundaries.

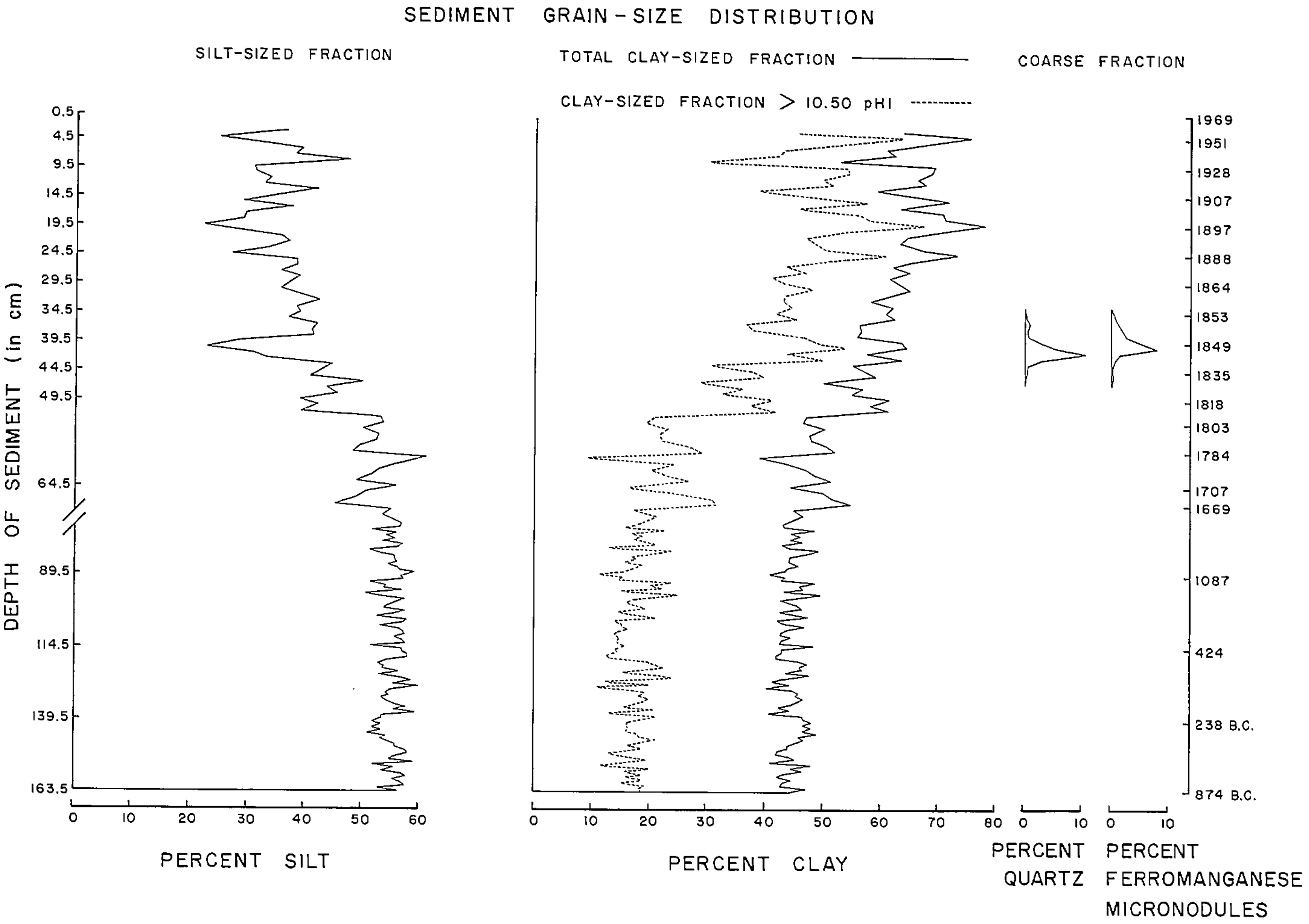

FIG. 8. Summary of the distribution of selected sediment-size fractions in the Glenora-B core as functions of sediment depth. The very fine (> 10.50 ø) clay-size fraction is indicated by the broken line as part of the total clay-size fraction.

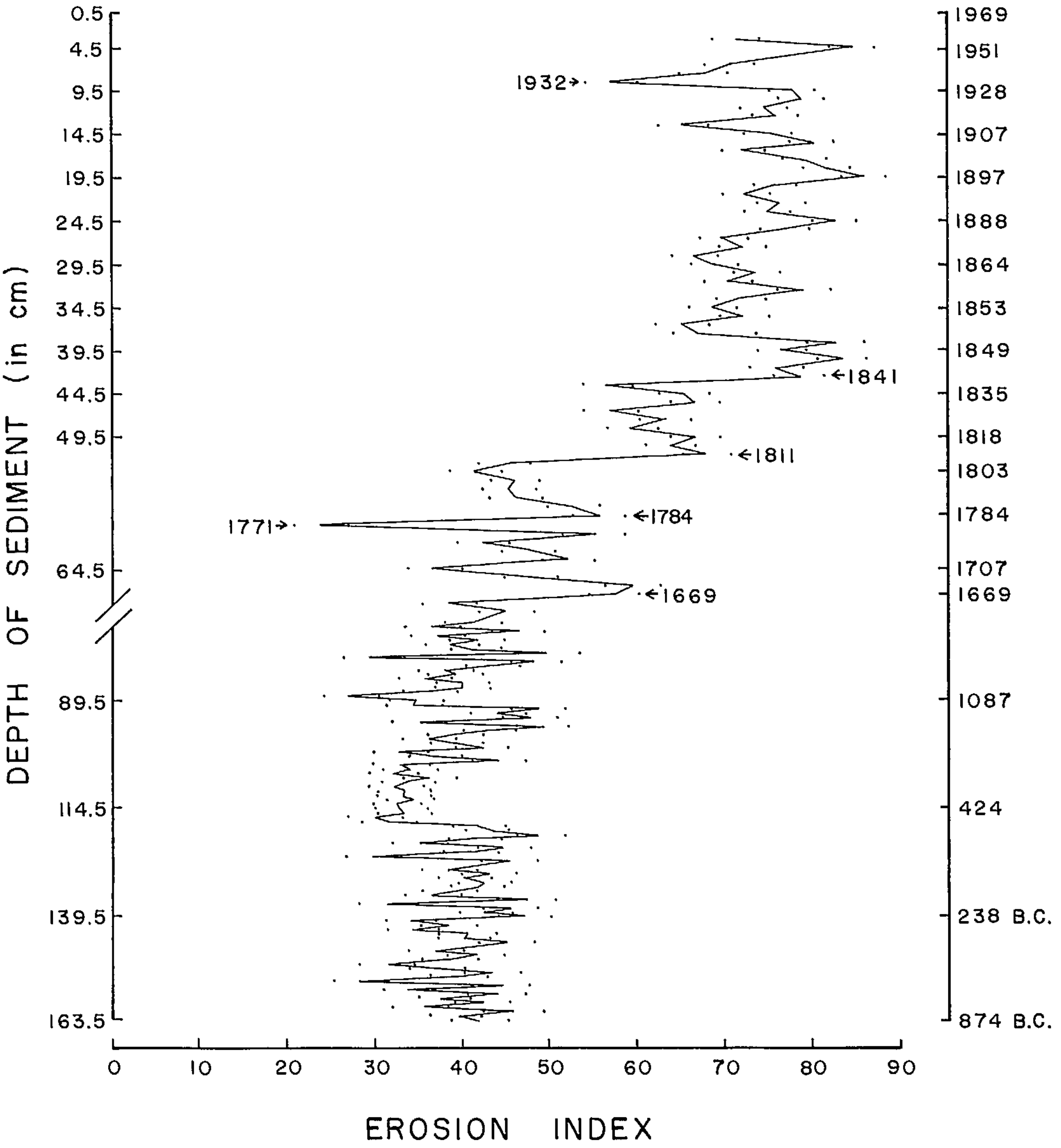

FIG. 9. The Erosion Index for the Glenora-B core as a function of sediment depth. Upper and lower confidence limits for each measurement are included (individual points). Special dates mark the periods of the Great Depression (1932), the last massed voluntary emigration to British North America (1841), the beginning of the square timber trade (1803–11), the arrival of the United Empire Loyalists (1784), the interim between the French and British regimes (1771), and the building of the Sulpician Mission (1669).

ment more or less complete, the most recent sediments are dominated by very fine particles, well sorted by time and distance.

3.3.1.3 Moment measures — The analysis of moment measures, a set of interrelated parameters based on grain size distribution data, similarly reflects the influence of the changing source of materials on sediment composition (Warwick unpublished data). The shift from a silt-size dominated to a clay-size dominated sediment noted in Fig. 7, 8 is similarly shown in the slight, but general, increase (in phi terms) in mean grain size and the decline from strongly positive to slightly negative skewness values in the more recent sediments (Fig. 10). The shift reflects the increased input to the sediments of fine mineral materials of different composition, particularly from the clay plains of the Trent watershed, as settlement spread progressively back from the Bay of Quinte.

The effect of the steadily increasing distances traveled by the sedimentary material from the new sources is reflected in the standard deviation and kurtosis profiles (Fig. 10). The general increase in standard deviation indicates that sedimentary material in the more recent sediments is more poorly sorted in comparison to the older sediments (Warwick unpublished data). The trend to more negative kurtosis values similarly suggests poorer sorting, in that the direction and magnitude of the divergence indicates the presence of two increasingly more distinct sediment size populations. Extremely high or low values of kurtosis indicate that part of the sediment was sorted elsewhere in a high-energy environment and transported, with its size characteristics essentially unmodified, into another environment where it was mixed with an indigenous material (Warwick unpublished data). In this case, sediments introduced into the Bay of Quinte as its watershed was opened up and settled, were progressively better sorted as the distance of transport increased. Sorting was particularly effective in the Trent River system, where the series of lakes interspersed along its route act as sequential sediment traps for the coarser sediment fractions. The well-sorted, fine fraction transported through this system was then deposited at the core site along with materials of more local origin. Thus, the more recent sediment at the core site is composed of two distinct, poorly sorted, size-class populations.

3.3.2 SEDIMENT ACCUMULATION

The magnitude of the sediment component impinging on the benthic community was estimated by calculating the accumulation of sediments in absolute terms. The sedimentation rates (Table 8) were determined from the chronological data discussed above, whereas sediment densities were provided from ignition data. The features of the sediment accumulation profile, shown in terms of grams of sediment per square centimeter per year (Fig. 11), demonstrate that, although sediment accumulation was reasonably constant in the older sediments (below 70 cm), it varied considerably in the sediments deposited since European settlement of the area. Above 70 cm the accumulation of sediments rose steadily from around 80 × 10^{-4}g·cm^{-2}·yr^{-1} to a peak of 643.13 × 10^{-4}g·cm^{-2}·yr^{-1} at 49.5 cm, before declining slightly to 583.64 × 10^{-4}g·cm^{-2}·yr^{-1} at 45.5 cm. The most dominant feature of the profile, the large peak between 44.5 and 30.5 cm, followed this slight decline. In the interval marking the peak, the greatest accumulation of sediment occurred at 36.5 cm where an accumulation of 9322.69 × 10^{-4} g·cm^{-2}·yr^{-1} was estimated. The accumulation of sediment then declined dramatically from 35.5 cm to a minimum of 679.34 × 10^{-4}g·cm^{-2}·yr^{-1} at 25.5 cm. Sediment accumulation increased again to 1227.06 × 10^{-4}g·cm^{-2}·yr^{-1} at 24.5 cm, then began to decline steadily towards the surface sediments. An average 203.78 × 10^{-4}g·cm^{-2}·yr^{-1} of sediment (based on an average for the uppermost 5 cm) appears to be accumulating at the present time.

3.3.3 SEDIMENT PARAMETERS

3.3.3.1 Carbonate carbon — Profiles for carbonate carbon measured independently by LOC and GSP were dissimilar (Fig. 12). The direct measure of inorganic carbon, C_I, determined by the

TABLE 8. Sedimentation rates determined for Glenora-B core sediments from a succession of techniques.

Applied interval (*cm*)	Sedimentation rate (*mm·yr^{-1}*)	Method
0.5–13.5	2.15464	Time average
13.5–18.5	5.19271	Lead-210
18.5–23.5	5.06779	Lead-210
23.5–25.5	5.04797	Lead-210
25.5–26.5	1.53242	Lead-210
26.5–27.5	1.59747	Lead-210
27.5–28.5	1.60696	Lead-210
28.5–33.5	3.53075	Lead-210
33.5–38.5	41.33509	Lead-210
38.5–43.5	3.67160	Lead-210
43.5–46.5	3.48910	Lead-210
46.5–58.5	2.66419	Time average
58.5–67.5	0.78261	Time average
67.5–159.5	0.37744	Carbon-14

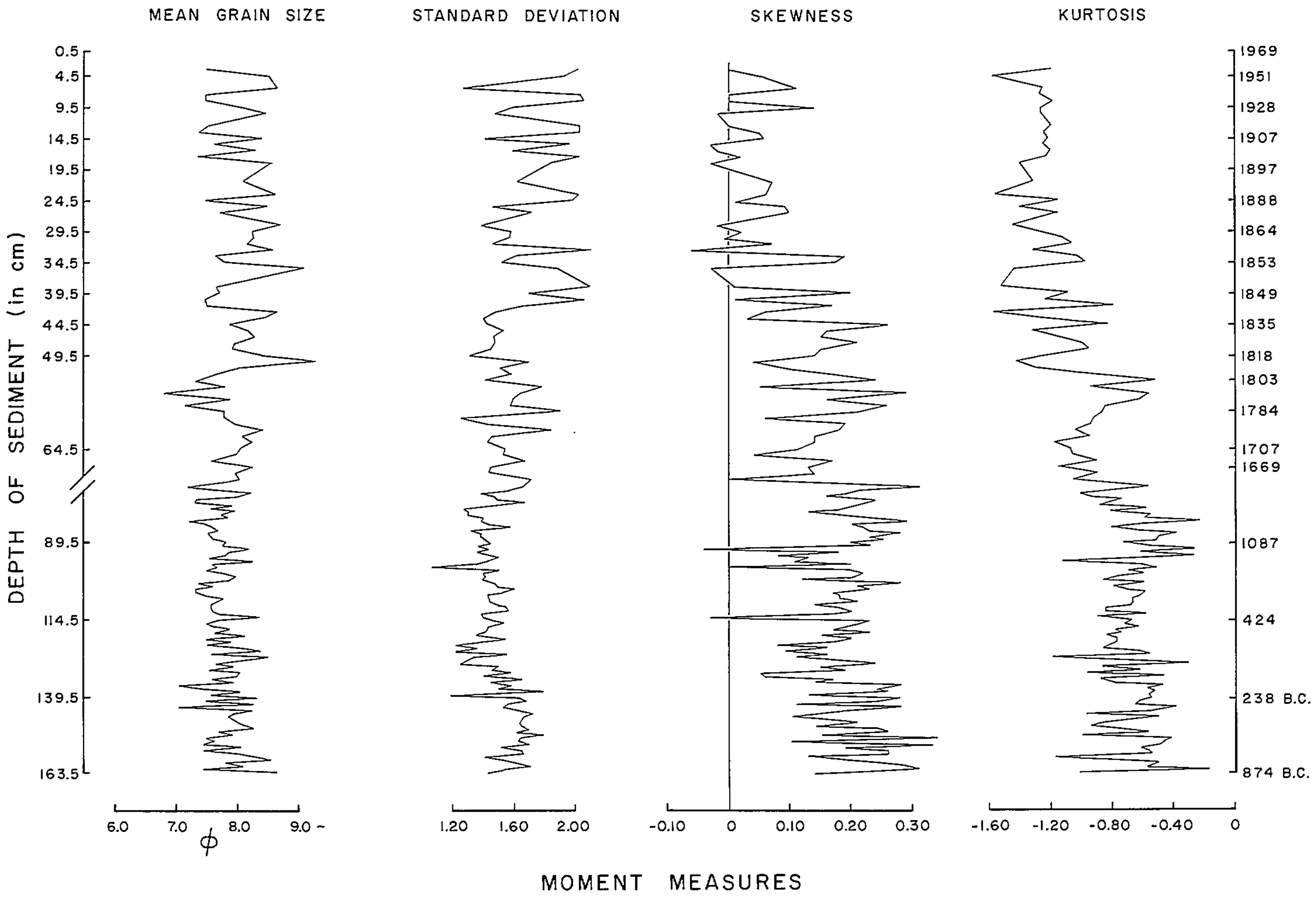

FIG. 10. The moment measures mean grain size, standard deviation, skewness, and kurtosis for sediment size ranges 4.0–11.0 ø in the Glenora-B core as functions of sediment depth.

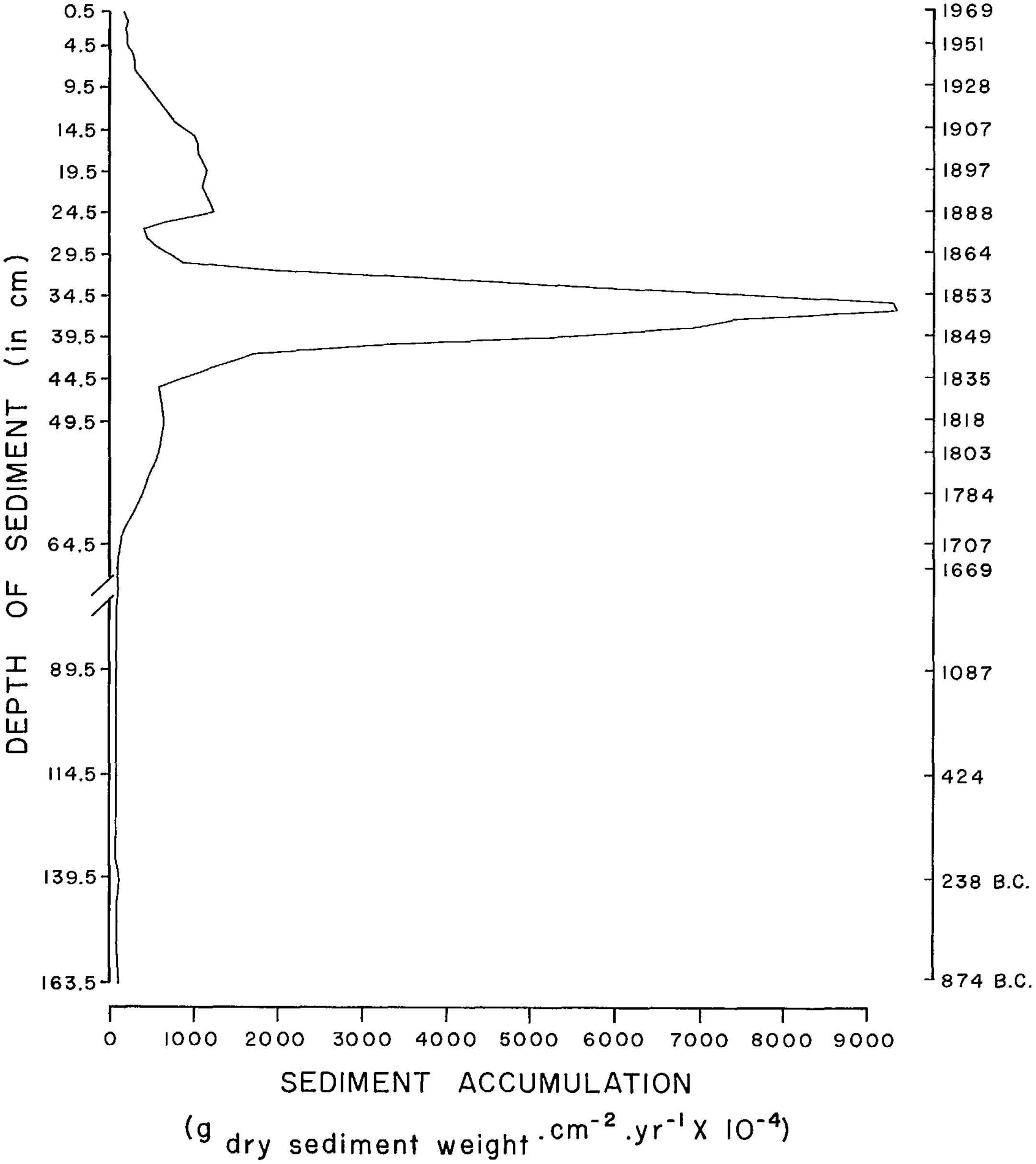

Fig. 11. Sediment accumulation as a function of sediment depth.

latter method, demonstrated a distinct change from highly carbonate sediments in the older sediments to less carbonate content in the more recent sediments. The qualitative change in sediments between 57.5 and 29.5 cm was caused by increased accumulation of clay mineral sediments. The presence of a highly mineral ferromanganese micronodule horizon accentuated the decline in inorganic content at 41.5–40.5 cm, and provides a sharp demarcation between older and more recent sediments. A significant peak in inorganic carbon content occurred at 68.5 cm, coincident with the arrival of the French in the bay. In the most recent sediments, the inorganic carbon fraction has begun to form an increasingly important component of the sediment material again.

The carbonate carbon profile determined by LOC, except for the sharp decline at 41.5 cm marking the ferromanganese micronodule horizon, bears little resemblance to the inorganic carbon profile determined by GSP. As the difference probably is related to the loss of water of hydration from clay minerals, the ratio between carbonate carbon, determined by LOC, and inorganic carbon, determined by GSP, was computed as a crude index of clay mineral content. The profile established for the LOC:GSP ratio bears a strong resemblance to the clay-size sediment profile in Fig. 7, and confirms that the transition to clay-size dominated sediments was in fact due to the accumulation of clay mineral sediments.

3.3.3.2 Water content — The sediment water content profile, whether expressed in terms of percentage or per gram dry sediment weight (Fig. 13), indicated that the compactness of the Glenora sediments was strongly influenced by the changes in sediment type. The sharp decline in the water content profiles at 41.5 cm effectively bisects the profiles into two distinct parts, and reflects the poor water-holding properties of the comparatively coarse, granular, ferromanganese micronodule horizon. In the older sediments below the ferromanganese micronodule horizon, the sediment water content declined steadily toward the bottom of the core, indicating that the sediments were becoming increasingly compact with depth. Immediately below the horizon contact, however, the sediment water content increased sharply suggesting that water percolating upward, as the steady accumulation of overburden increased the pressure on the underlying sediments, was unable to penetrate the overlying montmorillonite clay sediments, and was pooling at the interface between the two sediment types. The poor water-holding properties of the tightly packed clays predominating above the ferromanganese micronodule horizon are clearly reflected in the low water content at 29.5 cm. Above this level, the sediment water content increased rapidly up to the surface sediments as a result of the decrease in compressive pressure, and the transition from predominantly clayey sediments to sediments of a more highly organic nature.

3.3.3.3 Sediment density and mineral content — Profiles for sediment density and mineral content (Fig. 13) are generally the inverse of the water content profile. The sharp increase that effectively apportions the two profiles into two distinct parts is clearly caused by the presence of the coarse, highly mineralized, ferromanganese micronodules at 41.5–40.5 cm. The increase in the mineral content between 69.5 and 45.5 cm, unmatched in the sediment density profile, suggests that the accumulation of mineral sediments began well before that point. The general decreasing trend above the horizon reflects both decreasing mineral sediment accumulation and sediment compaction.

3.4 Chemical Parameters

3.4.1 MEASURES OF AQUATIC PRODUCTIVITY

3.4.1.1 Total carbon, nitrogen, and phosphorus — Concentrations of total carbon and nitrogen (Fig. 14) are of limited value in assessing the course of cultural eutrophication from the sediments. The profiles were useful in establishing the boundaries of the Iroquoian period between 102.0 and 68.5 cm. The striking, truncated peak in both profiles marking this period probably resulted from the introduction of ash material to the bay, when the Iroquois cleared land on a large scale for agricultural purposes (Warwick unpublished data). However, the fact that the concentration of total carbon in the most recent sediments was less than that measured throughout the older sediments, whereas the concentration of total nitrogen in the most recent sediments was only marginally greater than that recorded throughout the older sediments, demonstrates that carbon and nitrogen concentrations are of little use in defining changes in aquatic productivity in the bay. The susceptibility of sediment carbon and nitrogen concentrations to mineral sediment dilution (Warwick unpublished data) accounts in large measure for their unsuitability as an index of eutrophication.

The profile for total phosphorus concentrations (Fig. 14) features five prominent peaks throughout the lower sediments before culminating in a rapid rise in concentration in the surface sediments. Each of the five peaks in the post-Euro-

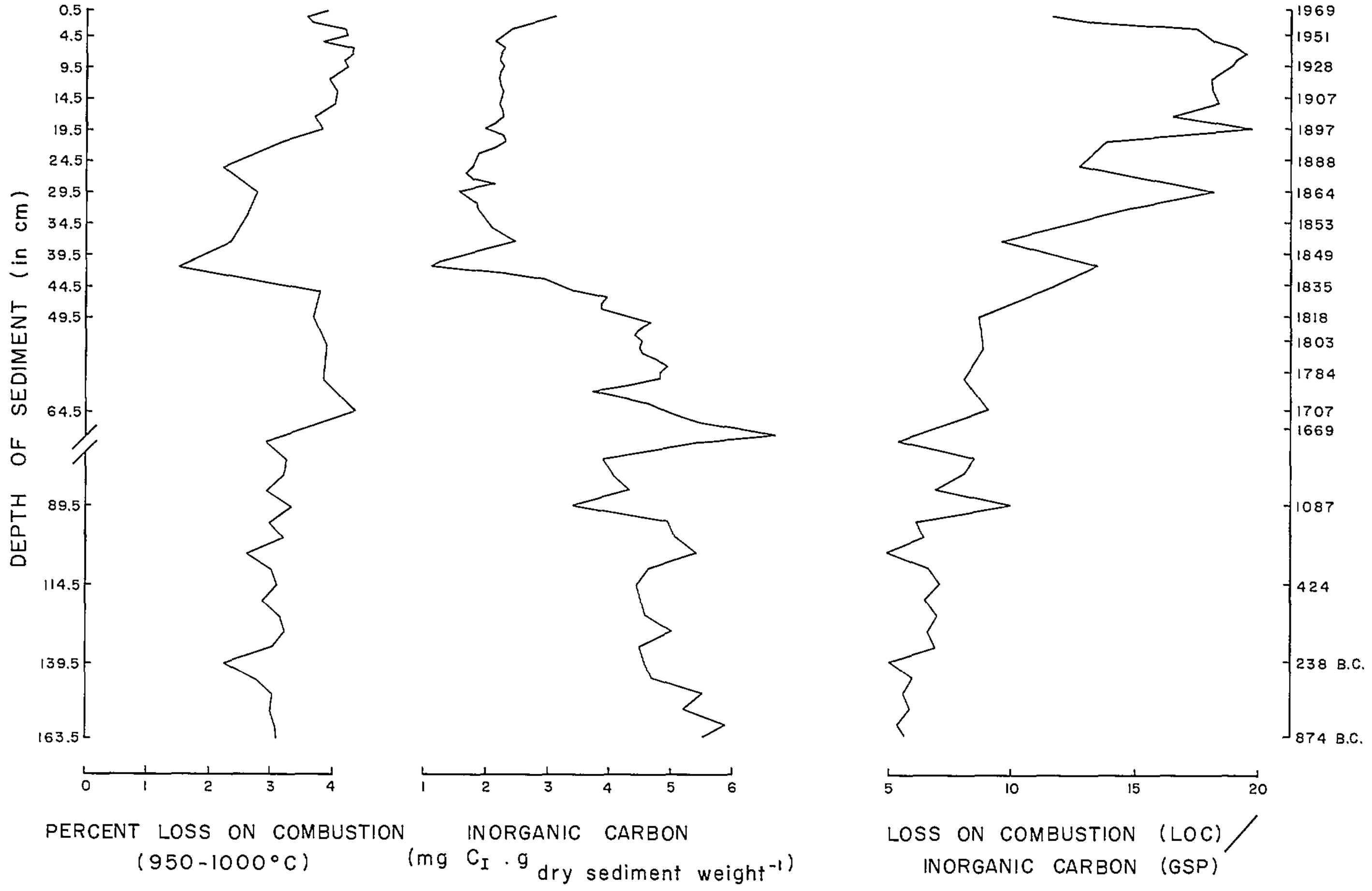

FIG. 12. Percentage loss on combustion (LOC), inorganic carbon by the gas stripping procedure (GSP) and their comparative ratio (LOC:GSP) as functions of sediment depth.

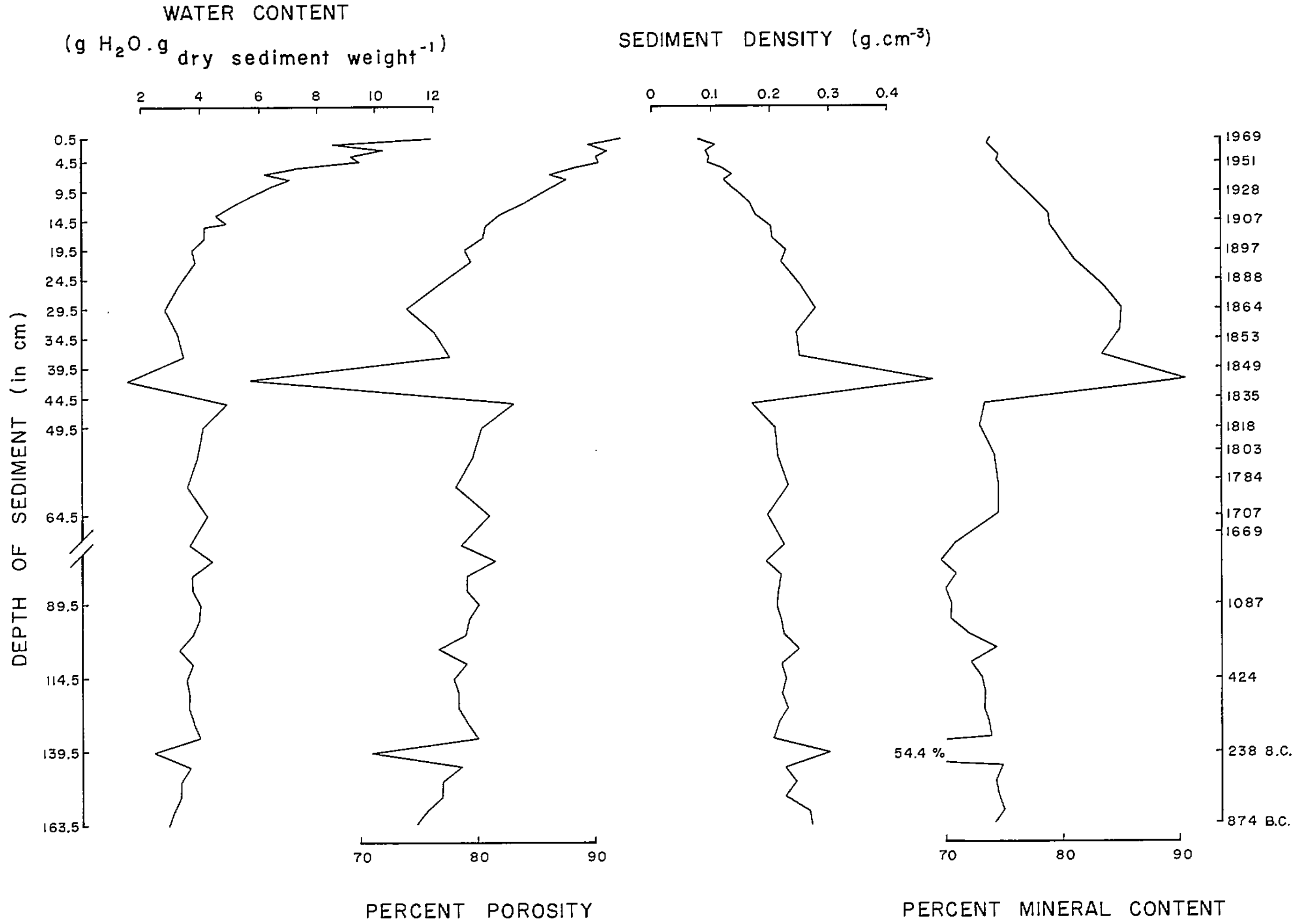

Fig. 13. Water content, porosity, sediment density, and mineral content as functions of sediment depth.

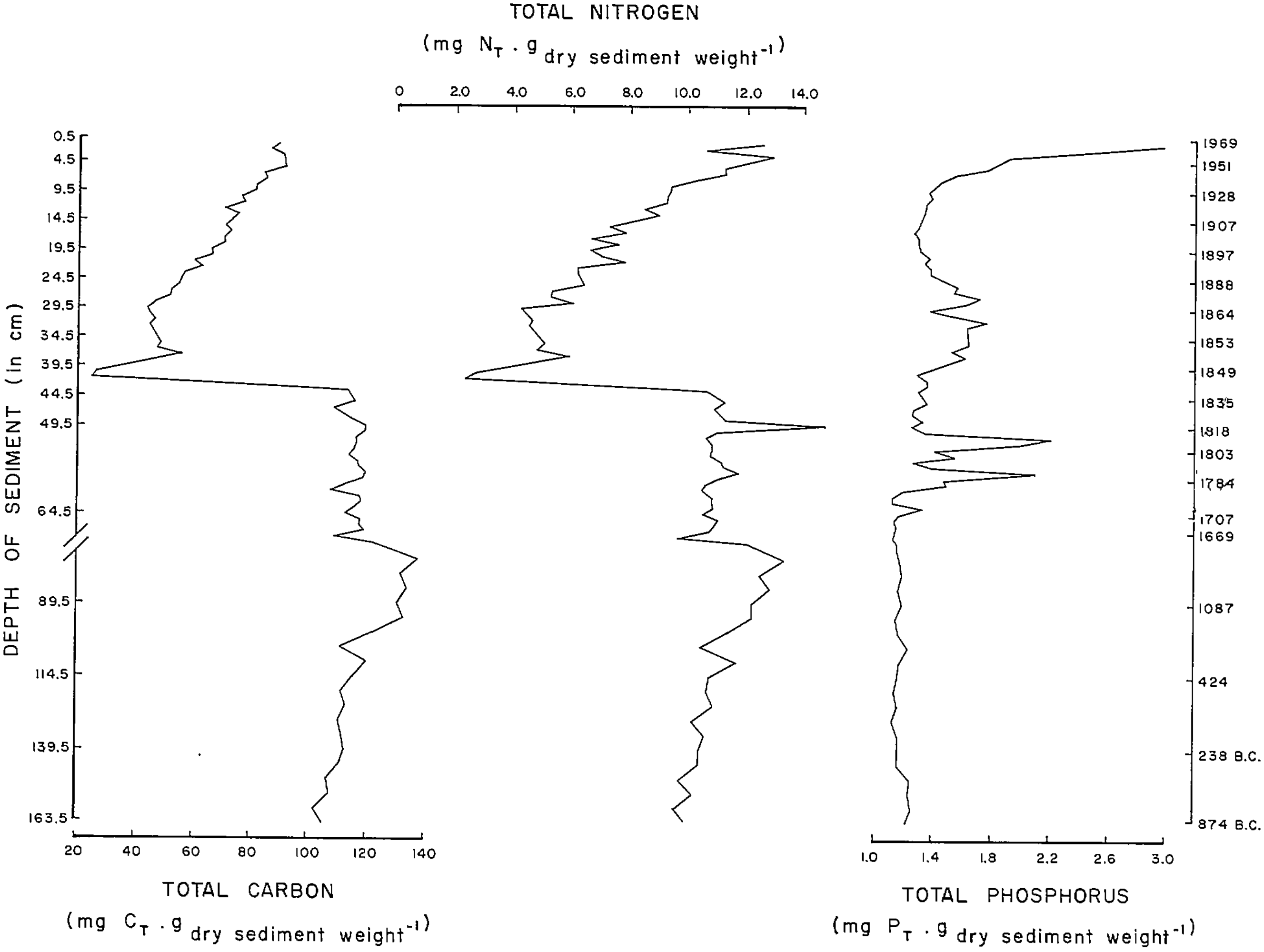

FIG. 14. Total carbon, nitrogen, and phosphorus concentrations as functions of sediment depth.

pean period was associated with a definite event in the accumulation of fine mineral sediments (Warwick unpublished data). The process involved two mechanisms: the arrival of fine mineral sediments at the sediment–water interface first trapped any phosphorus that pooled at the sediment surface, then proceeded to bring down any phosphorus present in the water column (in whatever form) to the sediments. Although the high concentrations in surface sediments of the core may be the result of the increasing input of phosphorus from cultural sources in recent times, they probably represent the migration of phosphorus from the deeper sediments and its pooling in the surficial sediments. The progressive decline in absorptive sites available to bind phosphorus in the sediments (indicated by the progressive decline in the accumulation of fine clay mineral sediments) combined with the progressive increase in the organic content in the surface sediments (which reduced the capacity of the available sites for phosphorus adsorption) were instrumental, in part, in causing the pooling in the surficial sediments.

3.4.1.2 Organic matter and organic carbon — Concentrations of organic matter determined by loss on ignition, and organic carbon determined by subtracting inorganic carbon (GSP) from total carbon (CHN), were of limited interpretive value as indices of cultural eutrophication. In both cases (Fig. 15), concentrations in the most recent sediments were less than those throughout the older sediments. These concentration profiles (like those for carbon and nitrogen) were markedly influenced by the accumulation of fine mineral sediments (Warwick unpublished data).

3.4.1.3 Organic carbon:total nitrogen — The ratio between organic carbon and total nitrogen provided an excellent measure of aquatic productivity. The profile for the C_O:N_T ratio (Fig. 16) is described by the highly significant ($P < 0.01$, d.f. 1,85, $F = 10.64$) third order polynomial regression equation

$$Y = 7.266025 + 0.087412x - 0.000800x^2 - 0.000002x^3$$

The plot of the curve clearly demonstrates the rapid increase in the rate of eutrophication in the Bay of Quinte, particularly in the recent period.

Corroborative evidence (Warwick unpublished data) confirms the increased aquatic productivity in the overlying water column shown by the C_O:N_T curve. Carbon and nitrogen expressed in absolute terms show that greater amounts of carbon-containing materials are currently reaching the sediments than in the past. At present, an estimated 1.72 mg $C_T \cdot cm^{-2} \cdot yr^{-1}$ is accumulating in the surface sediments compared to an average 1.01 mg $C_T \cdot cm^{-2} \cdot yr^{-1}$ in the older sediments, an increase in total carbon of 70%. Comparable terms for nitrogen were 0.29 mg $N_T \cdot cm^{-2} \cdot yr^{-1}$ in the most recent sediments and 0.10 mg $N_T \cdot cm^{-2} \cdot yr^{-1}$ in the older sediments, an increase in total nitrogen of 202%. The steady increase in the organic carbon to total carbon ratio in the surface sediments indicates that most increases in carbon content in more recent sediments were due to increased accumulation of the organic fraction. This proportionately greater organic content, which indicates a qualitative change in the total carbon fraction, is confirmed by aspects of the ratio between organic matter and organic carbon discussed below.

3.4.2 QUALITY OF SEDIMENT CARBON MATERIALS

3.4.2.1 Organic matter:organic carbon ratio — The ratio between organic matter and organic carbon (Fig. 15) provides a measure of the breakdown of carbon material accumulating in the sediments. Ratio values range in extremes from those characteristic of organic material that has been completely oxidized (1.94–2.05) to those characteristic of organic material that has been buried more or less intact (3.37). Values more characteristic of normal lake decomposition processes range from those characteristic of recalcitrant carbon (2.2), left after bacterial decomposition under oligotrophic conditions, to higher values (2.4) characteristic of organic material less well decomposed by bacteria under the higher accumulation rates of eutrophic lakes. The high values (2.6–2.7) in the most recent sediments probably represents organic material recently deposited at the sediment surface and currently undergoing active decomposition (Warwick unpublished data).

3.4.2.2 Total nitrogen:total phosphorus and organic carbon:total phosphorus — The profiles of the N_T:P_T and C_O:P_T ratios are similar to those of total nitrogen and phosphorus, but modified by the phosphorus profile. The value of the ratios as an index of the nutritional quality of the remains of sediment organic material has not been established adequately (Warwick unpublished data).

3.4.3 OTHER SEDIMENT QUALITATIVE FEATURES

3.4.3.1 Ferromanganese micronodules — The ferromanganese micronodule horizon around

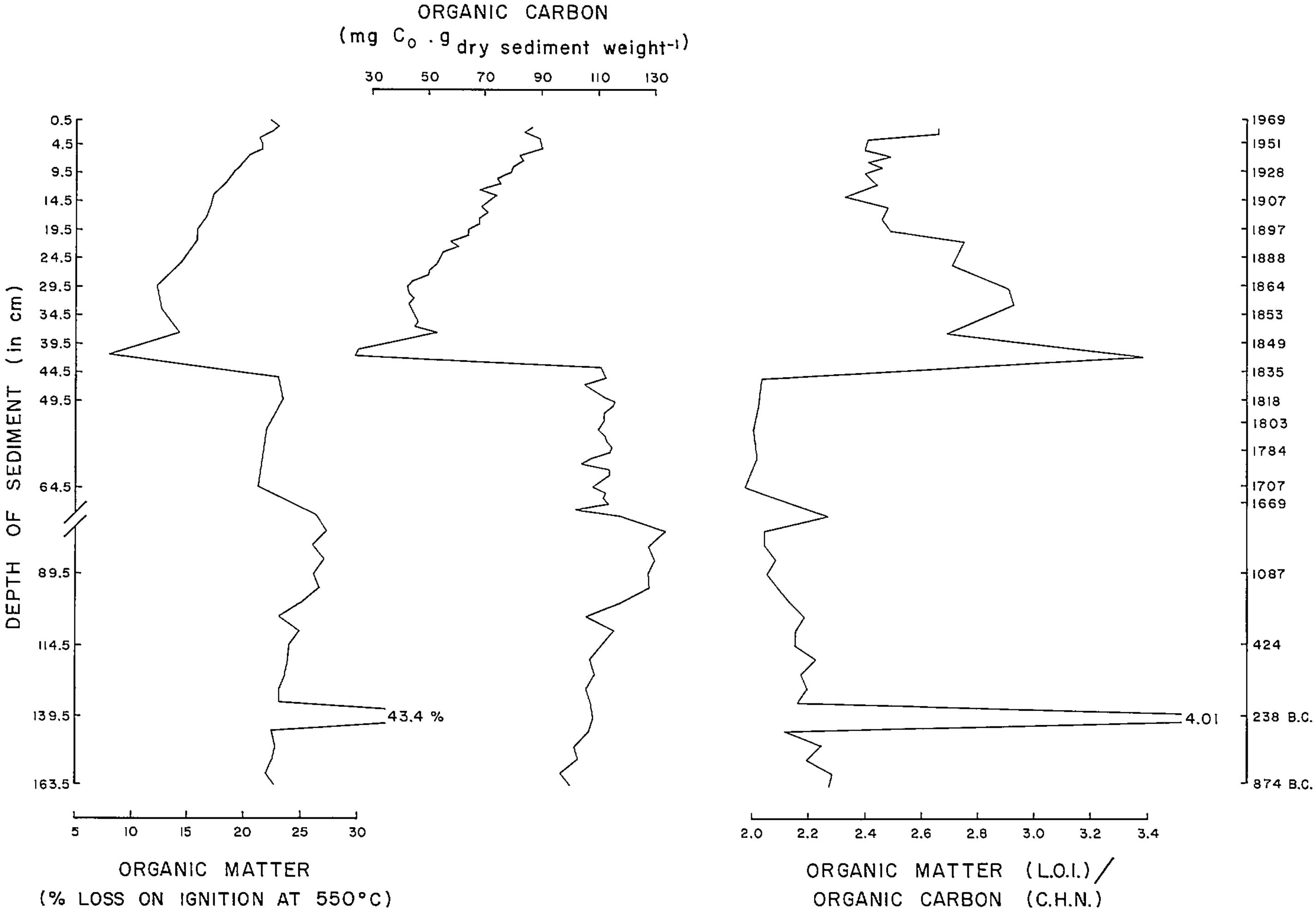

FIG. 15. Organic matter, organic carbon, and the ratio of organic matter:organic carbon as functions of sediment depth.

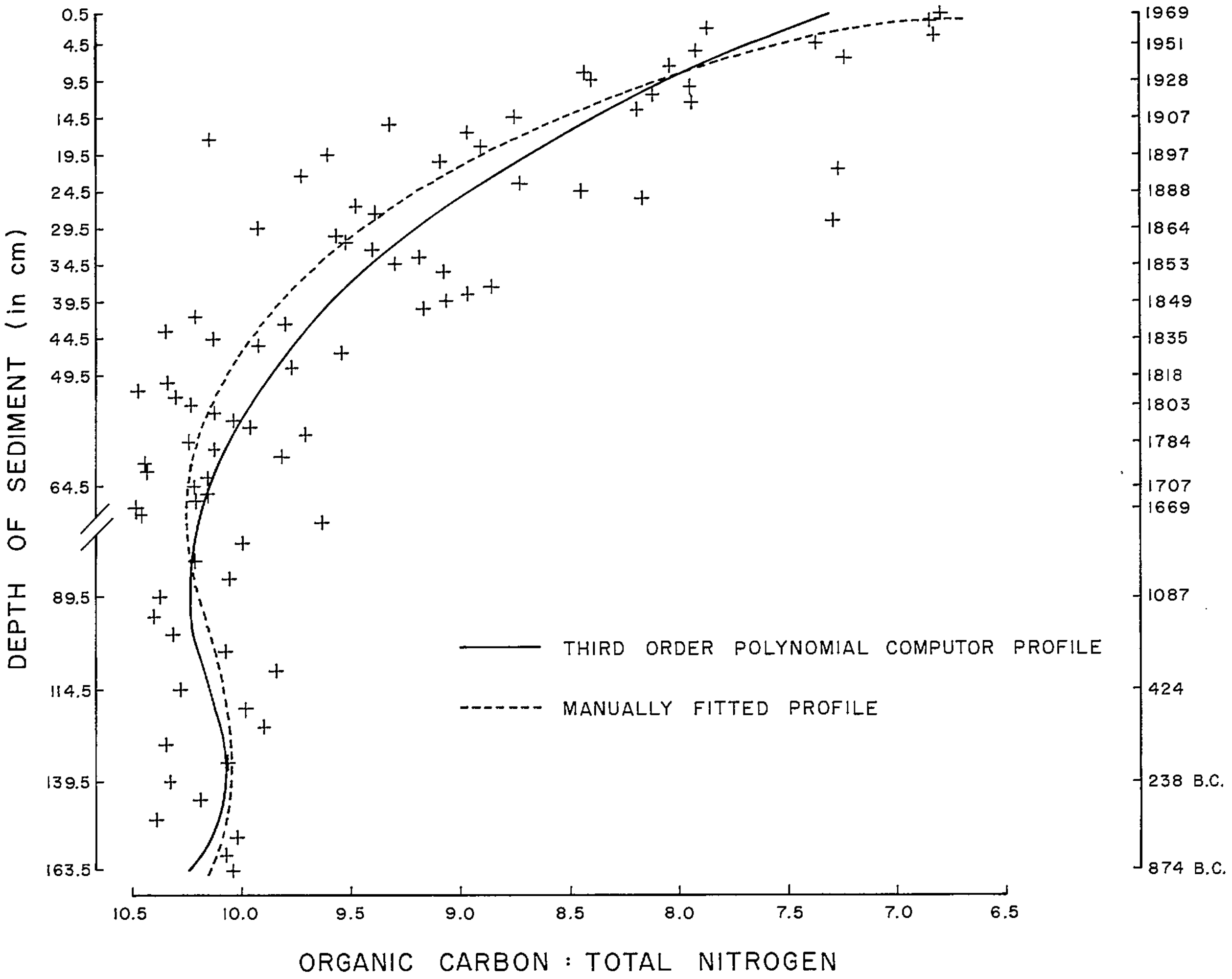

FIG. 16. Organic carbon:total nitrogen ratio as a function of sediment depth.

41.5–40.5 cm was made up of particles highly enriched in iron compared to manganese; the Fe:Mn ratio of 41.94 is considerably higher than that given for ferromanganese concretions from Big Bay, Bay of Quinte, by Damiani et al. (1973: 401) and considerably greater than ratios quoted for marine concretions by Mero (1965). Evidence from the core suggests the particles are of biological origin, but physical–chemical processes of formation may not be ruled out (Warwick unpublished data).

3.5 Biological Parameters

3.5.1 FAUNAL ANALYSES

A total of 11,972 unrated chironomid remnants was recovered for analysis from the Glenora-B core sediments; on a rated basis this figure was reduced to 11,055.5 rated specimens. A total of 158 taxa was enumerated during the course of the study.

3.5.1.1 Major subgroups — The largest number of chironomid taxa (100) was recovered from the sediments at 114.5 cm, compared to an average 87 found in the sediments throughout the older portions of the core (Table 9). The number of taxa declined steadily in more recent sediments (above 44.5 cm) and reached a minimum (18) in the surface sediments.

The largest number of taxa in each major subgrouping of the Chironomidae was recorded, in descending order, for the Orthocladiinae, Chironomini, Tanytarsini, and Prodiamesinae and Diamesinae (Table 9). The order of the first four subgroups is no doubt due largely to the degree to which individual species could be identified within each subgroup. The low numbers of Prodiamesinae and Diamesinae taxa primarily reflect the redeposited nature of the fauna.

The increase in the total volume of fresh sediment analyzed for chironomid remains, undertaken to maintain a minimum 200 chironomid remnants for population estimates in the more recent sediments, is apparent in Table 9.

The largest number of specimens (1486) was recovered from 114.5 cm, the same interval from which the largest number of taxa was recovered (Table 10). The number of specimens declined rapidly from an average 1138 specimens in the older portions of the core (159.5–64.5 cm) to a minimum (55) in the surface sediments. The decline in total specimens (above 64.5 cm) preceded the decline (above 44.5 cm) noted in the total taxa.

The largest number of specimens in each major subgrouping of the Chironomidae was almost the inverse of the order of the number of taxa: these, in descending order, were Tanytarsini, Chironomini, Tanypodinae, Orthocladiinae, and Prodiamesinae and Diamesinae (Table 10). The numbers of Tanytarsini specimens remained generally high up to 29.5 cm, in contrast to the other groups which began to decline above 64.5 cm.

The numbers of specimens per unit volume of fresh sediment began to decline above 89.5 cm, reached a minimum at 39.5 cm, rose slightly to 24.5 cm, then declined steadily to the surface sediments (Table 10).

Changes in the percentage composition of each major Chironomidae subgrouping at each sampling interval (Fig. 17) demonstrate that the percentage composition of the fauna was relatively constant throughout the older sediments, but underwent considerable change in more recent sediments. Initial changes involved a rapid increase in the Tanytarsini and the consequent decline (particularly pronounced in the Chironomini) in the other subgroups. The greater proportion of the Tanytarsini fauna involved in the increase that reached a maximum at 29.5 cm, belonged to Tanytarsini type 7 (including specimens resembling Hofmann's (1971b: 48, 50) *Tanytarsus* spec. *C* and/or *Paratanytarsus*). The subsequent decline in the Tanytarsini was paralleled by a rapid increase in the Chironomini, and, to a lesser extent, the Tanypodinae. Increases in the latter two subgroups in the more recent sediments were due almost entirely to the increased abundance of *Chironomus* and *Procladius*, respectively. Numerical data for Fig. 17 are in Appendix 5.

3.5.1.2 Individual taxa — Many individual taxa in the older parts of the core were progressively phased out in the more recent sediments (Fig. 18). The total number of taxa declined abruptly between 44.5 and 34.5 cm, more slowly between 29.5 and 4.5 cm, and then more sharply again in the surface (0.5 cm) sediments. The discrepancy between the total number of taxa and the number of original taxa that persisted throughout the sediment profile shows the degree of interchange in the fauna, as original types absent at certain intervals became reestablished in the population, or completely new taxa appeared. It is apparent that the numbers of new species added, or the reappearing types, did not make up for the attrition suffered by the original faunal assemblage, particularly in the more recent sediments.

The interchange of taxa is apparent in Fig. 19, where the presence of individual taxa in the sedimentary profile is plotted. *Cricotopus (Cricotopus)*

TABLE 9. Number of taxa, total numbers of taxa, and total size of sample (number of replicates × replicate size in cm^3 of fresh sediment) for major Chironomidae groupings at each sampling interval.

Sample interval median (*cm*)	Numbers of taxa					Total taxa (S)	Total sample size (no. × *cm*^{3})
	Chironominae		Orthocladiinae	Prodiamesinae and Diamesinae	Tanypodinae		
	Chironomini	Tanytarsini					
0.5	7	5	4	–	2	18	4 × 3
4.5	17	7	10	–	7	41	7 × 3
9.5	13	7	7	–	6	33	6 × 3
14.5	14	6	11	–	9	40	7 × 3
19.5	15	7	13	–	6	41	6 × 3
24.5	17	9	16	–	9	51	4 × 3
29.5	14	9	11	–	10	44	4 × 3
34.5	16	8	13	–	8	45	4 × 3
39.5	19	9	24	1	12	65	4 × 3
44.5	25	10	31	2	17	85	4 × 3
49.5	25	11	37	1	15	89	4 × 3
64.5	25	11	39	1	12	88	5 × 3
89.5	28	11	35	1	14	89	4 × 3
114.5	29	11	45	–	15	100	4 × 3
139.5	25	11	32	2	13	83	4 × 3
163.5	25	12	32	2	17	88	4 × 3
Total	44	12	75	5	22	158	

TABLE 10. Numbers of specimens, total numbers of specimens, and numbers of specimens per cm^3 for the major Chironomidae groupings at each sampling interval.

Sample interval median (*cm*)	Numbers of specimens					Total specimens (N)	Specimens per *cm*^{3}
	Chironominae		Orthocladiinae	Prodiamesinae and Diamesinae	Tanypodinae		
	Chironomini	Tanytarsini					
0.5	26.5	21.5	3.0	–	4.0	55.0	4.6
4.5	145.5	97.0	12.0	–	28.0	282.5	13.5
9.5	89.0	98.0	13.0	–	14.0	214.0	11.9
14.5	114.0	206.0	17.5	–	30.0	367.5	17.5
19.5	69.0	191.0	29.0	–	20.0	309.0	17.2
24.5	92.5	422.5	56.5	–	32.0	603.5	50.3
29.5	51.0	439.5	61.5	–	32.0	584.0	48.7
34.5	69.5	390.5	31.0	–	31.0	522.0	43.5
39.5	84.0	269.0	56.5	1.0	36.0	446.5	37.2
44.5	271.5	338.5	111.5	2.0	163.0	886.5	73.9
49.5	232.0	258.5	116.0	1.0	139.0	746.5	62.2
64.5	353.0	452.0	181.0	0.5	211.0	1,197.5	79.8
89.5	351.5	367.0	151.5	1.0	239.0	1,110.0	92.5
114.5	484.0	510.5	243.0	–	248.0	1,486.0	123.8
139.5	349.0	409.0	149.0	2.0	224.0	1,133.0	94.4
163.5	360.5	396.0	158.0	3.5	194.0	1,112.0	92.7
Total	3142.5	4866.5	1390.5	11.0	1645.0	11,055.5	

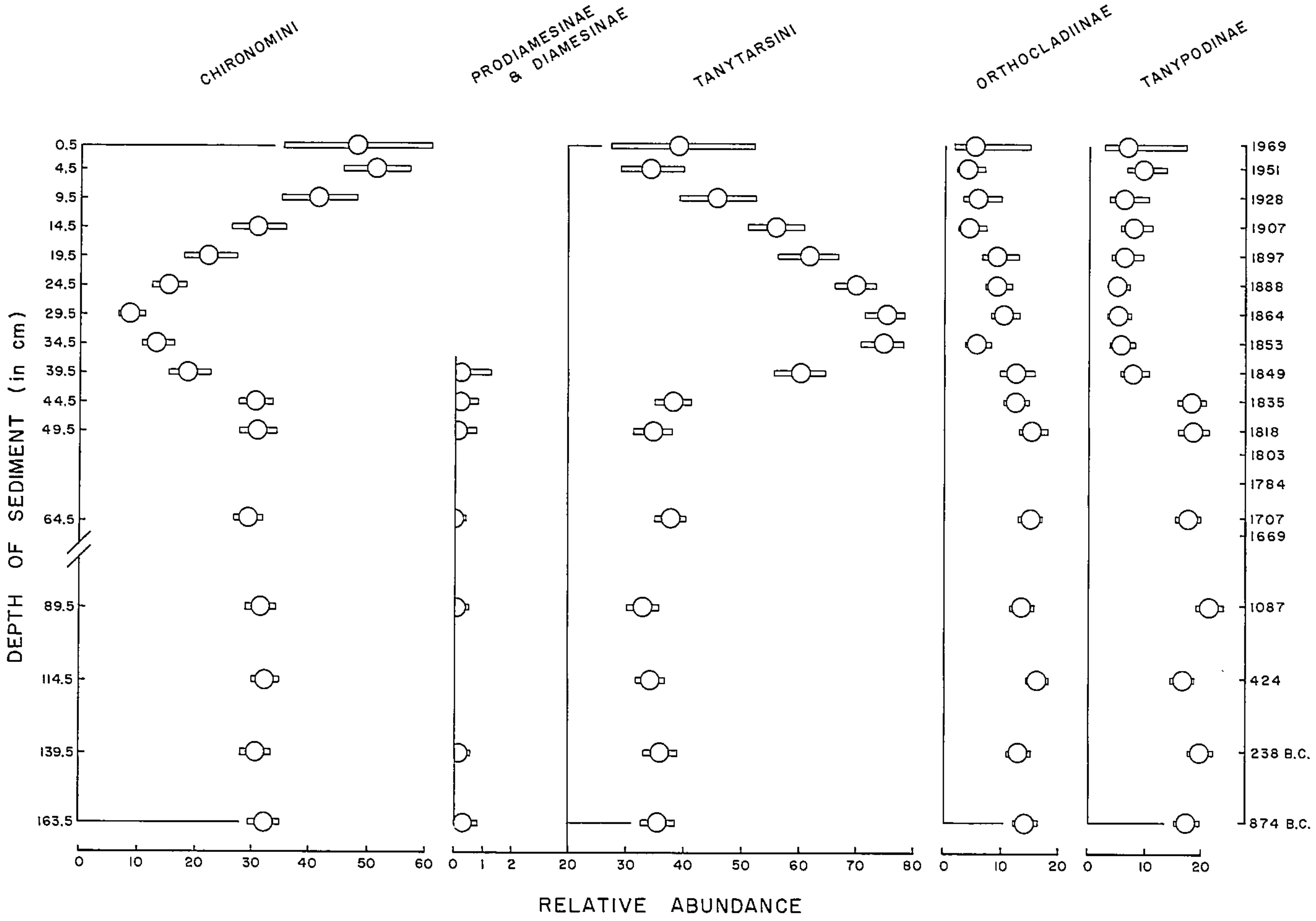

FIG. 17. Relative abundance of each major Chironomidae subgrouping as functions of sediment depth. The 95% confidence limits, shown as horizontal bars, were calculated according to Mosimann (1965: 643). Due to graphical limitations, upper confidence limits only are shown for the Prodiamesinae and Diamesinae.

cf. *tibialis* (Meig.) (taxon number 10), present in the original fauna for example, was absent at 114.5 cm, but reappeared again at 89.5 cm. True deepwater taxa like *Stictochironomus* (taxon number 122) did not appear in the original fauna, but were added to the chironomid community as environmental conditions changed. Not all the new species were true lake types, however; many like *Pseudosmittia* cf. *gracilis* Goetgh. (taxon number 146) were redeposited in the deepwater sediments from elsewhere. The total number of specimens in each chironomid taxon represented in the bar graph (Fig. 19) is summarized for each selected sampling interval in Appendix 6.

3.5.1.3 Trophic characterization — Distribution of the 17 taxa used in trophic characterization (Table 11) shows that significant changes have occurred in the succession of chironomid remains in the core sediments, and these changes, in part at least, are associated with changes in the trophic status of the Bay of Quinte. Faunal assemblages recovered from the older portions of the core indicate that oligotrophic conditions persisted in the Bay of Quinte before the arrival of European colonists. After their arrival, trophic conditions in the bay changed rapidly, and faunal assemblages found in the most recent sediments indicate that moderately eutrophic conditions exist in the bay at the present time.

3.5.1.4 Habitat characterization — The chironomid taxa were separated (Warwick unpublished data) according to habitat preference on the basis of the best currently available ecological data (Table 12). Lake types were separated into four categories as follows:

Lake Group 1—taxa restricted to the littoral zone often in association with aquatic plants

Lake Group 2—taxa from the littoral zone with a planktonic life stage

TABLE 11. Total rated numbers of specimens of 17 diagnostic Chironomidae taxa used to define trophic changes in the Bay of Quinte.

Taxa	Sample interval medians (*cm*)															
	0.5	4.5	9.5	14.5	19.5	24.5	29.5	34.5	39.5	44.5	49.5	64.5	89.5	114.5	139.5	163.5
Zalutschia cf. *lingulata* Sæth.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2.0
Nanocladius (Nanocladius) cf. *incomptus* Sæth.	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0	–	–
Nanocladius (Nanocladius) cf. *distinctus* (Mall.)	–	–	–	–	–	–	–	–	–	–	–	–	0.5	0.5	–	0.5
Monodiamesa depectinata Sæth.	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	–	–
Pagastiella cf. *ostansa* (Webb)	–	–	–	–	–	–	–	–	–	2.0	–	1.0	3.0	5.0	2.0	1.0
Abiskomyia Edw.	–	–	–	–	–	–	–	–	1.0	–	–	–	–	1.0	–	–
Heterotrissocladius sp. *B* Sæth.	–	–	–	–	–	–	–	–	1.0	–	1.0	–	–	–	–	–
Nanocladius (Nanocladius) cf. *balticus* (Palm.)	–	–	–	–	–	–	–	–	1.0	–	–	–	–	–	–	–
Stictochironomus Kieff.	–	–	–	–	–	–	–	1.0	1.0	1.0	–	1.0	1.0	–	–	–
Saetheria tylus (Town.)	–	–	–	–	–	–	1.0	–	–	–	–	–	–	–	–	–
Paracladopelma galaptera (Town.)	–	–	–	–	–	1.0	–	–	–	–	–	–	–	–	–	–
Harnischia curtilamellata (Mall.)	–	–	–	–	1.0	3.0	4.0	3.0	3.5	2.0	1.0	4.0	5.5	2.0	3.5	4.0
Heterotrissocladius changi Sæth.	–	0.5	0.5	–	2.5	13.5	11.5	10.0	7.0	6.0	2.0	5.5	5.0	9.0	10.0	4.5
Phaenopsectra sp. *1*	–	1.0	1.0	2.0	–	–	1.0	–	1.5	2.0	3.5	6.5	5.0	6.5	6.5	7.0
Einfeldia insolita gr. sp. *1*	1.0	1.0	1.0	–	–	–	–	–	–	1.0	1.0	–	–	–	2.0	–
Micropsectra spp.	1.0	6.5	3.0	–	16.0	51.5	53.0	95.5	74.0	46.0	13.0	21.0	20.5	41.0	50.5	41.0
Chironomus spp.	16.5	85.0	53.5	65.5	37.5	34.0	16.0	24.5	17.5	88.5	60.0	92.0	35.5	90.5	55.5	68.5

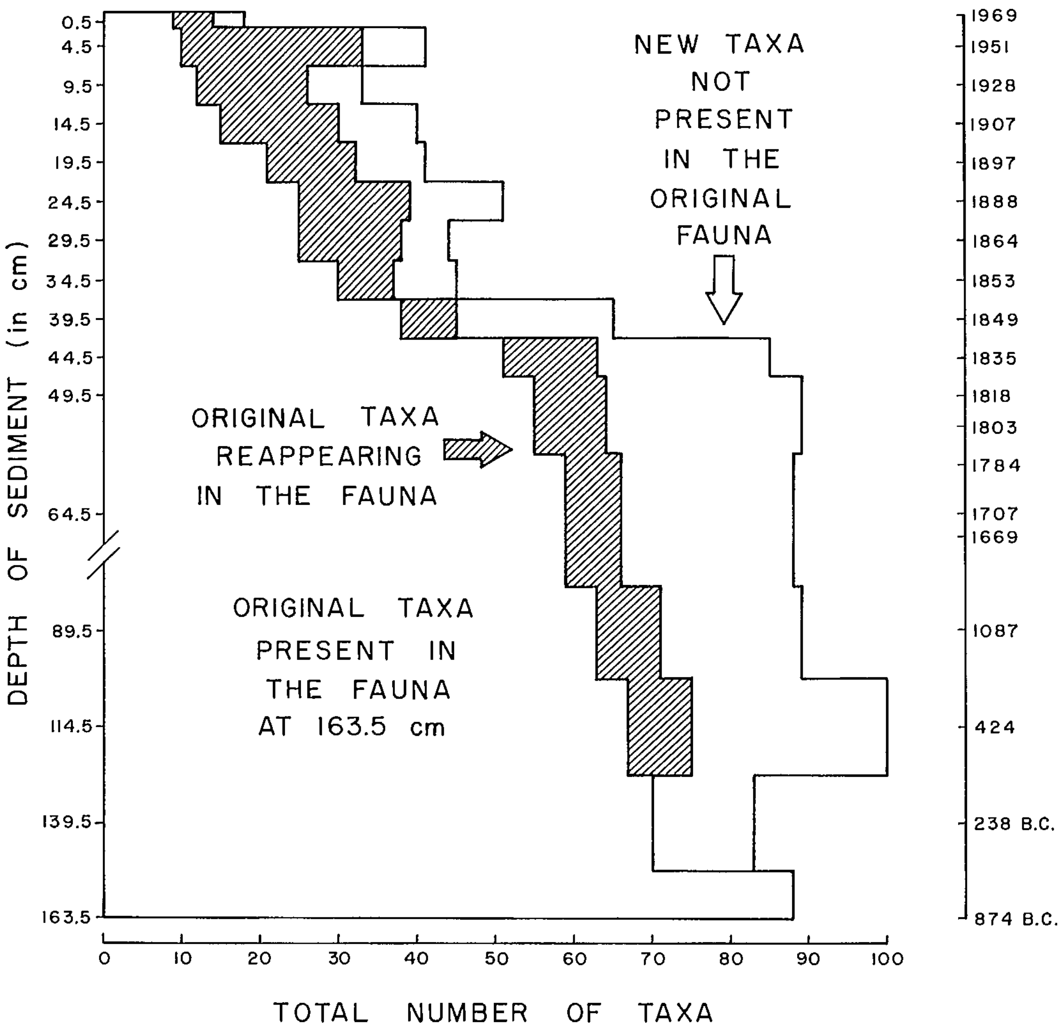

FIG. 18. Schematic summary of the numbers of chironomid taxa found at selected intervals in the sediments of the Glenora-B core indicating the general decline in number of taxa in more recent sediments. Original taxa reappearing in the fauna are indicated by the crosshatched area.

Lake Group 3—taxa whose distribution extends into the sublittoral zone, often in association with aquatic plants

Lake Group 4—taxa whose distribution extends into the profundal zone

The Lake Group divisions do not necessarily denote depth preference, but refer generally to the maximum depth to which individual taxa can range under ideal conditions. Totals for the columns representing the total number of taxa and percentage of total fauna (Table 12) slightly exceed the actual values because five taxa (*Parachironomus* sp. *2*, *Xenochironomus (Xenochironomus)* sp. *1*, "*Paracladius*" cf. *triquetra* Chern., *Phaenopsectra* ("*Phaenopsectra*") sp. *2*, and the Genus near *Heterotrissocladius*) fall into more than one category.

Lake Group 1

A number of taxa were recovered from the deepwater sediments that originated from the littoral habitat of Lake Group 1. These included *Glyptotendipes*, *Endochironomus*, *Tribelos*, *Einfeldia pagana* group sp. *1*, *Beckiella tethys* (Town.), *Psectrocladius* cf. *septentrionalis* Chern., *Psectrocladius (Allopsectrocladius)* sp., *Cri-*

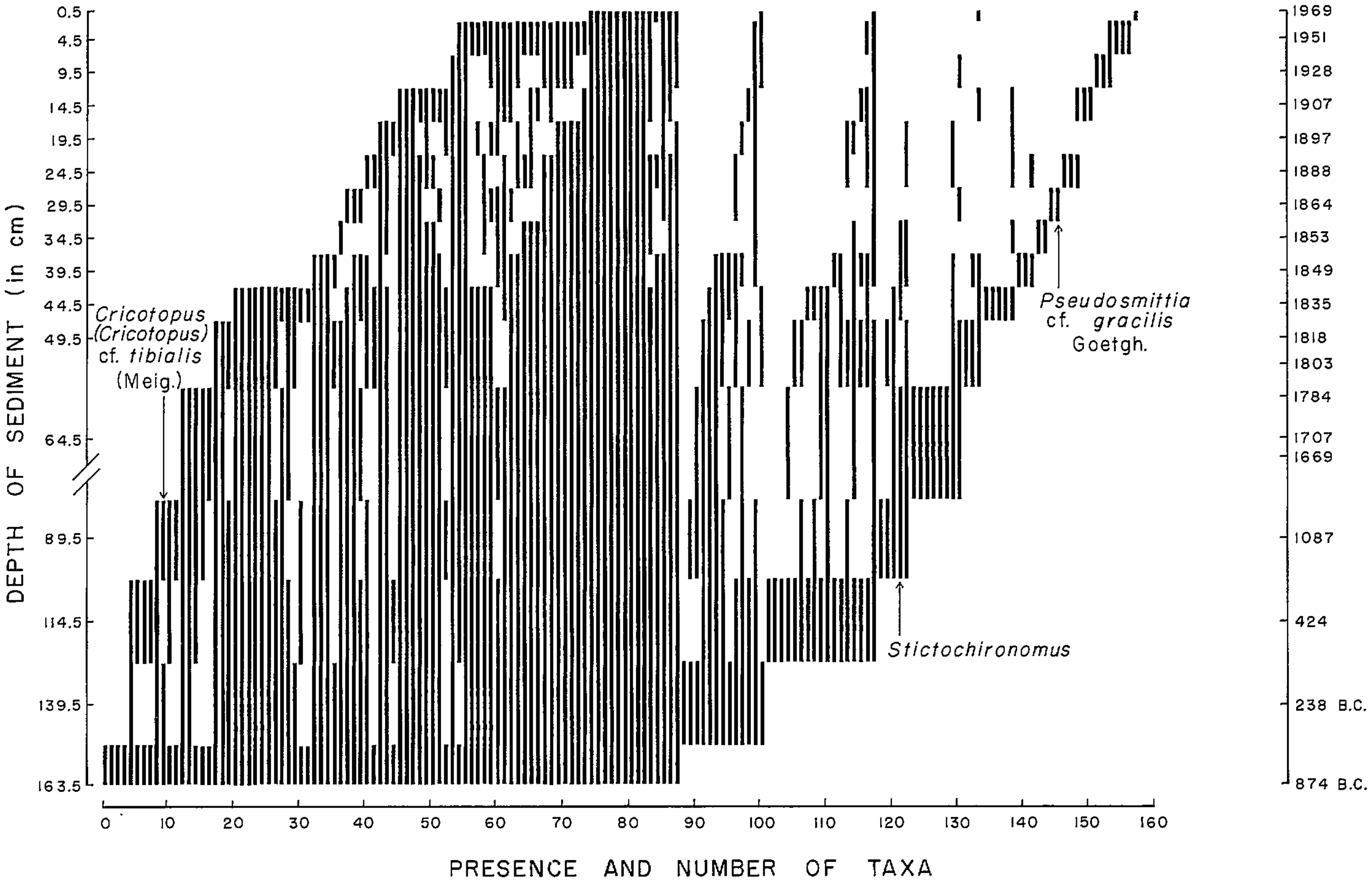

FIG. 19. Schematic summary of distribution of the chironomid taxa from the Glenora-B core. The occurrence of individual taxa at each selected sampling interval is outlined in bar form. Discontinuous distributions are shown by interrupted bars. Original taxa generally appear on the left-hand side of the figure; new or redeposited taxa on the right-hand side.

TABLE 12. Chironomid fauna recovered from Glenora-B core characterized by habitat preference.

Category	Total taxa[a]	Percentage total taxa	Percentage total fauna[a]
Lake Group 1	32	20.25	1.85
Lake Group 2	8	5.06	3.65
Lake Group 3	26	16.46	2.26
Lake Group 4	65	41.14	87.92
Terrestrial fauna	8	5.06	0.24
River fauna	12	7.59	0.60
New types	11	6.96	2.24
Unidentified			3.05

[a] Column totals are exaggerated because some individual taxa fall into more than one category.

cotopus (Isocladius) spp. *1* to *8*, and *Potthastia longimanus* Kieff. The following taxa of the genus *Orthocladius* were also included in Lake Group 1: *Orthocladius* spp. *1* to *4*, *Orthocladius* spp., and cf. *Orthocladius* spp. *1* and *2*. Although the genus is generally considered rheophile, a number of species live in the well-oxygenated surf zone in lakes. The erratic distribution of the majority of *Orthocladius* taxa found in the core suggests their original habitat was the surf zone. However, the distribution of *Orthocladius* sp. *1* suggests that of a rare component of the deepwater community. This may indeed be true because at least one species, *Orthocladius consobrinus* (Holmgr.), has been reported from profundal waters (Brundin 1949: 712, sub *O. crassicornis* Goetgh.). Because of the uncertainty involved in identification of the taxa, however, all members of the genus have been retained in Lake Group 1.

A number of other taxa, whose inclusion in this group may be questionable, have been assigned to the group on the basis of the limited available ecological data and their erratic distribution in the core sediments. These included *Polypedilum (Polypedilum) fallax* gr., *Polypedilum (Polypedilum)* cf. *ophioides* Town., *Cricotopus (Cricotopus)* cf. *albiforceps* (Kieff.), *Cricotopus (Cricotopus)* nr. *vierriensis* Goetgh., *Tanypus* cf. *neopunctipennis* Subl., *Thienemannimyia* gr. sp. *1*, and *Thienemannimyia* gr. sp. *3*. The last two taxa probably represent species of the littoral genus *Conchapelopia*. Two taxa, *Phaenopsectra ("Phaenopsectra")* sp. *2* and *"Paracladius"* cf. *triquetra* Chern., are also included in Lake Group 1 on the basis of distributional records. In total, the taxa included in Lake Group 1 represented only 1.85% of the total fauna.

Lake Group 2

Larvae from two genera made up Lake Group 2. These included *Corynoneura* spp. *1* to *5* and *Parachironomus* spp. *1* and *2*. Although the generic position is not precisely known, *Parachironomus?* sp. was also included in the group. Primarily littoral forms, the group made up 3.65% of the total fauna. Of this, members of the genus *Corynoneura* Winn. formed the greater (2.42%) proportion. The planktonic life stages of the larvae contained in Lake Group 2 undoubtedly accounts for their proportionately high abundance in deepwater sediments.

Lake Group 3

The majority of larvae in this group range into the deeper waters of the sublittoral zone through their association with aquatic vegetation. Included in this group were *Xenochironomus (Xenochironomus) xenolabis* (Kieff.), *Xenochironomus (Xenochironomus)* sp. *1*, *Polypedilum (Polypedilum)* cf. *aviceps* Town., *Polypedilum (Pentapedilum)* cf. *sordens* v.d. Wulp, *Polypedilum (Pentapedilum)* cf. *tritum* (Walk.), *Saetheria tylus* (Town.), *Stenochironomus*, *Psectrocladius (Psectrocladius)* type *1*, *Abiskomyia* sp., *Cricotopus (Cricotopus)* cf. *tibialis* (Meig.), *Cricotopus (Cricotopus)* cf. *algarum* (Kieff.), *Cricotopus (Cricotopus)* cf. *flavocinctus* (Kieff.), *Cricotopus (Cricotopus)* cf. *cylindraceus* (Kieff.), and *Nanocladius (Nanocladius)* cf. *balticus* (Palm.). Nine additional taxa of the genus *Cricotopus* v.d. Wulp were also included in the group, because of their known association with aquatic plants. These included *Cricotopus (Cricotopus)* cf. *pirifer* Hirv., *Cricotopus (Cricotopus)* cf. *fuscus* (Kieff.), *Cricotopus (Cricotopus)* cf. *slossonae* Mall., *Cricotopus (Cricotopus)* cf. *annulator* Goetgh., *Cricotopus (Cricotopus)* cf. *patens* Hirv., *Cricotopus (Cricotopus)* cf. *vierriensis* Goetgh., *Cricotopus (Cricotopus)* nr. *patens* Hirv., *Cricotopus (Cricotopus) bicinctus* (Meig.), and *Cricotopus (Cricotopus)* spp. unidentified. *Phaenopsectra ("Phaenopsectra")* sp. *2* and *"Paracladius"* cf. *triquetra* Chern. have tentatively been included in Lake Group 3 as well, because of their reported association with aquatic plants and their distribution in the core sediments. *Hydrobaenus* spp. was also included because of its reported depth preference; its distribution in the core also suggests it may penetrate into the deeper water habitat. The taxa in Lake Group 3 formed 2.26% of the total fauna.

Lake Group 4

The largest number of taxa and individuals recovered from the core sediments were types capable of penetrating into the profundal zone, environmental conditions permitting. These included *Chironomus*, *Dicrotendipes*, *Microtendipes*, *Paratendipes*, *Polypedilum (Tripodura) simulans* Town., *P. (T.) halterale* (Coq.) or *P. (T).*

digitifer Town., *Cryptochironomus, Cladopelma, Harnischia curtilamellata* (Mall.), *Stictochironomus, Pseudochironomus, Phaenopsectra* sp. *1*, *Cryptotendipes, Paralauterborniella nigrohalteralis* (Mall.), *Lauterborniella, Pagastiella* cf. *ostansa* (Webb), *Demicryptochironomus, Paracladopelma galaptera* (Town.), *Constempellina, Stempellinella, Stempellina, Micropsectra* spp., Tanytarsini types 1 to 8, *Heterotrissocladius changi* Sæth., *Heterotrissocladius* sp. *B* Sæth., *Parakiefferiella* cf. *bathyphila* Kieff., *Psectrocladius (Psectrocladius)* type 2, *Psectrocladius (Psectrocladius)* type 3, *Zalutschia* cf. *lingulata* Sæth., *Brillia longifurca* type, *Cricotopus (Cricotopus)* cf. *triannulatus* (Macq.), *Nanocladius (Nanocladius)* cf. *distinctus* (Mall.), *Nanocladius (Nanocladius)* cf. *incomptus* Sæth., cf. *Paracladius* sp., *Apsectrotanypus, Ablabesmyia (Karelia) peleensis* (Wall.), *Thienemannimyia* gr. sp. *2*, Tanypodinae sp. *2*, *Labrundinia* cf. *pilosella* (Loew), Tanypodinae sp. *3*, *Procladius (Procladius)* cf. *culiciformis* (L.), *Procladius (Procladius)* cf. *freemani* Subl., *Procladius (Procladius)* cf. *denticulatus* Subl., *Procladius (Psilotanypus)* cf. *bellus* (Loew), *Procladius* (immatures), cf. *Procladius* (immatures), cf. *Procladius (Psilotanypus) bellus* (Loew), *Procladius* (abnormal) sp. *1*, *Procladius* (abnormal) sp. *2*, Tanypodinae sp. *1*, Tanypodinae spp., and *Monodiamesa depectinata* Sæth. *Synorthocladius semivirens* Kieff. was included in this group because of its strong representation in the sediments; its inclusion as a deepwater form differs somewhat from its distribution as yet reported. The Genus near *Heterotrissocladius* was also included in this group on the basis of its strong representation; it obviously is a deepwater form. *Epoicocladius flavens* (Mall.) was included through its association with the common mayfly, on which it is parasitic. *Einfeldia insolita* gr. spp. *1* and *2* were tentatively included in Lake Group 4 (Sæther personal communication) as were *Polypedilum (Polypedilum) convictum* (Walk.) or *P. (P.) obtusum* Town., *Polypedilum (Tripodura) scalaenum* (Schrank), *P. (T.) parascalaenum* Beck or *P. (T.) albinodus* Town., and *Coelotanypus*. The 65 taxa in Lake Group 4 constitute 87.92% of the total fauna recovered from the core sediments.

Other groups found in the core included:

Terrestrial or semiterrestrial fauna

Eight taxa were recovered from the core sediments that were washed into deep water from a terrestrial or semiterrestrial habitat. These included *Pseudosmittia?* sp., *Smittia?* sp., *Paraphaenocladius* sp., *Pseudosmittia* cf. *gracilis* Goetgh., *Metriocnemus* sp., *Limnophyes* sp., cf. *Chaetocladius* sp., and cf. *Smittia* sp. In total, the terrestrial or semiterrestrial taxa formed 0.24% of the total fauna.

River fauna

Twelve taxa washed in from running-water habitats were recovered. These included *Cricotopus (Cricotopus)* cf. *tremulus* (L.), *Kiefferulus* sp., *Eukiefferiella fuldensis* type, *Eukiefferiella similis* type, *Eukiefferiella claripennis* type, *Eukiefferiella coerulescens* type, *Orthocladius (Euorthocladius)* sp., *Zavrelimyia* sp., *Tokunagaia* sp., *Diamesa* sp. *1*, *Diamesa* sp. *2*, and *Diamesa* sp. *3*. The last five taxa are characteristic of well-oxygenated, fast-running water habitats, and probably originated from the stream that tumbles down the cliff face from Lake-on-the-Mountain into the Bay of Quinte at Glenora, Ont. Representative taxa from the lotic habitat made up only 0.60% of the total fauna.

New types

Eleven new types were recorded that could not be identified from current accounts in the literature. These include Genus near *Microtendipes* spp. *1* and *2*, *Parachironomus* sp. *2*, *Harnischia* sp. *1*, *Xenochironomus (Xenochironomus)* sp. *1*, Chironomini unknown sp. *1*, Genus near *Heterotrissocladius*, *Parakiefferiella* spp. *1* to *3*, and the Genus near *Paracricotopus*. The Genus near *Heterotrissocladius* formed by far the most important component (1.71%) of this group, which represented 2.24% of the total fauna.

Three species particularly reflect the semiriverine characteristics of the Bay of Quinte. These included *Cricotopus (Cricotopus)* cf. *cylindraceus* (Kieff.), *Cricotopus (Cricotopus)* cf. *patens* Hirv., and *Beckiella tethys* (Town.). A number of other species recorded from the core sediments, for example *Pseudochironomus* Staeg. and *Harnischia curtilamellata* (Mall.), would fall into this group as well. The species are quoted above to demonstrate that the Bay of Quinte has characteristics of a large river and that the chironomid fauna reflect this fact correspondingly.

Only 3.05% of the total fauna remained unidentified.

3.5.1.5 Live fauna — The composition of live Chironomidae fauna collected at the Glenora site after completion of the coring operation is compared (Table 13) to the remnant fossil chironomid fauna recovered from 0.5, 4.5, and 163.5 cm in the Glenora-B core and Johnson's (1970) faunal lists for the Glenora station. The fauna collected at the time of coring (1972) was clearly dominated by

Chironomus of the *plumosus* type (61.69%) and *Procladius* species (23.88%). Comparison of live fauna with fossil fauna by percentage similarity of community (Table 14) demonstrates that the 1972 live chironomid fauna bore the greatest similarity to Johnson's (1970) live chironomid community, only some similarity with the communities established from the fossil assemblages recovered from 0.5 and 4.5 cm, and the least similarity with that recovered from 163.5 cm. Jaccard's (1912) coefficient of community reveals essentially the same pattern, but also suggests that Johnson's (1970) assemblage may be more closely related to the 0.5 and 4.5 cm fossil assemblages than that of the 1972 live chironomid fauna. Neither live faunal assemblage resembles that at 163.5 cm.

3.5.1.6 Incidence of deformities — A number of deformed specimens were recovered from the core sediments (Table 15). Although the majority were found in live fauna, or in remnants recovered from the most recent sediments, a few were recovered from older sediments. The percentage of deformed specimens of *Chironomus* and *Procladius* has clearly increased in the most recent period.

The deformed larvae were characterized by differing degrees of aberration in the mouthparts, particularly in the mentum and ligula (Fig. 20). Deformations in the mentum of *Chironomus* spp. (1) ranged from differing numbers of outer lateral teeth (Warwick 1979b: 260, fig. 3B$_1$) to gaps in the median tripartite tooth region (4) and rearrangements in the first two lateral teeth (2 and 3). Deformations in *Procladius* generally took the form of shortened and/or broadened outer teeth on the ligula (6 and 7). Some specimens of *Procladius* had differing numbers of teeth (8 and 9). The remainder of the mouthparts appeared normal, although the premandibles of two specimens of *Chironomus* may have been slightly deformed.

TABLE 14. Comparison of the chironomid communities established from live fauna sampling with communities estimated from faunal assemblages at the 0.5, 4.5, and 163.5 cm intervals. Values for coefficient of community and percentage similarity of community are presented in the lower left and upper right, respectively.

Community coefficient	Warwick (1972)	Johnson (1970)	0.5 cm (1969)	4.5 cm (1951)	163.5 cm (874 B.C.)
Warwick (1972)		92.04	48.38	53.21	28.63
Johnson (1970)	0.36		42.74	46.74	22.51
0.5 cm (1969)	0.17	0.33		81.84	40.84
4.5 cm (1951)	0.18	0.35	0.30		43.28
163.5 cm (874 B.C.)	0.06	0.13	0.15	0.35	

TABLE 13. Comparison of live chironomid faunal assemblage collected in 1972 with that of Johnson (1970) and those determined from faunal remains at the 0.5, 4.5, and 163.5 cm intervals.

	Live fauna		Fossil fauna		
	Warwick (1972)	Johnson (1970)	0.5 cm (1969)	4.5 cm (1951)	163.5 cm (874 B.C.)
Chironomus	61.69	67.81	30.00	30.19	6.16
Dicrotendipes	–	0.13	7.27	6.90	4.86
Microtendipes	–	–	1.82	3.54	2.38
Paratendipes	–	0.13	3.62	1.06	1.08
Glyptotendipes	–	–	1.82	0.89	–
Cryptochironomus	1.49	1.06	–	0.71	0.85
Cladopelma	1.00	0.13	–	1.77	2.70
Paralauterborniella nigrohalteralis (Mall.)	–	–	1.82	–	0.27
Einfeldia insolita gr. sp. *1*	–	–	1.82	0.35	–
Micropsectra spp.	–	0.13	1.82	2.30	3.69
Tanytarsini spp.	11.44	5.28	37.27	31.51	27.60
Corynoneura sp. *2*	–	–	1.82	0.35	0.36
Cricotopus (Cricotopus) cf. *triannulatus* Macq.	0.50	–	–	0.35	–
C. (Cricotopus) nr. *vierriensis* Goetgh.	–	–	1.82	–	–
cf. *Smittia* sp.	–	–	0.90	–	–
Procladius spp.	23.88	24.67	7.28	9.27	8.01
Other	–	0.66	0.92	10.81	42.04
Total taxa	6	18	18	41	88

TABLE 15. Distribution of *Chironomus* and *Procladius* in live fauna collected in 1972 and in Glenora-B core sediments showing deformed menta and mandibles.

Class	Depth (*cm*) (*yr*)	*Chironomus* (%)	*Procladius* (%)
Live fauna	0 (1972)	1.49	0.50
Fossil fauna	4.5 (1951)	0.35	0.71
	89.5 (1087)	–	0.09
	139.5 (238 B.C.)	–	0.09

Measurements of head capsule and body walls revealed no abnormal thickening. Pigmentation appeared normal.

3.5.2 COMMUNITY INDICES

Six methods of community analyses were used in interlevel comparisons to characterize changes in the structure of the chironomid communities. Each test clearly indicates that massive changes have occurred in the structure of chironomid communities since the arrival of European colonists and development of a modern society in the bay area.

3.5.2.1 Species diversity — The species diversity index, H(S), and the measure of equitability, ϵ, (Fig. 21) show that the Chironomidae community as a whole was remarkably stable throughout the older sediments[3]. The sharp decline in both indices between 39.5 and 29.5 cm, and the more gradual increase in both indices up to 4.5 cm, suggest that the Chironomidae community was reacting uniformly to the forces suppressing its diversity. In the very surface sediments, however, the sharp decrease in the diversity index, H(S), coincident with the sharp increase in the equitability component, ϵ, suggests that the Chironomidae community has become unstable and poorly adjusted to environmental conditions prevailing at the present time.

An examination of the same indices for each major Chironomidae grouping (Fig. 22) indicates that within the stable Chironomidae community of the older sediments there are minor variations in both indices not apparent in the overall calculation. Generally, the Chironomini and Orthocladiinae tend to vary in concert, possibly as a result of their similar life habits. Variations in the Tanytarsini tend to coincide with those of the Tanypodinae, but not as closely as the first two subgroups. In more recent sediments, the rapid decline in the diversity index, H(S), begins with the Orthocladiinae (44.5 cm), followed by the Tanytarsini (39.5 cm), and the Chironomini and Tanypodinae (34.5 cm). The decline in the Chironomini and Orthocladiinae diversity index is general (although considerably more erratic in the latter) toward the surface sediments, then abrupt in the surface sediment layers. The Tanypodinae diversity index generally follows the same pattern, but that of the Tanytarsini increases abruptly toward the surface sediments after reaching a minimum at 14.5 cm. The equitability function declines generally in more recent sediments then increases again toward the surface sediments. The increase in the equitability function, ϵ, begins with the Orthocladiinae (24.5 cm), followed by the Tanypodinae (9.5 cm), and the Chironomini and Tanytarsini (0.5 cm).

3.5.2.2. Percentage similarity of community — The results of percentage similarity of community analysis, outlined in the matrix of Table 16, show that a number of definite changes have occurred in the chironomid community structure. The most prominent feature of the matrix is the transition zone at 39.5 cm, which effectively divides the core into two distinct sections, and coincides exactly with the point where the diversity index of the Chironomidae began to decline rapidly. Fauna at the different intervals sampled throughout the older portion of the core (below 44.5 cm) appear to be similar. Somewhat closer relationships appear to exist between faunas at 49.5, 64.5, and 114.5 cm and between 139.5 and 163.5 cm. By comparison, fauna in the more recent portions of the core (above 44.5 cm) appear to bear little similarity to that of the older sediments.

The second feature shown in the percentage similarity matrix is the high degree of similarity between faunas of successive intervals throughout the more recent portions of the core. The fact that less and less similarity exists between samples, other than those immediately adjacent to one another, shows that the population composition is steadily changing between successive intervals. As indicated in Fig. 17, this is especially apparent in the portion of the core above 44.5 cm, where the confidence limits of each interval generally only overlap those of adjacent samples. In more detail,

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[3] According to Goulden (1969: 1067), a high diversity index, broadly speaking, represents a well-adjusted, stable community. Any changes in the lacustrine environment, however, will cause a decline in the diversity index with usually, although not always, a decrease in the number of species. In contrast, a low-equitability component is interpreted to represent a stable community, whereas a high-equitability component indicates a community experiencing environmental change.

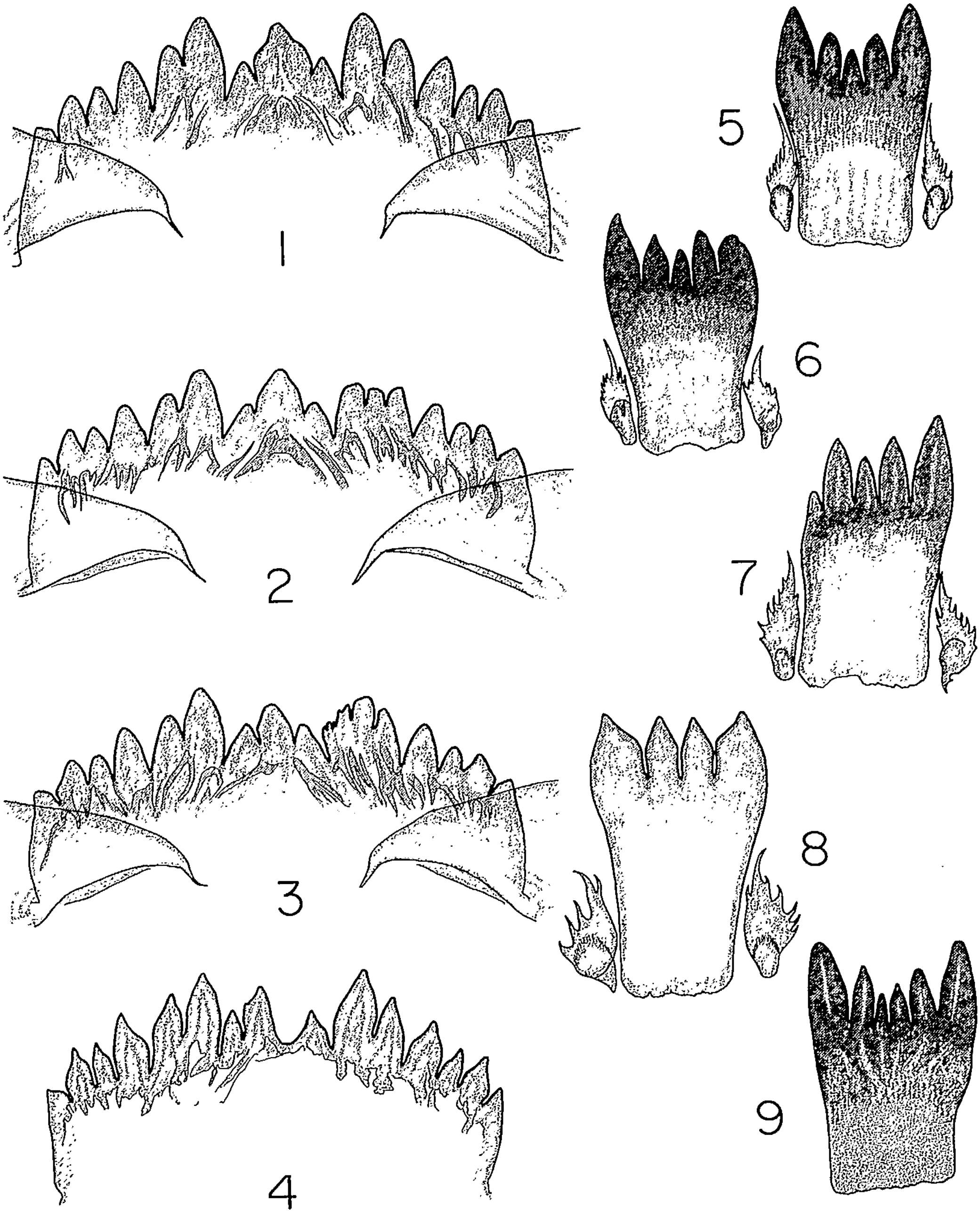


FIG. 20. Comparison of chironomid mouthparts: normal (1) and deformed (2, 3, and 4) menta of *Chironomus* and normal (5), deformed (6 and 7), and abnormal (8 and 9) ligula of *Procladius*.

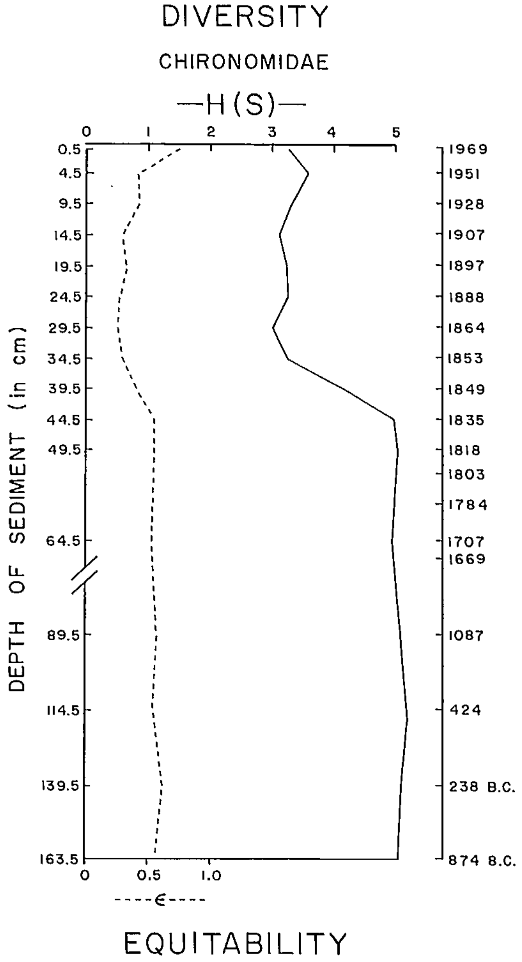


FIG. 21. The diversity index H(S) (solid line) and the equitability component ϵ (broken line) of the Chironomidae as a function of sediment depth.

the greater degree of similarity shown by the faunas at 34.5, 29.5, and 24.5 cm coincides precisely with the point of trend reversal in Fig. 17, where the confidence limits for the fauna of the three intervals overlap. This is particularly well shown in the Tanytarsini.

The third feature of the matrix is the large block of comparisons falling in the zone of low similarity. The lack of definition in this zone is probably a result of the tendency for the test to overvalue the dominant species in relation to rare species. In this case, the Chironomini–Tanytarsini type 7 suite constitutes the greater portion of the fauna throughout more recent sediments.

The final feature shown by the matrix is some apparent similarity between the fauna at 24.5 cm and at 49.5 cm. In each case, the faunas mark periods where well-established trends have started to change and thus may well describe transition faunas.

3.5.2.3 Coefficients of community — Matrices for the indices, collectively referred to as coefficients of community, are given in Tables 17–19. Although the scales are somewhat different, the salient features of all tests are similar, and bear a marked resemblance to the features defined by percentage similarity of community. The marked separation between faunas of the older and more recent portions of the core is similarly apparent in the three coefficients of community. In the older sediments, however, the apparently greater similarity between the faunas at 139.5, 114.5, and 89.5 cm is more pronounced in the community coefficients. In the more recent sediments, the relationship between faunas found at 34.5, 29.5, and 24.5 cm indicated by the percentage test is also evident in the community coefficients, but in a somewhat more extended form.

The lack of definition shown in more recent sediments by the percentage similarity test is compensated for by the coefficients of community, which stress the rarer species relative to the more dominant. The coefficients identify three zones not apparent in the former test. The three zones bear progressively less relationship to the populations found in older portions of the core.

3.5.2.4 Kendall's tau coefficient — Kendall's (1962) tau coefficient appears to be of relatively limited value in defining community changes. In contrast to the other methods, Kendall's tau (Table 20) lacks definition throughout the greater portion of the matrix and provides only a crude indication of change in the most recent communities. An arbitrary division of the Z values accompanying the tau statistic (Table 21) may prove to be useful in defining changes in community structure. Although scale values were drawn up arbitrarily, many features outlined in the other indices of community change are present. The usefulness of the Z scale, however, remains to be tested in further studies.

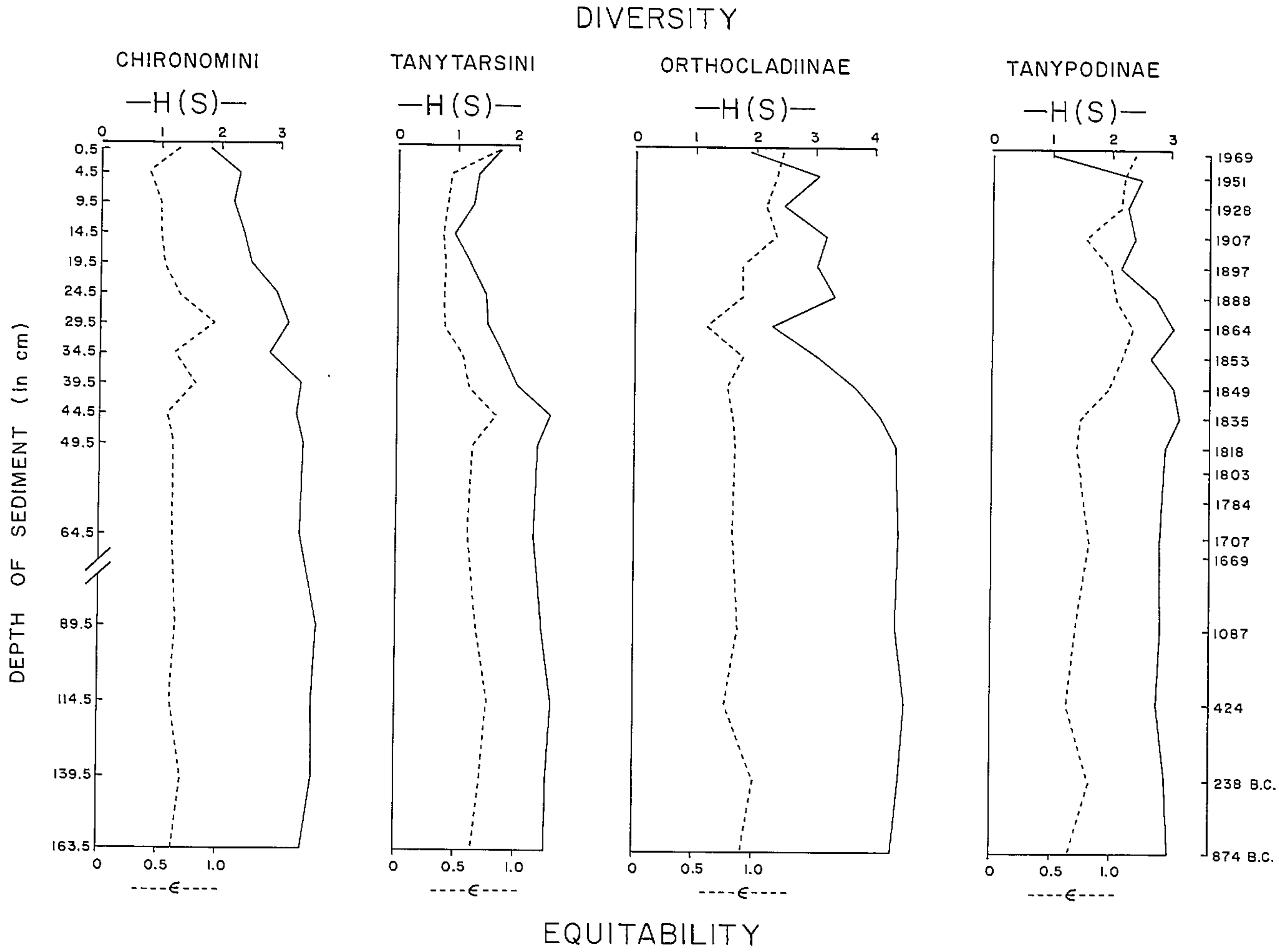


FIG. 22. The diversity index H(S) (solid line) and the equitability component ε (broken line) of the major chironomid groups as a function of sediment depth. The comparative values for each index depend in large measure on the degree of taxonomic separation attained in each group.

TABLE 16. Percentage Similarity of Community between fossil chironomid communities found at selected sampling intervals in sediments of the Glenora-B core. High values indicate high similarity.

	Depth of sediment (*cm*)															
Depth of sediment (*cm*)	163.5	139.5	114.5	89.5	64.5	49.5	44.5	39.5	34.5	29.5	24.5	19.5	14.5	9.5	4.5	0.5
0.5	40.84	37.45	40.35	42.13	45.82	44.49	45.89	46.85	46.93	42.58	47.32	53.40	61.93	72.05	77.43	
4.5	43.28	39.57	44.34	46.25	47.69	47.42	47.31	55.37	51.73	46.17	51.76	58.18	66.04	76.78		
9.5	41.18	40.59	43.85	43.90	49.04	49.98	46.81	56.26	61.51	58.85	62.26	67.55	76.21			
14.5	40.42	39.08	42.36	41.33	46.53	47.73	47.70	56.81	63.81	68.05	73.19	80.77				
19.5	41.00	41.17	42.78	41.34	46.11	47.93	49.46	62.13	69.72	74.98	81.20					
24.5	45.94	47.44	48.51	47.79	49.69	51.27	51.54	69.71	79.53	86.30						
29.5	39.85	41.94	41.89	44.06	44.70	44.34	45.42	67.52	76.92							
34.5	43.42	44.12	44.81	45.58	47.83	45.98	48.96	76.80								
39.5	52.04	52.39	53.82	54.00	54.41	54.99	56.60									
44.5	78.32	78.46	80.78	74.86	81.35	83.22										
49.5	76.99	78.98	83.28	83.09	86.44											
64.5	83.88	82.62	85.10	83.29												
89.5	78.97	79.25	83.57													
114.5	84.71	83.37														
139.5	86.41															
163.5																

> 85.00%	zone of greatest similarity
85.00–70.00%	zone of high similarity
70.00–60.00%	zone of moderate similarity
60.00–50.00%	zone of some similarity
50.00–35.00%	zone of low similarity
< 35.00%	zone of least similarity

TABLE 17. Jaccard's (1912) Coefficient of Community between fossil chironomid communities found at selected sampling intervals in sediments of the Glenora-B core. High values indicate high similarity.

	Depth of sediment (*cm*)															
Depth of sediment (*cm*)	163.5	139.5	114.5	89.5	64.5	49.5	44.5	39.5	34.5	29.5	24.5	19.5	14.5	9.5	4.5	0.5
0.5	0.149	0.169	0.142	0.158	0.160	0.183	0.178	0.211	0.250	0.275	0.268	0.240	0.304	0.395	0.333	
4.5	0.347	0.376	0.343	0.354	0.357	0.354	0.368	0.410	0.508	0.508	0.484	0.458	0.424	0.638		
9.5	0.289	0.315	0.278	0.296	0.313	0.296	0.295	0.373	0.464	0.577	0.443	0.436	0.426			
14.5	0.320	0.333	0.330	0.327	0.317	0.354	0.354	0.467	0.508	0.483	0.508	0.458				
19.5	0.340	0.354	0.374	0.388	0.392	0.402	0.389	0.493	0.569	0.517	0.590					
24.5	0.402	0.418	0.405	0.436	0.412	0.465	0.469	0.571	0.667	0.562						
29.5	0.412	0.462	0.415	0.418	0.453	0.418	0.436	0.513	0.593							
34.5	0.398	0.415	0.389	0.433	0.453	0.404	0.421	0.533								
39.5	0.423	0.525	0.513	0.481	0.529	0.416	0.545									
44.5	0.575	0.626	0.619	0.593	0.613	0.552										
49.5	0.569	0.664	0.681	0.673	0.634											
64.5	0.602	0.670	0.644	0.694												
89.5	0.670	0.728	0.711													
114.5	0.664	0.703														
139.5	0.692															
163.5																

> 0.700	zone of greatest similarity
0.700–0.550	zone of high similarity
0.550–0.400	zone of moderate similarity
0.400–0.250	zone of low similarity
< 0.250	zone of least similarity

TABLE 18. Sørenson's (1948) Quotient of Similarity (QS) between fossil chironomid communities found at selected sampling intervals in sediments of the Glenora-B core. High values indicate high similarity.

Depth of sediment (cm)	163.5	139.5	114.5	89.5	64.5	49.5	44.5	39.5	34.5	29.5	24.5	19.5	14.5	9.5	4.5	0.5
0.5	0.259	0.288	0.248	0.273	0.275	0.309	0.302	0.349	0.400	0.431	0.423	0.387	0.467	0.566	0.500	
4.5	0.515	0.547	0.510	0.522	0.526	0.522	0.538	0.582	0.674	0.674	0.653	0.628	0.595	0.779		
9.5	0.448	0.479	0.435	0.457	0.476	0.457	0.455	0.544	0.634	0.734	0.614	0.608	0.597			
14.5	0.485	0.500	0.497	0.493	0.481	0.522	0.523	0.636	0.674	0.652	0.674	0.628				
19.5	0.507	0.523	0.544	0.559	0.563	0.574	0.561	0.661	0.725	0.681	0.727					
24.5	0.575	0.590	0.577	0.607	0.583	0.634	0.638	0.727	0.800	0.720						
29.5	0.584	0.632	0.587	0.570	0.623	0.590	0.607	0.678	0.745							
34.5	0.569	0.586	0.560	0.604	0.623	0.576	0.593	0.696								
39.5	0.595	0.688	0.678	0.650	0.692	0.588	0.705									
44.5	0.730	0.770	0.764	0.744	0.760	0.711										
49.5	0.725	0.798	0.810	0.804	0.776											
64.5	0.751	0.802	0.784	0.820												
89.5	0.802	0.843	0.831													
114.5	0.798	0.825														
139.5	0.818															
163.5																

> 0.825	zone of greatest similarity
0.825–0.700	zone of high similarity
0.700–0.575	zone of moderate similarity
0.575–0.450	zone of some similarity
0.450–0.325	zone of low similarity
< 0.325	zone of least similarity

TABLE 19. Kulezynski's (1928) Coefficient of Community between fossil chironomid communities found at selected sampling intervals in sediments of the Glenora-B core. High values indicate high similarity.

Depth of sediment (*cm*)	Depth of sediment (*cm*)															
	163.5	139.5	114.5	89.5	64.5	49.5	44.5	39.5	34.5	29.5	24.5	19.5	14.5	9.5	4.5	0.5
0.5	0.467	0.504	0.490	0.498	0.499	0.565	0.535	0.527	0.499	0.538	0.558	0.470	0.556	0.631	0.595	
4.5	0.594	0.620	0.620	0.607	0.609	0.607	0.616	0.616	0.676	0.676	0.662	0.628	0.595	0.786		
9.5	0.556	0.583	0.574	0.572	0.593	0.572	0.559	0.606	0.685	0.748	0.640	0.616	0.602			
14.5	0.559	0.567	0.603	0.572	0.557	0.607	0.598	0.674	0.676	0.654	0.683	0.628				
19.5	0.575	0.584	0.649	0.638	0.641	0.655	0.631	0.693	0.726	0.682	0.749					
24.5	0.615	0.625	0.643	0.654	0.627	0.684	0.680	0.739	0.803	0.725						
29.5	0.648	0.691	0.682	0.659	0.694	0.695	0.669	0.702	0.745							
34.5	0.632	0.642	0.651	0.675	0.694	0.643	0.653	0.720								
39.5	0.607	0.698	0.708	0.665	0.707	0.601	0.717									
44.5	0.730	0.770	0.769	0.745	0.760	0.712										
49.5	0.725	0.799	0.813	0.804	0.776											
64.5	0.751	0.803	0.787	0.820												
89.5	0.802	0.844	0.833													
114.5	0.802	0.832														
139.5	0.819															
163.5																

> 0.825	zone of greatest similarity
0.825–0.725	zone of high similarity
0.725–0.625	zone of moderate similarity
0.625–0.525	zone of some similarity
0.525–0.425	zone of low similarity
< 0.425	zone of least similarity

TABLE 20. Kendall's (1962) tau between fossil chironomid communities found at selected sampling intervals in sediments of the Glenora-B core. High values indicate high similarity.

	Depth of sediment (*cm*)															
Depth of sediment (*cm*)	163.5	139.5	114.5	89.5	64.5	49.5	44.5	39.5	34.5	29.5	24.5	19.5	14.5	9.5	4.5	0.5
0.5	0.126	0.134	0.133	0.123	0.135	0.128	0.136	0.133	0.121	0.180	0.147	0.164	0.236	0.294	0.248	
4.5	0.223	0.198	0.238	0.228	0.260	0.178	0.226	0.207	0.208	0.123	0.157	0.169	0.210	0.342		
9.5	0.179	0.177	0.170	0.169	0.226	0.169	0.169	0.195	0.229	0.285	0.179	0.237	0.319			
14.5	0.187	0.189	0.194	0.163	0.209	0.164	0.218	0.208	0.112	0.194	0.230	0.209				
19.5	0.247	0.178	0.242	0.222	0.269	0.206	0.241	0.287	0.303	0.343	0.403					
24.5	0.288	0.268	0.312	0.316	0.314	0.277	0.368	0.466	0.426	0.424						
29.5	0.278	0.260	0.282	0.287	0.334	0.256	0.281	0.344	0.426							
34.5	0.274	0.275	0.290	0.290	0.338	0.273	0.327	0.364								
39.5	0.306	0.330	0.344	0.314	0.347	0.301	0.378									
44.5	0.457	0.489	0.480	0.460	0.490	0.481										
49.5	0.465	0.538	0.543	0.532	0.561											
64.5	0.557	0.610	0.583	0.623												
89.5	0.544	0.576	0.596													
114.5	0.528	0.593														
139.5	0.584															
163.5																

95% at 2.038

99% at 2.715

TABLE 21. Kendall's (1962) tau (the Z statistic) between fossil chironomid communities found at selected sampling intervals in sediments of the Glenora-B core. High values indicate high similarity.

Depth of sediment (*cm*)	163.5	139.5	114.5	89.5	64.5	49.5	44.5	39.5	34.5	29.5	24.5	19.5	14.5	9.5	4.5	0.5
0.5	1.803	1.867	2.026	1.777	1.934	1.850	1.915	1.655	1.285	1.874	1.618	1.695	2.374	2.653	2.458	
4.5	3.278	2.829	3.674	3.365	3.809	2.655	3.279	2.719	2.378	1.394	1.863	1.929	2.426	3.513		
9.5	2.611	2.503	2.619	2.478	3.282	2.504	2.444	2.503	2.537	3.024	2.065	2.593	3.503			
14.5	2.775	2.741	3.006	2.426	3.120	2.448	3.185	2.676	1.284	2.240	2.727	2.393				
19.5	3.654	2.581	3.715	3.253	3.919	3.043	3.494	3.687	3.423	3.930	4.672					
24.5	4.316	3.934	4.890	4.716	4.700	4.147	5.365	6.090	4.937	5.073						
29.5	4.051	3.660	4.315	4.213	4.827	3.808	4.045	4.455	4.966							
34.5	4.017	3.940	4.478	4.233	4.886	4.073	4.735	4.689								
39.5	4.807	4.919	5.436	4.854	5.261	4.596	5.661									
44.5	7.263	7.553	7.771	7.301	7.705	7.463										
49.5	7.534	8.363	8.774	8.374	8.928											
64.5	8.827	9.346	9.425	9.624												
89.5	8.460	8.694	9.462													
114.5	8.506	9.330														
139.5	8.842															
163.5																

> 8.825	zone of greatest similarity
8.825–7.132	zone of high similarity
7.132–5.433	zone of moderate similarity
5.433–3.735	zone of some similarity
3.735–2.038	zone of low similarity
< 2.038	zone of least similarity

4. INTEGRATION OF STRATIGRAPHIC PARAMETERS

4.1 Overview

The overall investigation and the events and processes that have had an impact in and around the Bay of Quinte were summarized in Fig. 1. The same general outline is used in Fig. 23 to illustrate in a pictorial manner how specific, and often distant, events have had a profound impact on the watershed, the bay, and the life systems within the bay.

The network of linkages and relationships between man's activities and environmental responses is extremely complicated, and the linkages and relationships that have been identified during the course of this study are only a portion of those that could be defined. By necessity, only those that are the clearest, best documented, and of more general significance are treated in the text. Others, more specific or more tenuous, have been included in the Appendices. The complexity of the network of interrelationships sometimes made it necessary to deviate slightly from a straight forward, step-by-step presentation of arguments and rationale. The sections on history and the environmental responses in and around the Bay of Quinte establish the major linkages between man's activities, watershed disturbance, and the impact on the physical and chemical characteristics of the environment in the Bay of Quinte. Responses of the chironomid community were then analyzed, first in general terms and then in more detail, to ascertain and assess the impact of changes in the aquatic environment of the bay on the biological community.

4.2 Major Cultural Periods and Impact Processes

4.2.1 Periods of Cultural Development

The periods of tenure and stages in the development of each culture that evolved in the Bay of Quinte area are related to the sedimentary profile in Fig. 24. Boundaries for these divisions were ascertained on the basis of historical census data, the *Ambrosia* pollen profile, the carbon and nitrogen profiles, and the Erosion Index. The basic principles relating to the sedimentary indices, developed during the historically documented European periods, were used to define the cultural periods in older portions of the core. The Erosion Index in particular demonstrated a high degree of reliability in defining periods or events in human activity during this older period, through its connection with erosion processes (Warwick unpublished data). *Ambrosia* pollen (which demonstrated its relationship to the disturbance of soils in the watershed due to the land-clearing activities of Europeans during the early part of the colonial phase) was also useful as an indicator of the abandonment of cultivated soils. The significance of the figure lies in the evidence it provides for the relationship between human populations and the sedimentary record.

The beginning of the British-Modern Period was identified in the more recent portions of the core (see Section 2.2) by the large rise in the Erosion Index at 58.5 cm, which corresponds to the arrival of the United Empire Loyalists in the immediate area in 1784. The period was further subdivided into stages on the basis of definite trends in historical documentation and census data.

The beginning of the French Period, like the British-Modern, was identified on the basis of a sharp rise in the Erosion Index. The rise at 67.5 cm corresponds to the beginning of French activity in building the Sulpician Mission on Quinte's Isle, in 1669. The period was divided into two stages to mark the period when the French were actively involved in the area, and the period after the fall of the French regime, when the area was almost totally abandoned. The Abandonment Stage is clearly marked by the sharp decline in the Erosion Index and a small *Ambrosia* pollen rise. This *Ambrosia* rise is contiguous with a sharper rise marking the disruptions caused by the arrival of the United Empire Loyalists at the beginning of the British-Modern Period.

The beginning of the Iroquois Period was established by the *Ambrosia* rise at 110.5 cm, but the period itself was largely defined by the large, truncated peak in the carbon and nitrogen profiles

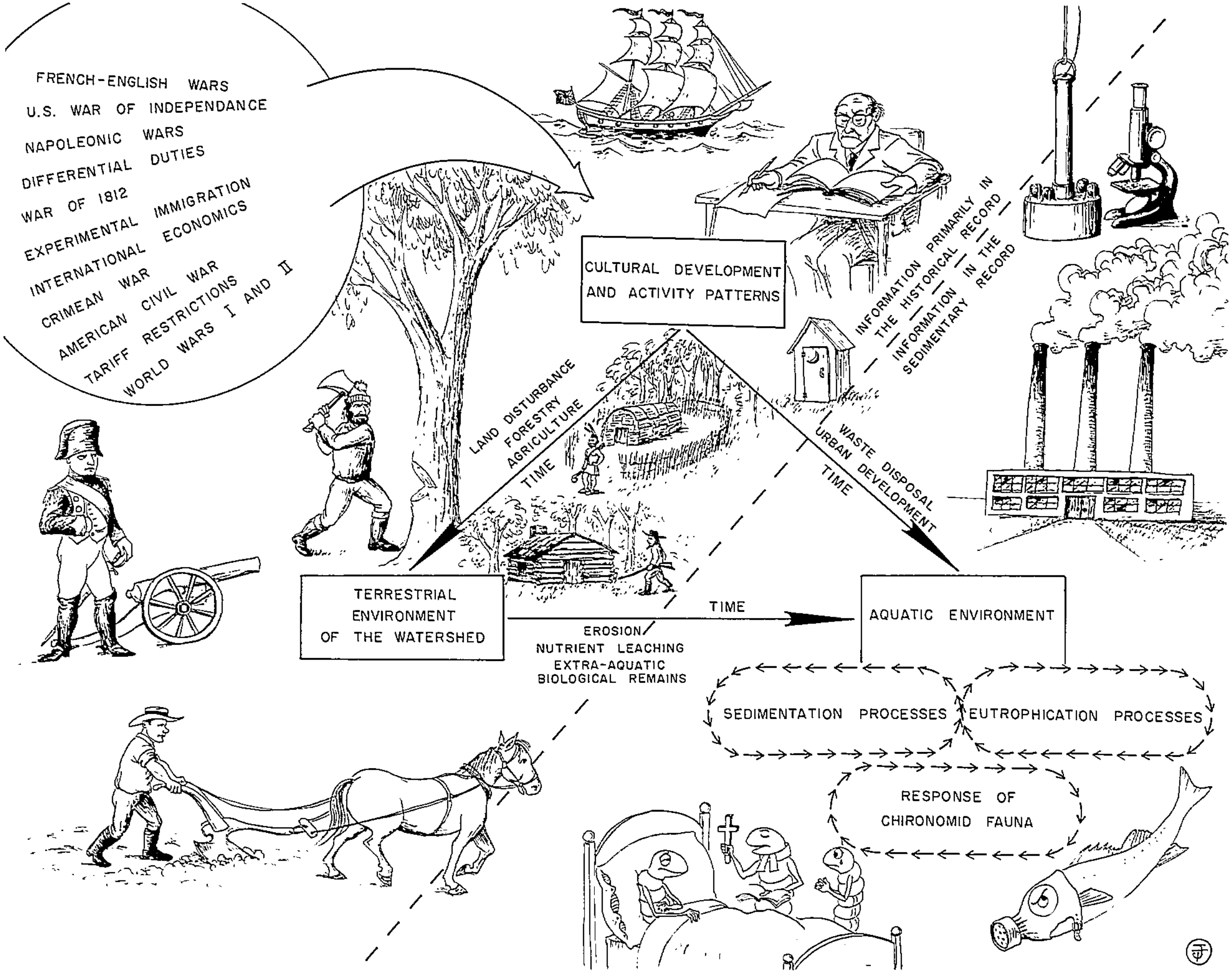


FIG. 23. Pictorial summary of the major processes and events influencing the Bay of Quinte and surrounding watershed.

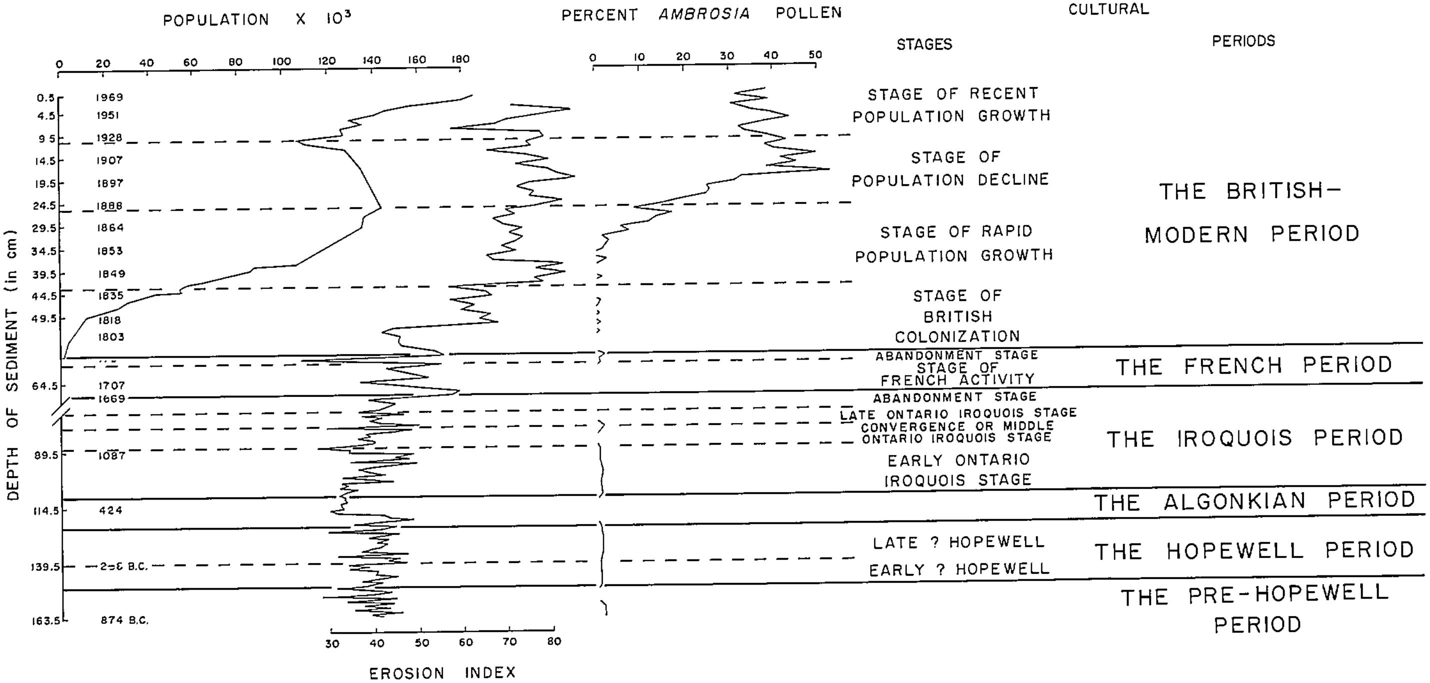


FIG. 24. Definition of cultural periods from historical census data, the occurrence of *Ambrosia* pollen, the distributions of carbon and nitrogen, and the Erosion Index in the sedimentary profile.

(Fig. 14). This feature has been interpreted as marking the input to the sediments of fully combusted ash material from land-clearing activities of these agricultural people. The three stages in the cultural development of the Iroquois Tradition were identified from the Erosion Index. A fourth stage, perhaps properly belonging to the Late Ontario Iroquois Stage, marks the withdrawal of the historical Ontario Iroquois to the northwest. The immediate area around the Bay of Quinte then became an uninhabited buffer zone between the Iroquois and their warring kinsmen to the south of Lake Ontario. Although not to the same degree, this Abandonment Stage, like that in the French Period, was marked by a definite decline in the Erosion Index. Most of the *Ambrosia* pollen deposited during the Iroquois Period accumulated in the Early and Convergence or Middle Ontario Iroquois stages. The limited appearance of pollen in the Late Ontario Iroquois Stage probably reflects the high degree of sophistication attained by Iroquois agricultural methods by this time. The complete lack of pollen in the Abandonment Stage clearly reflects the fact that the area had become uninhabited by 1550.

The Algonkian Period was established between the Hopewell and Iroquois periods, and was notable for the absence of *Ambrosia* pollen and a marked decline in the Erosion Index. Relatively few in number, the Algonkian were nomadic hunters and probably had little impact on the watershed or the bay itself.

The Hopewell Period was identified on the basis of the *Ambrosia* pollen profile. The beginning of the period marked by the *Ambrosia* rise coincides with a definite break in the Erosion Index profile at 150.5 cm. The period has tentatively been divided into an Early and Late Stage on the basis of the Erosion Index. The remainder of the core has simply been labeled the Pre-Hopewell Period.

4.2.2 SEDIMENTATION AND EUTROPHICATION PROCESSES

In relating sedimentation and eutrophication processes to the sedimentary profile (Fig. 25), primary boundaries for subdividing the sedimentation data were established primarily from the Erosion Index profile, and grouped into major zones of sedimentation on the basis of relatively easily definable periods of historical activity. Sediments deposited during the European period were analyzed initially (Warwick unpublished data) to establish the fundamental relationships between sedimentation processes, particularly those connected with the Erosion Index, and the historical development of the watershed. These principles were then applied to the interpretation of the sedimentary profile from older portions of the core. Although the relationship between historical development and sedimentation processes is strong, there are discrepancies generally attributable to the lag involved between the action and reaction of land and water processes.

Generally, the rate of response of sedimentation processes to activity in the watershed is strongly dependent on the number of people and type of activity involved. Initiation of the accumulation of fine sediment materials at 51.5 cm, in response to intense lumbering activity by a fairly large population in close proximity to the core site, was most immediate and well defined by the sharp increase in the Erosion Index. In contrast, the accumulation of fine sediment, marking human activity during the Iroquois Period did not begin until 103.5 cm, although the Period probably began as early as 110.5 cm. The delay in the appearance of evidence in the sedimentary record for the beginning of the Iroquois Period may be due in part to the fact that early Iroquois villages were sited well back from navigable rivers, to avoid detection from hostile parties traveling along these waterways. A similar delay suggested by the Erosion Index may push back the beginning of the Hopewell Period to 154.5 cm.

Erosion and sedimentation processes on the other hand, once started, were more difficult to stop. This is clearly shown by the fact that the accumulation of fine sediment material initiated at 51.5 cm by the surge in lumbering activity did not decline markedly when this activity ceased during the War of 1812. Similarly, the accumulation of fine mineral sediments resulting from the activities of the Hopewell was not terminated until well into the Algonkian Period. The Hopewell Period ended around 123.5 cm, but the accumulation of fine sediments continued up to 118.5 cm. The discrepancy between the lower boundary of the Stage of Population Decline (26.0 cm), which was based on population census data, and the lower boundary of sediment Zone VIId (25.5 cm), also illustrates that sedimentation processes relate more to the activities of people than population numbers in the strict sense.

Changes in trophic status of the waters of the bay were related to the sedimentary profile through the plot of organic carbon:total nitrogen ratio in the sediments (Fig. 25). The figure provides evidence for the relationship between sedimentation and eutrophication processes with cultural development around the Bay of Quinte.

The magnitude of environmental pressure exerted by processes of sedimentation and eu-

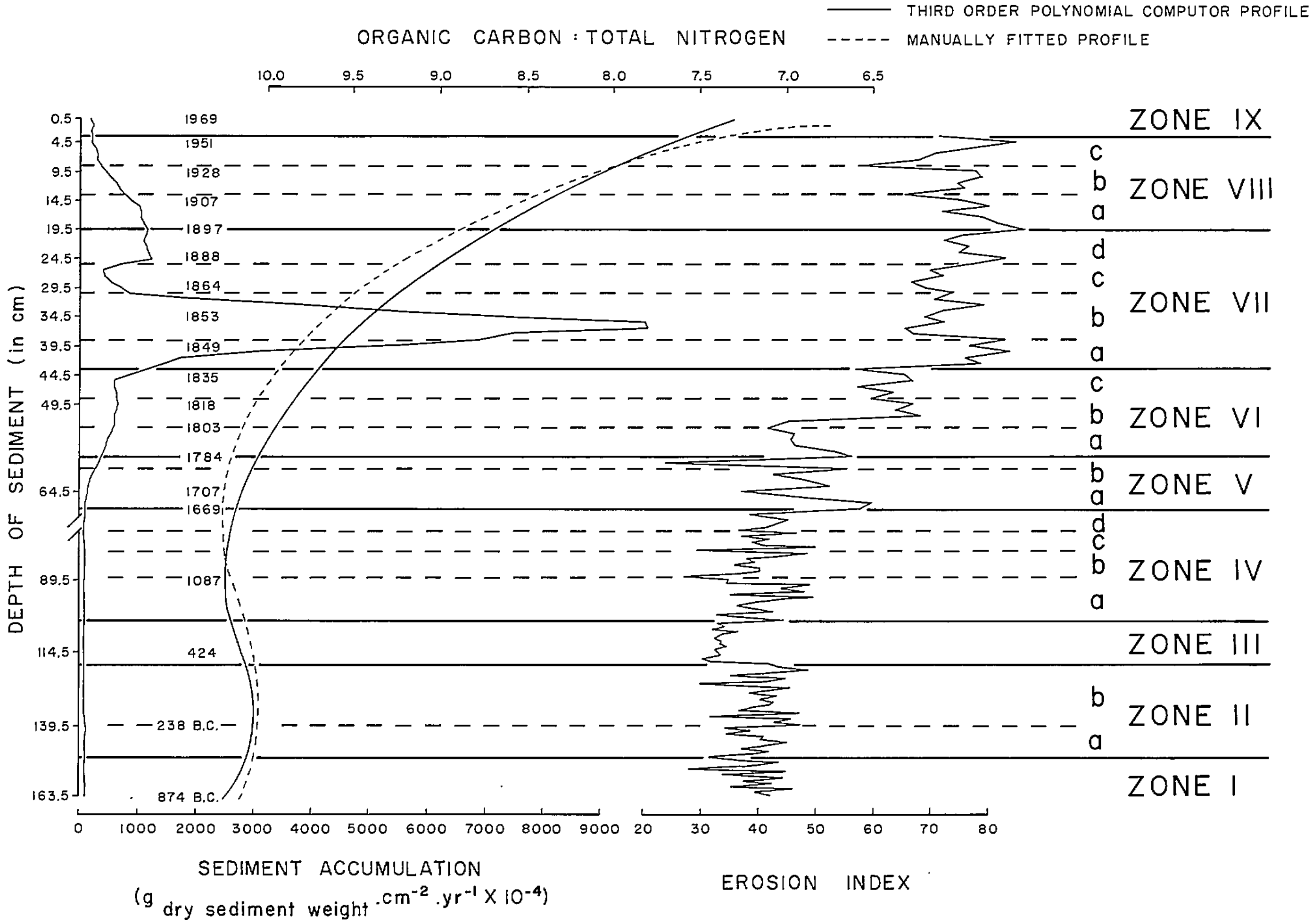


FIG. 25. Definition of zones of sedimentation in relation to productivity measurements. The zones of sedimentation were established primarily on the basis of the Erosion Index and, to a lesser extent, on sediment accumulation. The productivity measurement organic carbon:total nitrogen is superimposed on the sediment measures.

trophication on the benthic communities is summarized in Fig. 26, where sediment accumulation is plotted against the organic carbon: total nitrogen ratio. The figure clearly demonstrates a number of points. (1) The range of sedimentation–eutrophication processes characteristic of the Pre-Settlement Oligotrophic Phase was patently limited, compared to those characteristic of the four more recent phases of the British-Modern Period. In comparative terms, these processes remained remarkably stable for approximately 2600 yr, then underwent profound changes in the last 188 yr. (2) Sedimentation processes, initially the dominant factor influencing bottom habitat in the early stages of the British-Modern Period, were gradually supplanted by eutrophication processes later in the period, as mineral sediment accumulation declined, and the input of materials fostering eutrophication processes increased. The rate of sediment accumulation increased markedly during the Initial Impact Phase, and reached its maximum during the Imbalanced Oligotrophic Phase. In both phases the rate of increase in sedimentation was proportionately more rapid than the increase in the rate of eutrophication. In the Mesotrophic Phase, however, where the rate of sediment accumulation markedly decreased, the rate of eutrophication was proportionately much higher. This trend continued into the Moderately Eutrophic Phase, where the rate of increase in the processes of eutrophication was much higher than that of sediment accumulation. Within individual phases (3) the separation of Zone II (Fig. 26) of the Pre-Settlement Oligotrophic Phase from the other pre-European zones (I, III, and IV) indicates that sedimentation–eutrophication processes were different during the Hopewell Period compared to the other aboriginal periods. (4) The difference between the field of Zone V and fields representing the remainder of the zones of the Pre-Settlement Oligotrophic Phase suggests that the French Period should possibly be included in the Initial Impact Phase. (5) Within the Initial Impact Phase, the early colonization activities of the British in Zones VIa,b had only limited influence on sedimentation–eutrophication processes; however, once the colony around the immediate area of the bay was established well enough to support the movement of colonists into the interior (Zone VIc), the two processes began to be altered markedly. (6) The accumulation of mineral sediments increased sharply during the Imbalanced Oligotrophic Phase, and reached a maximum of 9322.69 × 10^{-4} g dry sediment weight·cm^{-2}·yr^{-1} in Zone VIIb. This massive influx of mineral sediments was a result of the almost complete deforestation of the Bay of Quinte watershed by the lumber industry. (7) After declining in Zone VIIc, sediment accumulation increased again in Zone VIId. The increase possibly was the result of renewed activity in the forest products industry, but could also reflect the expansion of agricultural interests, as farmers moved into lands cleared by the lumber industry. (8) Within the Mesotrophic Phase, the vertical axes of Zones VIIIa–c demonstrates the rapid decline in the accumulation of mineral sediments, while the horizontal axes show the increase in the rate of eutrophication. (9) Eutrophication processes were clearly the dominant factor influencing the benthic communities in the Moderately Eutrophic Phase. The effect of accumulation of mineral sediments was minimal.

The concentration of carbon in sediments was drastically reduced through dilution by the massive inputs of mineral sediments characteristic of Zones VIIa,b (Fig. 27). Although the organic carbon concentrations in the most modern sediments are not as high as in the older sediments, the organic matter:organic carbon ratio clearly demonstrates a qualitative difference in the carbonaceous material (Warwick unpublished data). The ratio in the older sediments approximates that of recalcitrant carbon, whereas that in the more recent sediments indicates material of a relatively high nutritive value. Much of this more nutritive material probably remained unavailable to the chironomid fauna because it was buried intact under the rapidly accumulating mineral sediments. However, with the subsequent decline in accumulation of mineral sediments and increase in productivity of the bay, concentrations of carbon in the sediments increased and organic materials suitable for food became more readily available to the fauna.

Concentrations of phosphorus in the sediments (Fig. 27) were also influenced by the accumulation of mineral sediments, although more likely through the latter's absorptive capacities for the element (Warwick unpublished data). The first large bifid phosphorus peak in the initial stages of the British-Modern Period (59.5–57.5 cm), for example, coincided with two peaks in the inorganic carbon profile. This would suggest that carbonates, probably of calcium, were implicated in the precipitation. As well, the major spike of phosphorus in the pair coincides with the large pulse in the Erosion Index (58.5–57.5 cm) identified with the initial land-clearing by the United Empire Loyalists. The interpretation of the peaks is as follows: the initial input of fine sediments, introduced as a result of clearing the limestone-based soils in the immediate vicinity of the core site by the Loyalists, first

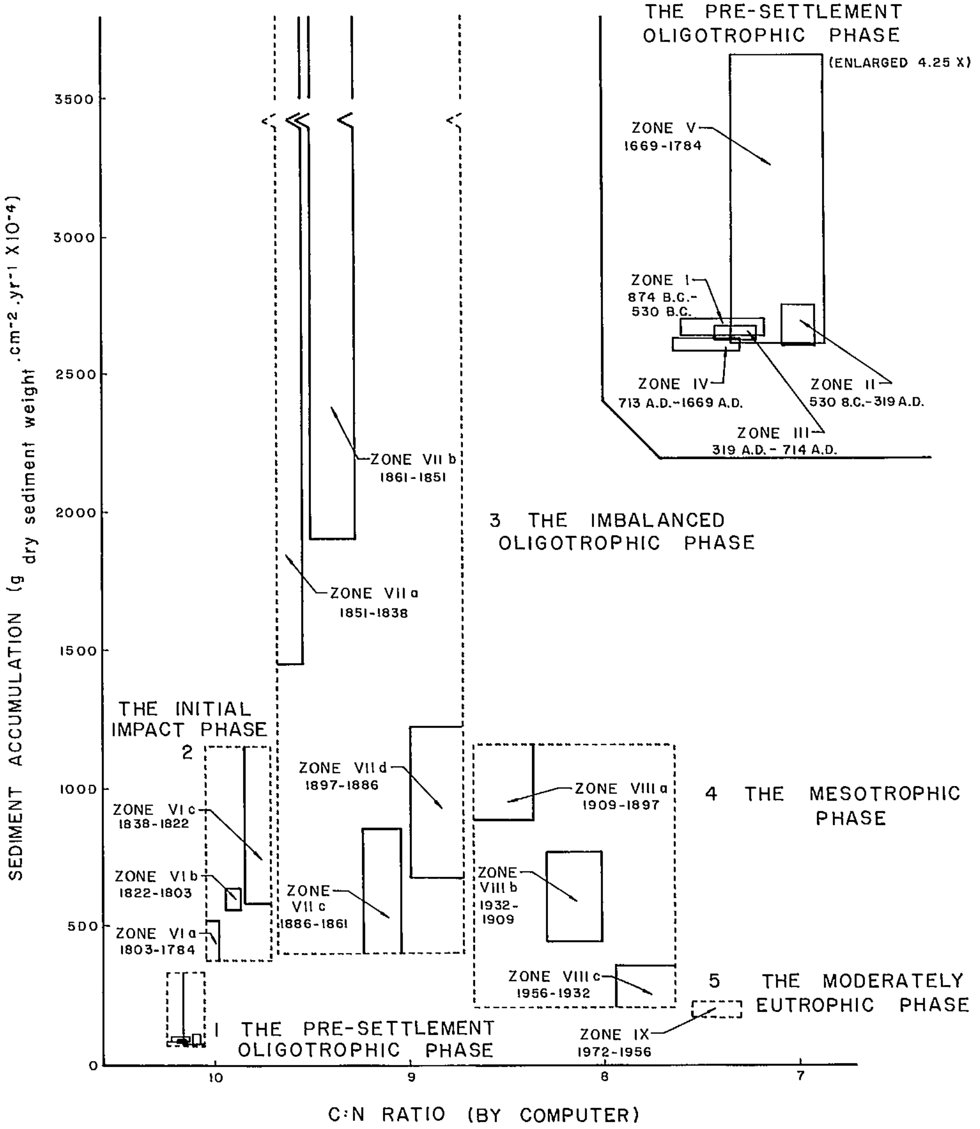


FIG. 26. The magnitude of environmental pressure exerted by the processes of sedimentation and eutrophication. The independent fields identified by zone and subzone designations (solid line boxes) represent the maximum and minimum limits of the two parameters (sediment accumulation in g·cm^{-2}·yr^{-1} × 10^{-4} and the C:N ratio) for sedimentation zones VI to IX (the British-Modern Period). The fields (inset) representing zones I to V (up to and including the French Period) are not divided into subzones for ease of presentation. The individual zone and subzone fields are grouped according to the five major phases (broken line boxes) which outline the course of trophic changes in the Bay of Quinte identified in terms of the fossil chironomid communities. The five major phases, in decreasing order of age, are: (1) the Pre-Settlement Oligotrophic Phase 874 B.C.–1784 A.D., (2) the Initial Impact Phase 1784–1838, (3) the Imbalanced Oligotrophic Phase 1838–97, (4) the Mesotrophic Phase 1897–1956, (5) the Moderately Eutrophic Phase 1956–72.

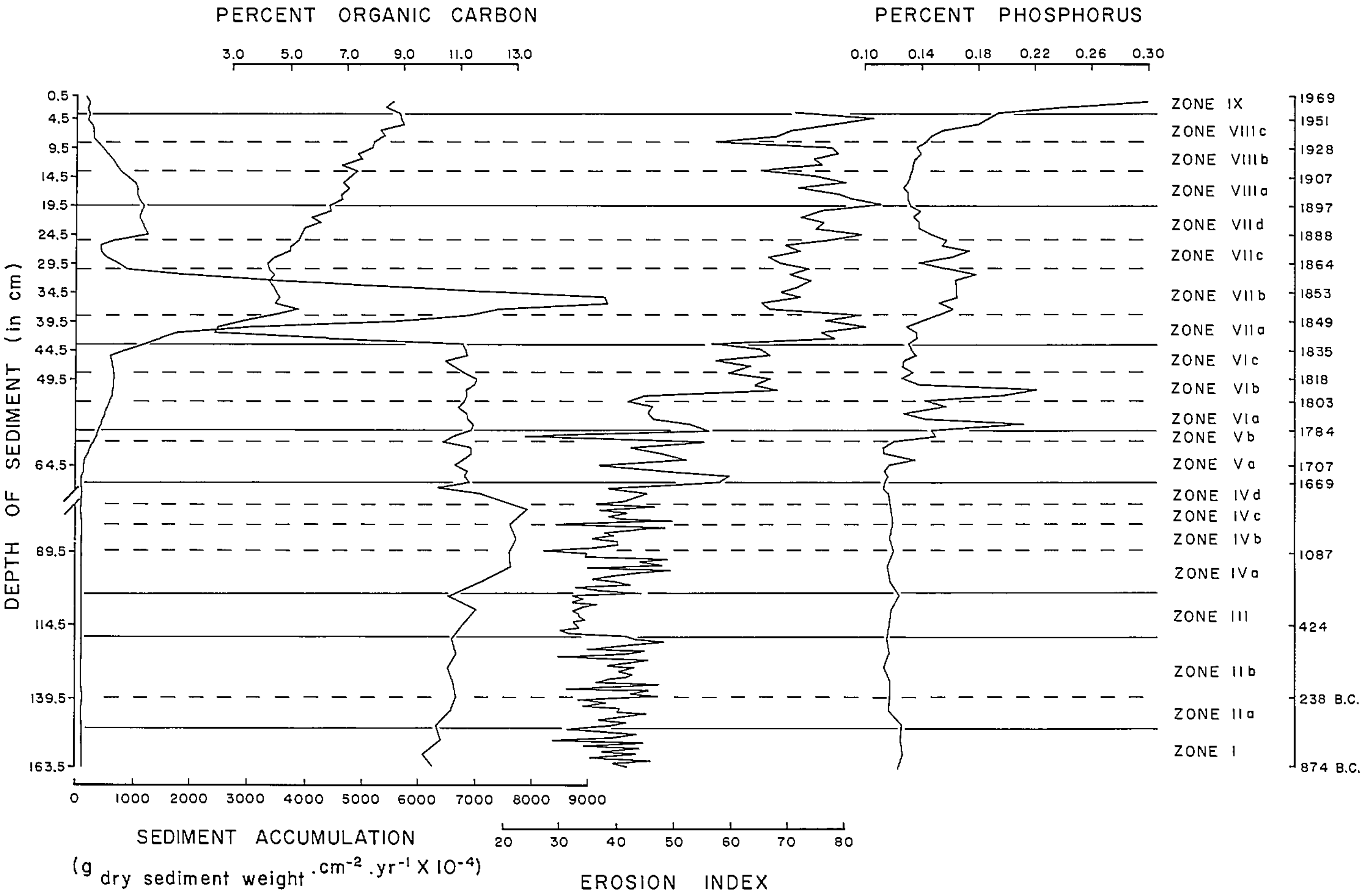


FIG. 27. The effect of sedimentation processes on organic carbon and phosphorus concentrations.

trapped the phosphorus accumulated at the sediment–water interface during the Abandonment Stage of the French Period (59.5-cm peak), then stripped the water column of phosphorus, either residing in the water at that time or introduced as a result of leaching processes, to form the second (57.5-cm) peak. The sediment–phosphorus complex, possibly hydroxyapatite, was sufficiently stable for the feature to persist in the sediments.

The scenario probably was similar in the case of the other two bifid phosphorus peaks (66.5–63.5 cm and 54.5–51.5 cm); however, the sediment data suggest that clay materials, rather than limestone materials, were probably involved in their formation.

Although the clay minerals purported to be involved in the formation of the above peaks were not identified, the material involved in the formation of the larger peak of phosphorus between 40.5 and 30.5 cm was identified as smectic montmorillonite clays. Montmorillonites, because of their high base exchange capacity, are considered one of the most efficient members of the clay family in the adsorption of phosphorus. The efficiency of the material in the removal of phosphorus to the sediments may be interpreted from the truncation of the phosphorus peak. The truncation probably reflects the almost total removal of phosphorus by the massive influx of clay materials at this time. The truncation probably occurred because phosphorus was limited in comparison to the number of adsorption sites available for complexing. If the supply of phosphorus had not been limited, the phosphorus peak probably would not have been truncated, but would have followed more faithfully the sediment accumulation peak.

4.3 Responses of Chironomidae to Impact Processes

4.3.1. ALTERATIONS AT THE COMMUNITY LEVEL

The response of chironomid communities to changes in sedimentation and eutrophication processes is shown by the rapid changes in the diversity of the Chironomidae community (Fig. 28). The diversity of all aspects of the fauna remained relatively constant to 44.5 cm, but changed abruptly above this level in the more modern sediments. For the Chironomidae as a whole, the decline in diversity began at 39.5 cm and dropped to a minimum at 34.5 cm, where it remained almost constant throughout the more modern sediments. The disruption of the Chironomidae community at this point was directly linked to massive inputs of fine mineral sediments during sedimentation zones VIIa and VIIb (Fig. 27).

Various groups within the family responded differently to changes in sedimentation and eutrophication processes (Fig. 28). The Orthocladiinae appeared to be affected to the greatest degree by rapid mineral sediment accumulation, and the Tanypodinae the least. The difference in susceptibility undoubtedly lies in their different life styles. The development of unstable bottom conditions created by the rapid accumulation of mineral sediments actually appears to have favored the predatory Tanypodinae, possibly by forcing their prey species to the sediment surface. These same conditions probably forced the generally smaller, detritus-feeding Orthocladiinae to migrate or face elimination because of interference with their feeding activities, and/or the general destruction of their habitat. In all aspects of the chironomid community, diversity declined markedly in the most recent sediments, possibly because conditions favored the development of communities of one or two species rather than by the elimination of more species. The disruption of the chironomid community initiated by the processes of sedimentation was continued in the more recent sediments by the processes of eutrophication.

Analyses of percentage similarity of community and coefficients of community (Table 16–21) detailed similar community responses. In each case, the abrupt disruption of the chironomid community at 39.5 cm, caused by the commencement of heavy mineral sediment accumulation, effectively splits the fauna into pre- and post-event community types.

4.3.2 FAUNAL RESPONSES TO SEDIMENTATION PROCESSES

A number of taxa responded positively to the rapid accumulation of fine mineral sediments (Fig. 29). This is particularly evident during the period of rapid, fine mineral sediment accumulation characterizing the Imbalanced Oligotrophic Phase, where *Micropsectra* spp. reached their greatest abundance in zones VIIa,b. As a result of similar experiences, Pagast (1943: 479) and later Reiss (1968: 274) concluded that lakes receiving allochthonous mineral sediments should be referred to as *Micropsectra* lakes because of this characteristic development, rather than *Tanytarsus* lakes as proposed in lake classification theory. The very rare *Abiskomyia* Edw. appeared in Zone VIIa just in advance of the heaviest influx of mineral sediments. Grimås (1961: 227) suggested that *Abiskomyia* is able to flourish in zones of rapid mineral sedimentation because its moveable tube renders the species less dependent on the physical properties of the bottom sediments. Three other species (*Heterotrissocladius changi* Sæth., *Harnischia curtilamellata* (Mall.), and the Genus near *Heterotrissocladius*) appeared to be favored by the accumulation of mineral sediments, but at more moderate rates of accumulation. However, none of these appeared to favor the extreme rates favored by *Micropsectra* spp.; indeed the Genus near *Heterotrissocladius* was inhibited by the high accumulation rates in Zone VIIb. According to O. A. Sæther (personal communication) both *Heterotrissocladius changi* and *Harnischia curtilamellata* do well under the agitated conditions of turbid Lake Winnipeg.

The four major sediment-positive species (*Micropsectra* spp., *Heterotrissocladius changi, Harnischia curtilamellata,* and the Genus near *Heterotrissocladius)* demonstrated a similar response in sedimentation Zone II of the Hopewell Period. Although not as great as that apparent in the more recent sediments, the response to the accumulation of fine mineral sediments is definite and confirms the interpretation of the Erosion Index for this period. In general terms, Chutter (1969: 71) stated that fine minerogenic sediments receiving allochthonous inputs were inhabited by surface-dwelling groups of the Tanytarsini and Orthocladiinae. This contrasts with more stable environments, where species that burrow into the sediments are more numerous.

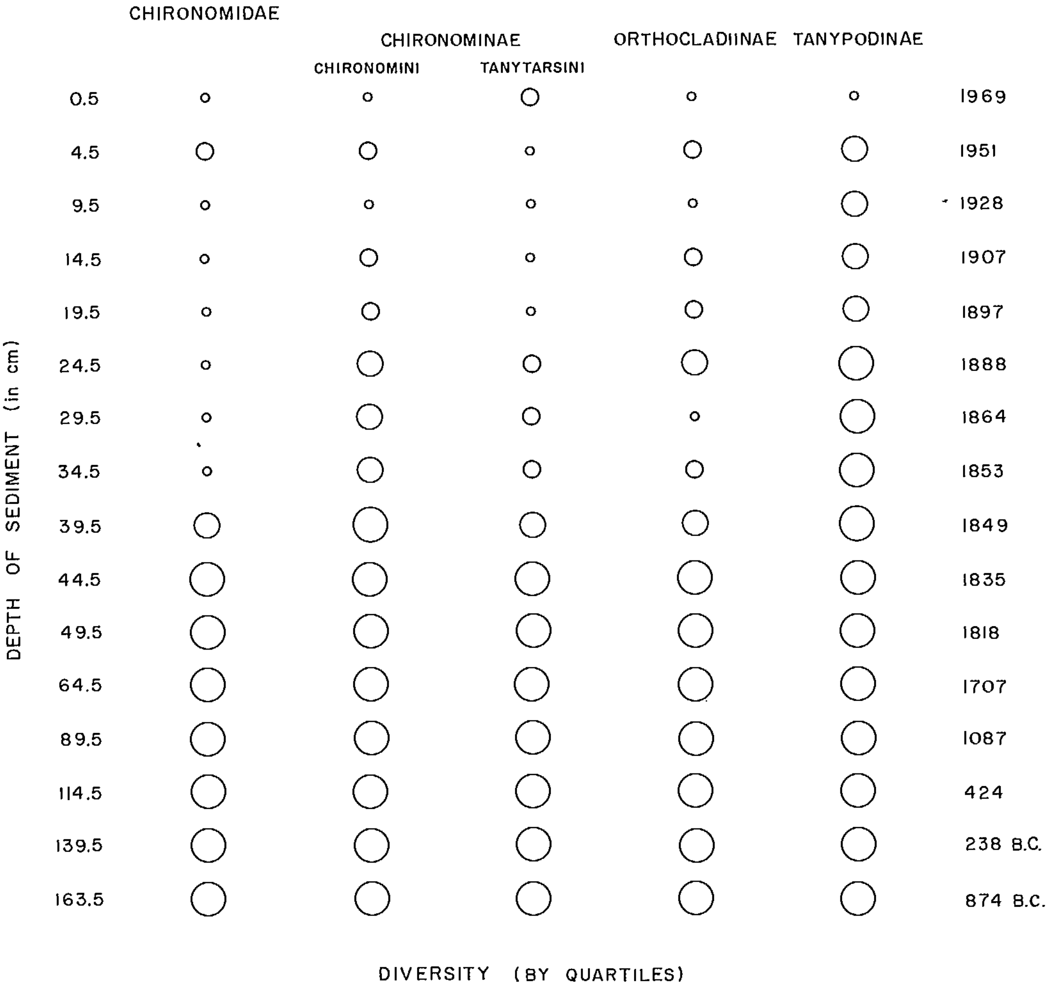


FIG. 28. Diversity indices for the family Chironomidae and its main subgroups expressed as functions of sediment depth. The data are presented by quartiles with the first quartile represented by the smallest diameter circle.

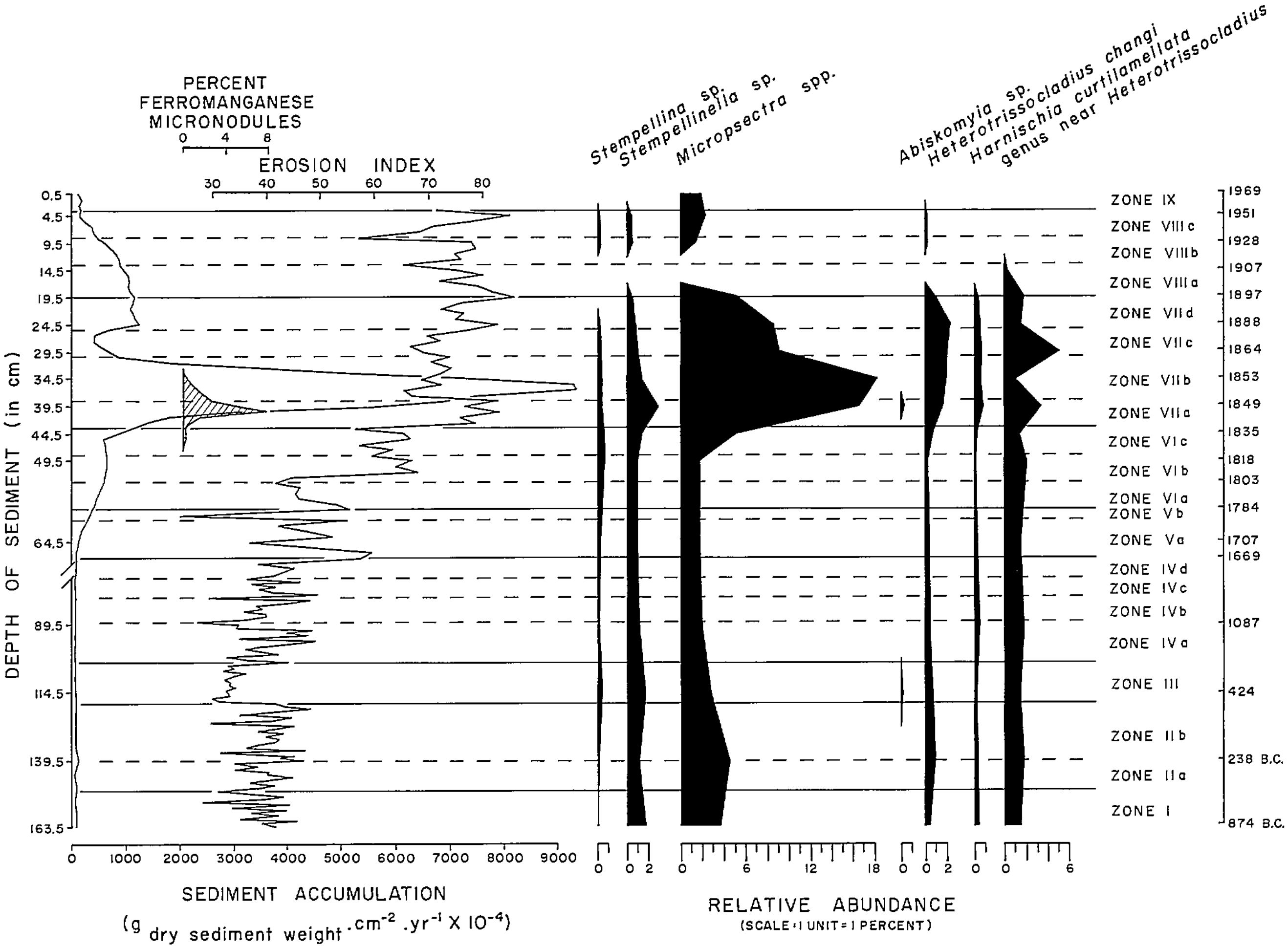


FIG. 29. Chironomid taxa responding positively to mineral sediment accumulation and other sedimentary parameters.

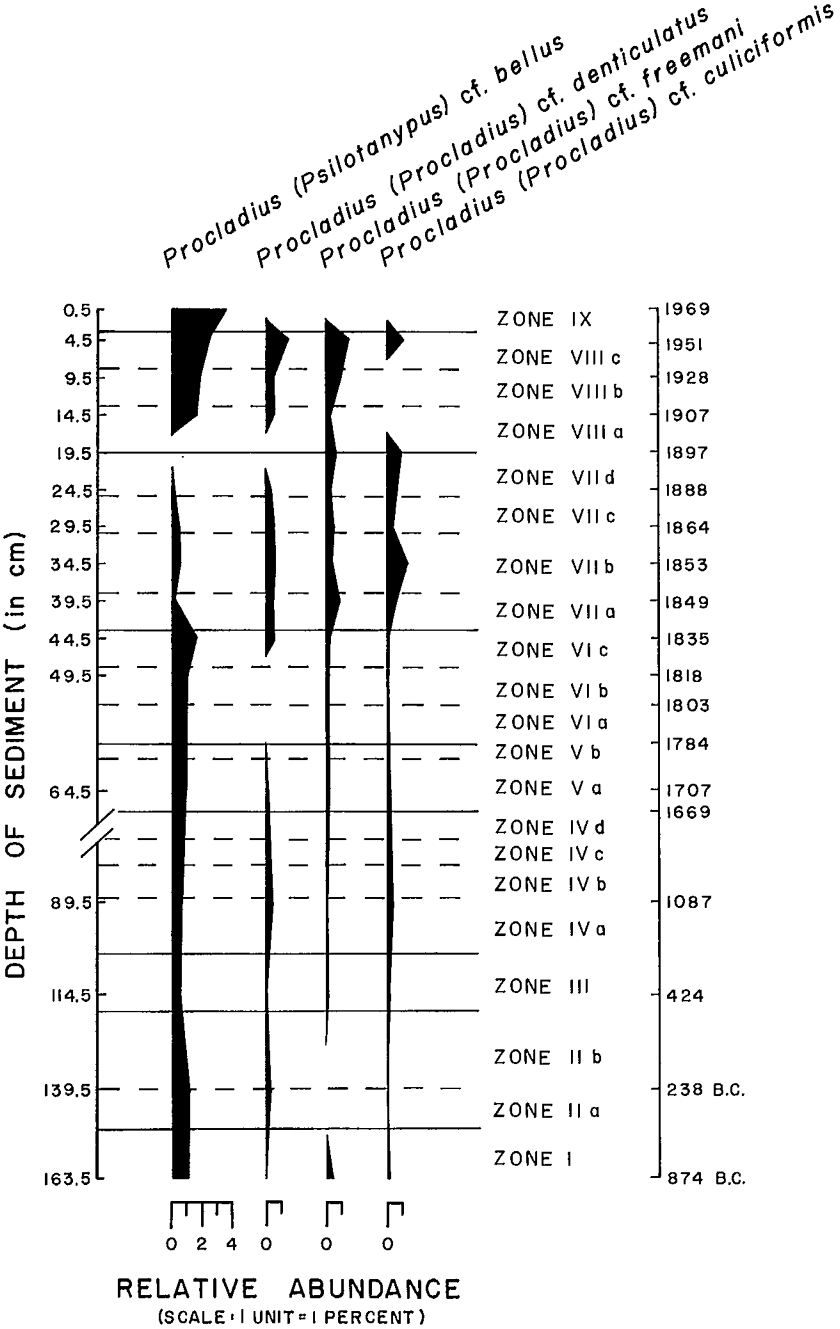


FIG. 30. The response of *Procladius* spp. to mineral sediment accumulation.

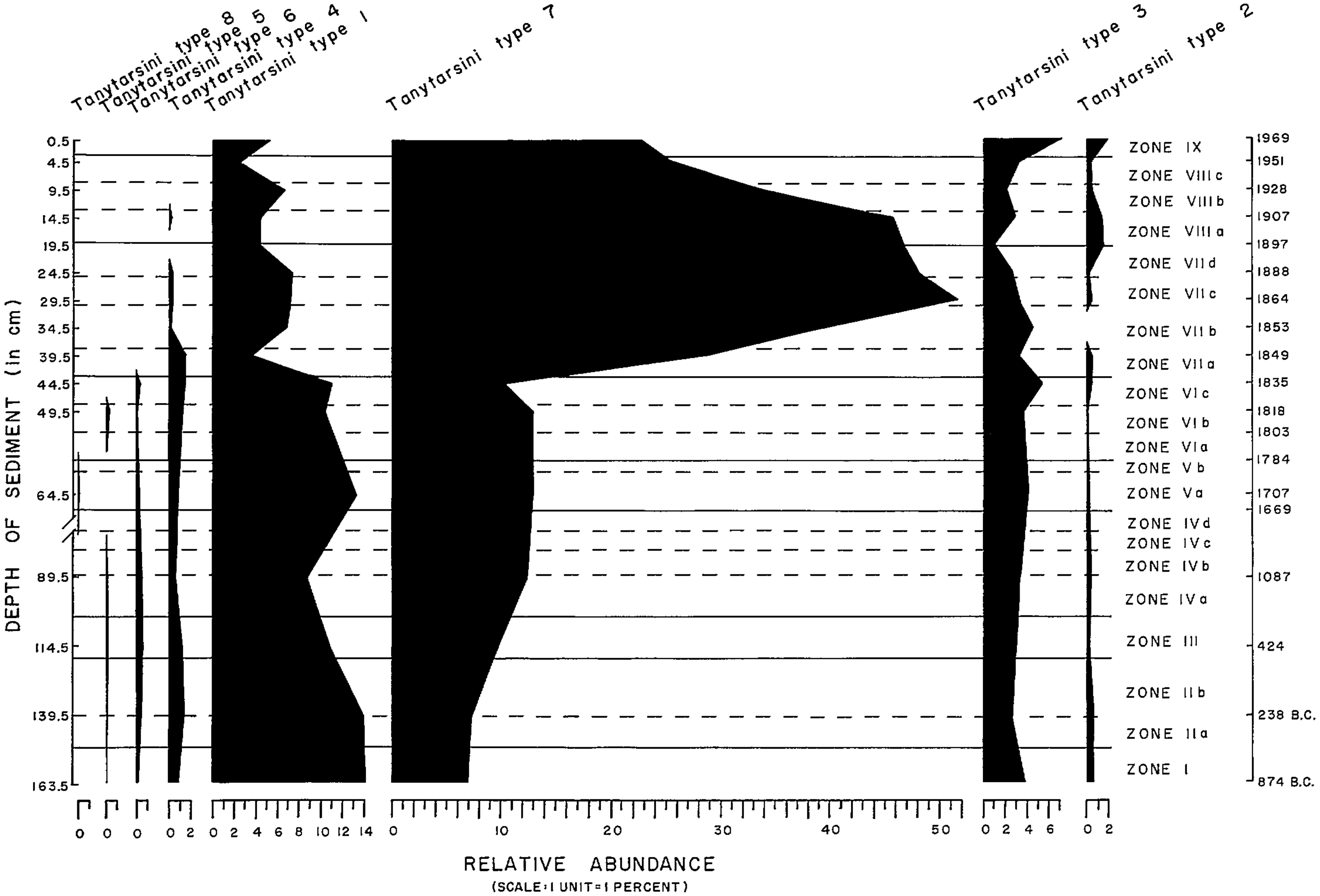


FIG. 31. The response of the Tanytarsini to mineral sediment accumulation.

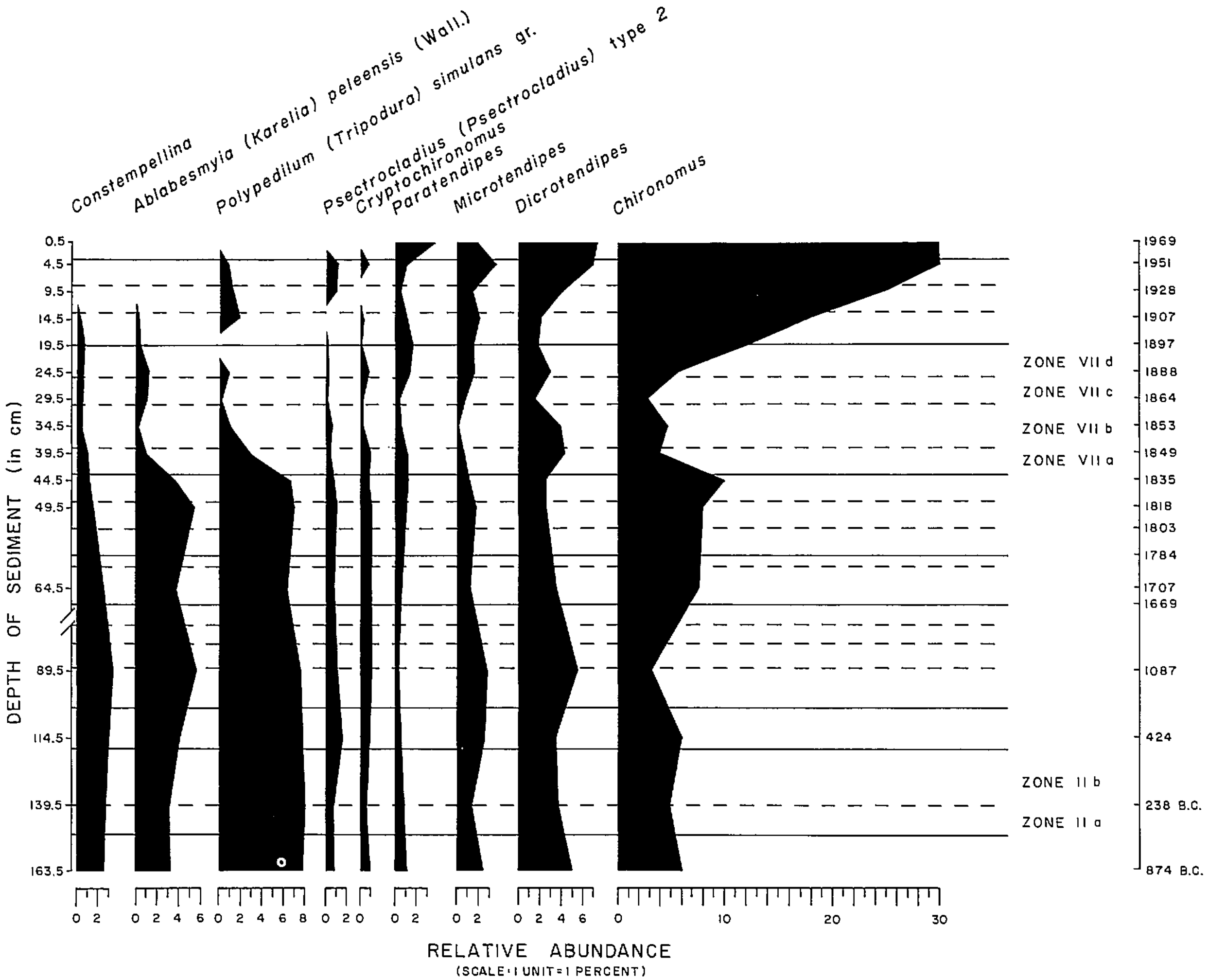


FIG. 32. Chironomid taxa suppressed by mineral sediment accumulation.

Another sediment-related development is the association of *Stempellinella* sp. and *Stempellina* sp. with the ferromanganese micronodule horizon at 40.5 cm (Fig. 29). Brundin (1949: 859) similarly reported the association of members of the subtribe Zavreliina with lakes containing ferromanganese "excrement balls." In contrast to the present situation, he cited species of *Stempellina* Bause and *Constempellina* Brund., but does not mention the genus *Stempellinella* Brund. It is possible that *Stempellinella* fulfils the role of the latter genus in North America. Brundin (1949: 859) regarded the association as a valuable indicator of an oligotrophic profundal environment, poor in humus but rich in oxygen.

The four species of *Procladius* Skuse appear to demonstrate a perceptually graded positive response (Fig. 30) to the increasingly rapid accumulation of fine mineral sediments in the more recent sediments. The abundance of *Procladius (Psilotanypus)* cf. *bellus* (Loew), and to a lesser degree *Procladius (Procladius)* cf. *denticulatus* Subl., increased markedly during sedimentation Zone VIc; *Procladius (Procladius)* cf., *freemani* Subl. during sedimentation Zone VIIa; and *Procladius (Procladius)* cf. *culiciformis* (L.) during sedimentation Zone VIIb. The latter species, *Procladius (Procladius)* cf. *culiciformis* (L.), appears to be the most tolerant of rapid mineral sediment accumulation, whereas *Procladius (Psilotanypus)* cf. *bellus* appears to be the least tolerant. The response of *Procladius (Psilotanypus)* cf. *bellus* in the older sediments may provide some measure of the rate of sediment accumulation in Zone II during the Hopewell Period. Although the relationship has not been noted before in the literature, it is hypothesized that the rapid accumulation of mineral sediments favor the predatory *Procladius,* by destroying their prey's cover and forcing them to the sediment surface where they are more vulnerable to attack by *Procladius*.

The response of Tanytarsini types to the accumulation of mineral sediments is outlined in Fig. 31. Unfortunately, taxonomic restrictions preclude any definitive comments; however, the rapid increase in the abundance of Tanytarsini type 7 in Zone VII is particularly noteworthy.

The greater proportion of the deeper water chironomid community responded negatively to the accumulation of fine mineral sediments, particularly to the rapid rate of accumulation in sedimentation Zone VII. The degree of response evinced by different taxa varied according to their individual tolerance to mineral sediments, from suppression of their abundance, as shown by the distribution of the taxa in Fig. 32 to their virtual elimination as demonstrated by the taxa in Fig. 33. A number of the taxa in Fig. 33 were eliminated during the periods of heaviest accumulation, but reappeared after the accumulation of mineral sediments slowed down again. This suggests the possibility that some taxa migrated up the basin walls to avoid extinction by the sediments, or that sufficient stocks capable of supporting recolonization existed elsewhere. (As discussed below, a number of taxa typically associated with vegetation were also eliminated.) The sensitivity demonstrated by many taxa to the accumulation of mineral sediments in the more recent period is also evident in Zone II (Fig. 32), where the fine sediment accumulation characterizing the Hopewell Period was apparent.

A major effect of the rapid accumulation of fine mineral sediments was to alter the zonal subdivision of the bottom habitat. The fact that the majority of the taxa associated with plants in Lake Group 3 (with the exception of *Hydrobaenus* spp., *Phaenopsectra ("Phaenopsectra")* sp. 2, and *"Paracladius"* cf. *triquetra* Chern.) were confined to the older pre-European period sediments indicates that the bottom habitat of the Glenora site was characteristically sublittoral, or possibly upper profundal in nature throughout the pre-European period (Fig. 34). The presence of a truly profundal assemblage in the most recent sediments, coupled with the marked absence of the assemblage associated with plants, demonstrates that the bottom habitat has changed to a truly profundal zone. The presence of the truly profundal species *Heterotrissocladius* sp. *B* Sæth. at 49.5 cm suggests that the transition from a sublittoral–upper profundal zone to a truly profundal zone may have begun this early. The major part of the transition occurred, however, between 44.5 and 29.5 cm. This is shown by the marked decline in the number of plant-associated taxa and their contribution to the overall fauna between these levels. The presence of limited numbers of *Cricotopus (Cricotopus)* cf. *patens* Hirv. and *Cricotopus (Cricotopus) bicinctus* Meig. up to 19.5 cm suggests that the transition may have extended to this level. Except for the single specimen of *Xenochironomus (Xenochironomus) xenolabis* (Kieff.) recovered from 4.5 cm (probably a redeposited specimen), the plant-associated assemblage was absent in the most recent sediments. The fact that the transition occurred within the period of maximum mineral sediment accumulation characterizing sedimentation Zone VII, directly implicates sedimentation processes as the motivating force fostering the habitat change. The burial of plants by silting, the development of unstable bottom conditions, and the inhibition of light penetration through turbidity screening undoubtedly were involved in the initial transition in zonal type. In more recent times, heavy plankton growth has probably perpetuated the screening effects of heavy silt loads.

4.3.3 FAUNAL RESPONSES TO EUTROPHICATION PROCESSES

Boundaries of the five major phases marking the course of trophic change in terms of the selected remnant chironomid fauna have been considerably refined (Fig. 35) on the basis of historical, physical, and chemical data from those initially presented (Warwick 1975: 3137). The major phases were subdivided where applicable according to the zonation established above for sedimentation processes. Those zones or subzones not encompassing levels in which the remnant chironomid fauna was analyzed, were treated together.

Interpretation of the changes in trophic status from the remnant chironomid fauna was based on 17 taxa whose identity and ecological preferences have been established. However, the interpretation is complicated by the fact that the bottom habitat, as discussed above, changed from a sublittoral–upper profundal habitat to a truly profundal habitat. The transition necessitates treating the faunal communities from different portions of the core independently. Faunal assemblages in the older portions of the core were interpreted as sublittoral communities, whereas those in the more recent portions were treated as true profundal communities (Warwick 1979a).

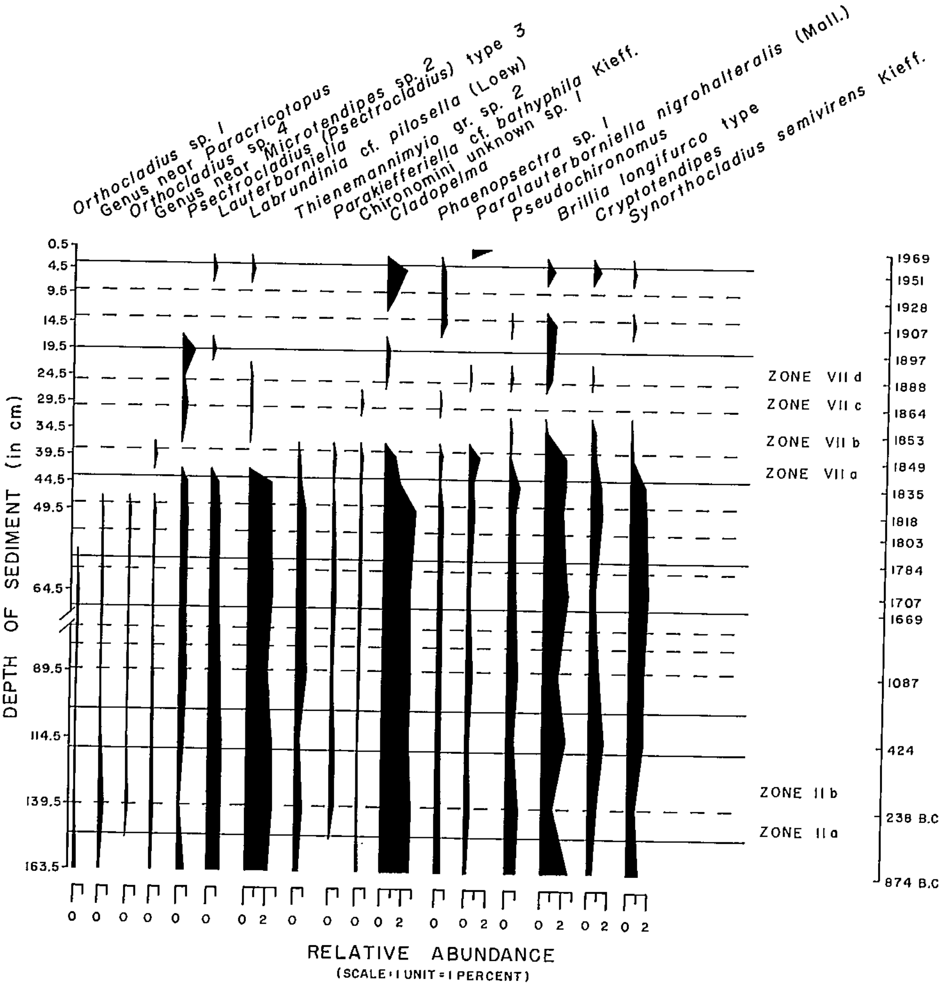


FIG. 33. Chironomid taxa displaced or eliminated by mineral sediment accumulation.

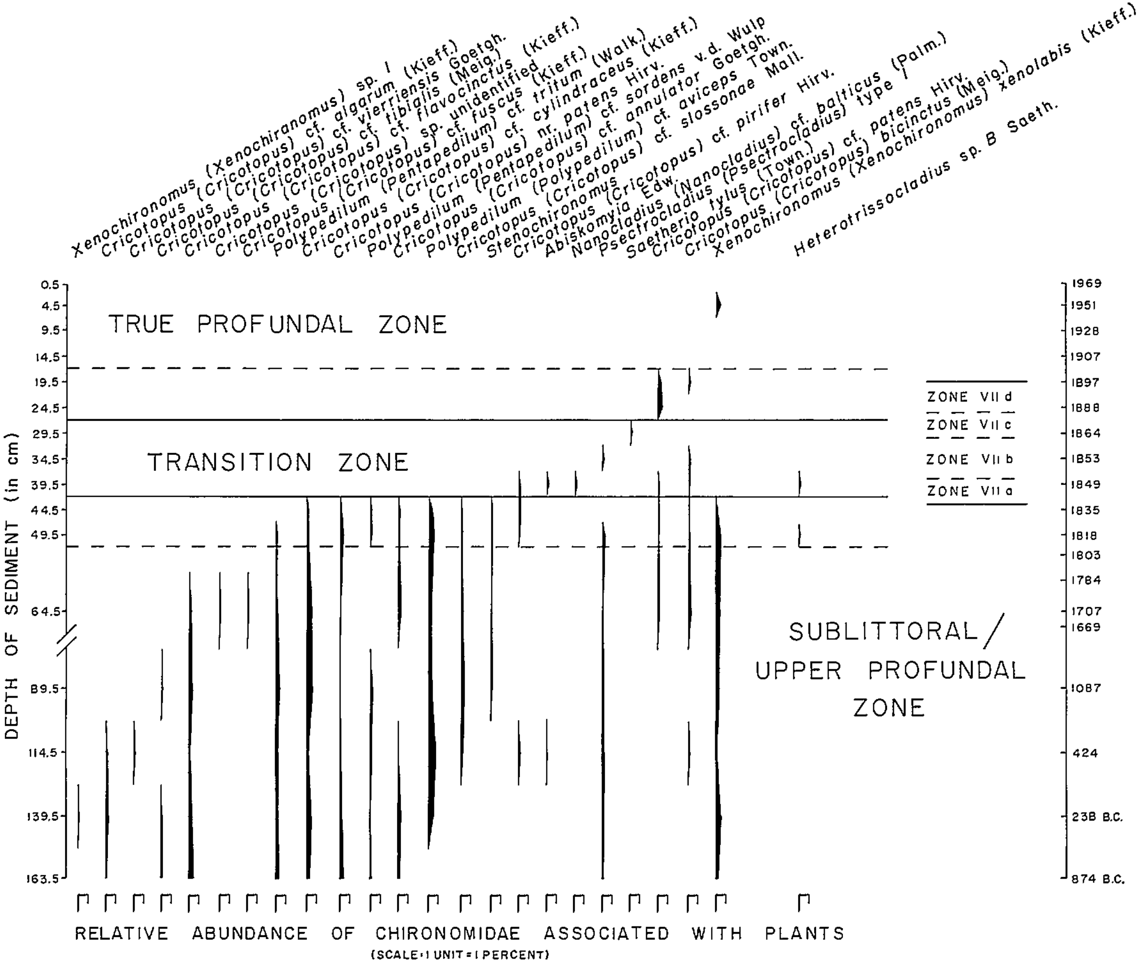


FIG. 34. Assessment of the zonal shift in bottom habitat induced primarily by mineral sediment accumulation.

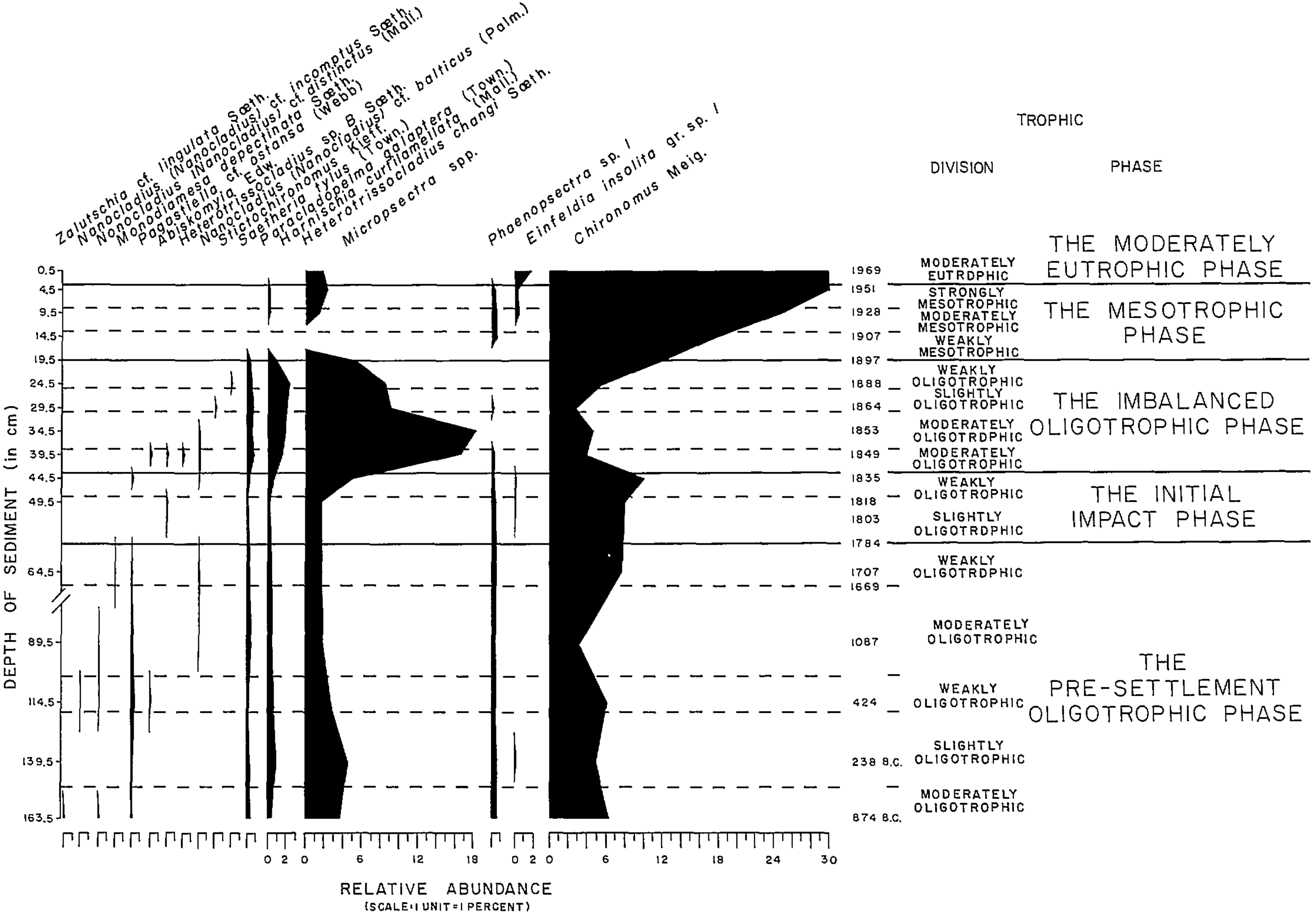
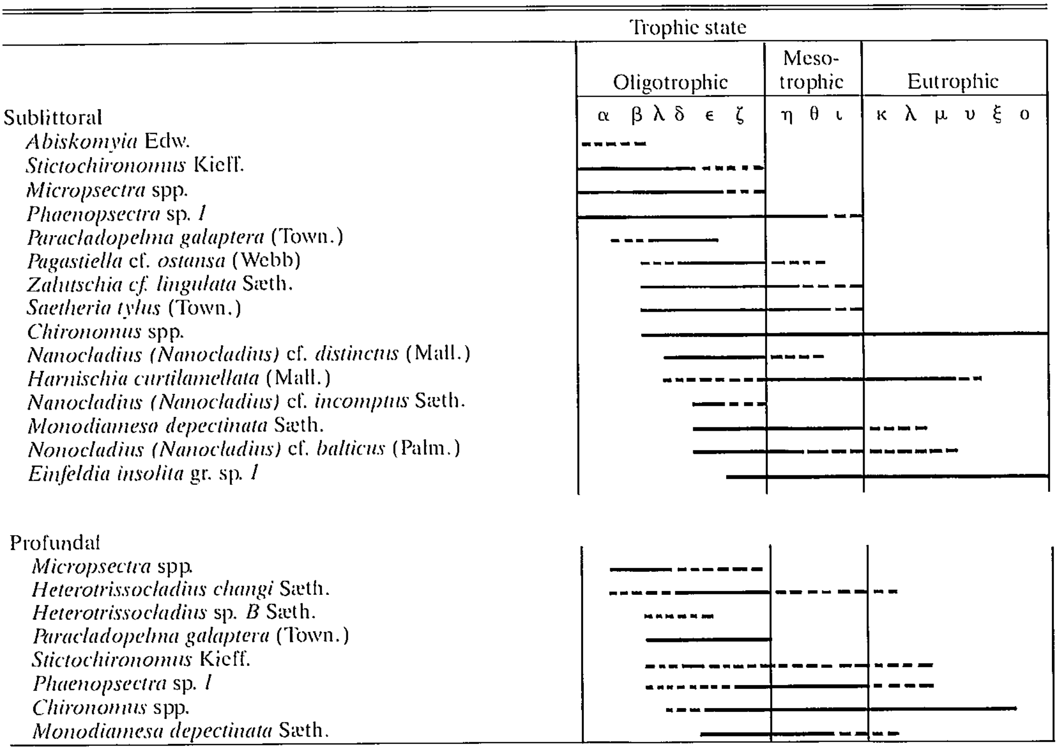


FIG. 35. Assessment of trophic changes based on selected members of the Chironomidae.

TABLE 22. Sublittoral and profundal trophic characterization of selected taxa applied to Glenora core sediments (after Sæther 1979: 67).



Sublittoral
Abiskomyia Edw.
Stictochironomus Kieff.
Micropsectra spp.
Phaenopsectra sp. *1*
Paracladopelma galaptera (Town.)
Pagastiella cf. *ostansa* (Webb)
Zalutschia cf. lingulata Sæth.
Saetheria tylus (Town.)
Chironomus spp.
Nanocladius (Nanocladius) cf. *distinctus* (Mall.)
Harnischia curtilamellata (Mall.)
Nanocladius (Nanocladius) cf. *incomptus* Sæth.
Monodiamesa depectinata Sæth.
Nonocladius (Nanocladius) cf. *balticus* (Palm.)
Einfeldia insolita gr. sp. *1*

Profundal
Micropsectra spp.
Heterotrissocladius changi Sæth.
Heterotrissocladius sp. *B* Sæth.
Paracladopelma galaptera (Town.)
Stictochironomus Kieff.
Phaenopsectra sp. *1*
Chironomus spp.
Monodiamesa depectinata Sæth.

The fauna found in sediments marking the transition phase between (17–)27–42(–52) cm utilized characteristics of both habitats.

The trophic requirements of the 17 taxa chosen as biological indices to interpret the changes in trophic status in the Bay of Quinte were evaluated (Table 22) according to Sæther (1979: 67). The trophic information given for *Abiskomyia* Edw. pertains to *Abiskomyia virgo* Edw., *Stictochironomus* to *Stictochironomus rosenschoeldi* (Zett.), *Phaenopsectra* sp. *1* to *Phaenopsectra coracina* (Zett.), and *Einfeldia insolita* gr. sp. *1* to *Einfeldia dissidens* (Walk.). The trophic information for *Micropsectra* spp. is a composite combining information for *Micropsectra lindebergi* Säw., *M. contracta* Reiss, and *M. groenlandica* And. Similarly, *Chironomus* spp. combine information for *Chironomus atritibia* Mall., *C. decorus* Joh., and *C. plumosus* L. Considerable subjective judgment must be exercised in using the Chironomidae as biological indices, because no one species is specific for a particular trophic condition. Instead, single species may tolerate a fairly wide range of conditions, but prefer and thrive best under more specific conditions. Therefore, any interpretation of trophic changes based on the Chironomidae must take this fact into consideration.

Terminology employed in evaluating the trophic stages is outlined below in Table 23 in order of increasing eutrophy. Division of the general classification used in lake-type theory initiates an attempt to standardize the terminology used throughout the literature (Warwick 1979a). The Trophic Index Number (TIN) provides a semiquantitative value for Sæther's trophic divisions. Analyses of the trophic changes in the Bay of Quinte based on the changes in the faunal assemblages is discussed below, in relation to the changes in sedimentation patterns outlined in Fig. 25, 27, and the organic carbon:total nitrogen and organic matter:organic carbon ratios outlined in Fig. 15, 16, and summarized in Table 24.

TABLE 24 (p. 76, 77). Tabulated summary of events and processes influencing the aquatic environment of the Bay of Quinte. Abbreviations: D = dominant species (species comprising > 15% of the total chironomid fauna). P = present, MRA = maximum relative abundance, TIN = trophic index number, A = absent. (Chart should be read from past to present, i.e. bottom to top.)

Chronology		Historical Events			Sedimentary Parameters			Chemical
Depth of Sediment	Year	Periods	Stages	Activities	Zones		Accumulation	Organic Matter : Organic Carbon
	1972							
0.0 3.5	1956	THE BRITISH-MODERN PERIOD	Stage Of Recent Population Growth	increased industrial activity	ZONE IX		increased organic material accumulation	2.65 organic material respiration active
3.5 8.5	1932			pulp and paper industry in Bay of Quinte area peaks then declines	ZONE VIII	(c)	increased organic material accumulation	2.42 organic respiration incomplete
8.5 11.0	1921			pulp and paper industry begins all forest products industries decline during the Great Depression		(b)	increasing organic content accumulation of mineral sediments declining	2.42 organic respiration incomplete
11.0 13.5	1909		Stage Of Population Decline					
13.5 19.5	1897			forest product industries decline agricultural land abandonment continues		(a)	decline in accumulation of mineral sediments organic fraction increasing	2.41 organic respiration incomplete
19.5 25.5	1886			indigenous Southern Ontario industry develops agricultural lands abandoned	ZONE VII	(d)	increased sediment accumulation clay content high organic fraction increasing	2.61 some immature organics trapped in sediments
25.5 26.0	1883			select pine timber resources of Bay of Quinte watershed virtually exhausted agriculture develops on cleared lands		(c)	rapid decline in accumulation of montmorillonite clay mineral sediments	2.80 considerable immature organics trapped in sediments
26.0 30.5	1861		Stage Of Rapid Population Growth					
30.5 38.5	1851			massive deforestation begins as American lumber markets open up		(b)	maximum accumulation of montmorillonite clay mineral sediments	2.80 considerable immature organics trapped in sediments
38.5 43.5	1838			heavy volunteer immigration opens back townships square timber trade develops rapidly		(a)	rapid increase in accumulation of montmorillonite clay mineral sediments	3.37 much immature organics trapped in sediments.
43.5 48.5	1822		Stage Of British Colonization	experimental and pauper immigration into old established townships	ZONE VI	(c)	slight decline in accumulation of clay mineral sediments	2.03 combusted organic material present
48.5 53.5	1803			Napoleon's Continental System fosters square timber trade in area		(b)	increased accumulation of clay mineral sediments	2.02 combusted organic material present
53.5 58.5	1784			United Empire Loyalists colonize immediate area		(a)	moderate increase in rate of sediment accumulation clay content only slightly increased	2.00 combusted organic material present
58.5 60.5	1758	THE FRENCH PERIOD	Abandonment Stage	Quinte area uninhabited after French defeat	ZONE V	(b)	accumulation of clay materials declines carbonate sediment content increases	2.01 combusted organic material present
60.5 67.5	1669		Stage Of French Activity	Sulpician Mission established fur traders active		(a)	marked increase in accumulation of fine clay mineral sediments	1.97 fully combusted organic material present
67.5 72.5	1537	THE IROQUOIS PERIOD	Abandonment Stage	area becomes uninhabited buffer zone between warring Iroquois	ZONE IV	(d)	accumulation of clay type materials reduced carbonate sediment content increased	2.26' some immature organics trapped in sediments
72.5 79.5	1352		'Late Ontario Iroquois' Stage	historical Huron, Petun, Neutral and Erie tribes develop.		(c)	accumulation of clay type materials increased.	2.04 combusted organic material present.
79.5 88.5	1113		'Convergence Or Middle Ontario Iroquois' Stage			(b)	moderate decline in accumulation of clay type sediments.	2.06 combusted organic material present
88.5 103.5	716		'Early Ontario Iroquois' Stage			(a)	general increase in accumulation of clay-type sediments towards end of zone	2.09 combusted organic-material present.
103.5 110.5	530				ZONE III		proportionate decline in accumulation of clay type sediments midway through zone.	2.16 organic material of average lake maturity.
110.5 - 118.5	318	THE ALGONKIAN PERIOD						
118.5 - 123.5	186 A.D.				ZONE II	(b)	proportionate increase in accumulation of clay-type sediments.	2.55 period average-maximum 4.01. considerable immature organics trapped at 139.5cm.
123.5 - 139.5	238 B.C.	THE HOPEWELL PERIOD	Late?					
139.5 - 150.5	530 B.C.		Early?			(a)	slight increase in accumulation of carbonate-type sediments.	2.18 organic material of average lake maturity.
150.5 - 163.5	874 B.C.	THE PRE-HOPEWELL PERIOD			ZONE I		slight decline in accumulation of carbonate-type sediments.	2.25 some immature organics trapped in sediments.

Parameters	Biological Parameters				Interpretive Remarks
Organic Carbon : Total Nitrogen	**Phases**	**Diversity Index 'H(S)'**	**Composition**	**Trophic Level**	
7.39 period average. increasing trophy.	**THE MODERATELY EUTROPHIC PHASE**	3.27	D *Chironomus*. M.R.A *Chironomus*. P. Chironomini. Tanytarsini type 7 and *Procladius* abundant	**TIN 12 moderately eutrophic**	Evidence of industrial and or agricultural contaminants impinging on moderately eutrophic chironomid fauna.
7.68 period average. increasing trophy.	**THE MESOTROPHIC PHASE**	3.58	D. *Chironomus*. M.R.A. *Procladius*. P. *Phaenopsectra* sp. *1* Abundance of Tanytarsini type 7 declining	**TIN 9 strongly mesotrophic**	Rapid accumulation of organic materials reduce oxygen levels available to chironomid communities.
9.09 period average. increasing trophy		3.32	D Tanytarsini type 7. P. *Phaenopsectra* sp. *1* Abundance of *Chironomus* increasing	**TIN 8 moderately mesotrophic**	Development of mesotrophic *Phaenopsectra* population probably inhibited by very rapid increase in rate of eutrophication
8.46 period average. increasing trophy		3.12	D Tanytarsini type 7. M.R.A *Phaenopsectra* sp *1*. Abundance of *Chironomus* increasing.	**TIN 7 weakly mesotrophic**	Marked increase in eutrophication with cessation in fine mineral sediment accumulation.
8.81 period average increasing trophy	**THE IMBALANCED OLIGOTROPHIC PHASE**	3.26	D Tanytarsini type 7; slight decline in abundance M.R.A *Heterotrissocladius changi*. Abundance of *Chironomus* increasing	**TIN 5 weakly oligotrophic**	Oligotrophication induced by renewed accumulation of fine mineral sediments.
9.10 period average increasing trophy		3.02	D Tanytarsini type 7. M.R.A Tanytarsini type 7, Genus near *Heterotrissocladius*. *Micropsectra* abundant	**TIN 6 slightly oligotrophic**	Repression of eutrophication processes revealed as accumulation of mineral sediments declines
9.38 period average increasing trophy.		3.25	D. *Micropsectra*, Tanytarsini type 7 M.R.A *Micropsectra* Most components of fauna severely reduced or absent.	**TIN 4 moderately oligotrophic**	Induced oligotrophication maximized by rapid accumulation of fine mineral sediments.
9.62 period average increasing trophy		4.18	D *Micropsectra*, Tanytarsini type 7 P *Stictochironomus*. Plant associated fauna generally absent	**TIN 4 moderately oligotrophic**	Presence of *Stempellinella* indicates profundal oligotrophic environment poor in humus, but rich in oxygen.
9.77 period average increasing trophy	**THE INITIAL IMPACT PHASE**	5.00	P. *Pagastiella* cf. *ostansa*, *Stictochironomus*, plant associated fauna. Abundance of *Chironomus* increasing, Orthocladiinae declining	**TIN 5 weakly oligotrophic**	Oligotrophication initiated by accumulation of fine mineral sediments.
9.89 period average increasing trophy		5.05	Abundance of *Chironomus* increasing *Ablabesmyia (Karelia) peleensis*, *Polypedilum (Tripodura) simulans* group abundant. Orthocladiinae abundant. Other groups generally abundant.	**TIN 6 slightly oligotrophic**	Eutrophication accelerated by arrival of 1,814 United Empire Loyalists in immediate area of core site
10.00 period average increasing trophy					
10.05 period average increasing trophy	**THE PRE-SETTLEMENT OLIGOTROPHIC PHASE**	4.96	M.R.A *Synorthocladius semivirens*. P. *Monodiamesa depectinata*, *Pagastiella* cf. *ostansa* and *Stictochironomus*. Abundance of *Chironomus* increasing	**TIN 5 weakly oligotrophic**	Increase in eutrophication probably begun as early as 'Late Ontario Iroquois' Stage
10.12 period average increasing trophy					
10.18 period average slight increase in trophy		5.11	M.R.A. *Ablabesmyia (Karelia) peleensis*, *Thienemannimyia* gr. sp. *2*, *Dicrotendipes*, *Microtendipes* and *Constempellina*. P. *Nanocladius (Nanocladius)* cf. *distinctus*, *Pagastiella* cf. *ostansa* and *Stictochironomus*. Abundance of *Chironomus* reduced.	**TIN 4 moderately oligotrophic**	Oligotrophication reaches maximum through nutrient deprivation and influence of sedimentation processes in earlier stages of period
10.22 period average. slight increase in trophy.					
10.24 period average. trophy steady.					
10.24 period average. decreasing trophy.					
10.17 period average. decreasing trophy.		5.20	M.R.A. *Pagastiella* cf. *ostansa*, *Cryptotendipes*, *Psectrocladius (Psectrocladius)* type *2* and *Lauterborniella*. P. *Nanocladius (Nanocladius)* cf. *incomptus*, *N.(N.)* cf. *distinctus* and *Abiskomyia*. Abundance of *Chironomus* reduced.	**TIN 5 weakly oligotrophic**	Stage of maximum faunal diversity. Oligotrophication begins because of nutrient deprivation.
10.10 period average. slight decline in trophy.		5.12	M.R.A. *Labrundinia* cf. *pilosella*, *Pseudochironomus*, *Polypedilum (Tripodura) simulans* gr. and *Parakiefferiella* cf. *bathyphila*. P. *Einfeldia insolita* gr. sp. *1*. Abundance of *Micropsectra* and *Heterotrissocladius changi* increasing; *Chironomus* declining.	**TIN 6 slightly oligotrophic**	Fauna respond to increased productivity resulting from development of Hopewell culture. Oligotrophication possibly initiated by sedimentation processes in latter part of period.
10.09 period average. increasing trophy.					
10.19 period average. increasing trophy.		5.08	M.R.A. *Brillia longifurca* type and Tanytarsini type 1. P. *Zalutschia* cf. *lingulata* and *Nanocladius (Nanocladius)* cf. *distinctus*.	**TIN 4 moderately oligotrophic**	Erosion Index suggests earliest oligotrophic fauna artificially maintained by sedimentation processes.

TABLE 23. Terminology used in evaluation of trophic stages recorded in the history of the Bay of Quinte.

General classification	Trophic stage evaluation	Trophic stage division (Sæther 1979:67)	Trophic Index Number
Oligotrophy	Ultraoligotrophic	α	1
	Strongly oligotrophic	β	2
	Oligotrophic	γ	3
	Moderately oligotrophic	δ	4
	Weakly oligotrophic	ε	5
	Slightly oligotrophic	ζ	6
Mesotrophy	Weakly mesotrophic	η	7
	Moderately mesotrophic	θ	8
	Strongly mesotrophic	ι	9
Eutrophy	Slightly eutrophic	κ	10
	Weakly eutrophic	λ	11
	Moderately eutrophic	μ	12
	Eutrophic	ν	13
	Strongly eutrophic	ξ	14
	Ultraeutrophic	ο	15

The Pre-Settlement Oligotrophic Phase was divided into five trophic zones roughly equivalent to each cultural period recorded in the older sediments:

Zone I (874–530 B.C.)

Zone I is equivalent to the Pre-Hopewell Period and ranked moderately oligotrophic. The absence of typically ultraoligotrophic species such as *Heterotrissocladius oliveri* Sæth., or *Protanypus caudatus* Edw., or the typically strongly oligotrophic *Heterotrissocladius* sp. *B* Sæth. of the *maeaeri* group, precludes a more oligotrophic measure. Although the faunal assemblage suggested the zone should possibly be ranked as high as weakly oligotrophic, the more conservative measure was adopted on the basis of the presence of *Zalutschia* cf. *lingulata* Sæth. and *Nanocladius (Nanocladius)* cf. *distinctus* (Mall.). The comparatively high organic matter:organic carbon ratio characteristic of the beginning of the period, coupled with a relatively high Erosion Index, suggests food materials arriving at the sediment surface may not have been readily available to the faunal assemblage at 163.5 cm. This factor may account for the moderately oligotrophic fauna found at the bottom of the core.

Zone II (530 B.C.–319 A.D.)

Roughly equivalent to the Hopewell Period, Zone II was comparatively more eutrophic according to the faunal assemblage at 139.5 cm. The period was ranked slightly oligotrophic from the presence of *Einfeldia insolita* gr. sp. *I* (probably *Einfeldia dissidens* (Walk.)?) and *Parakiefferiella* cf. *bathyphila* Kieff. The increase in trophic state indicated by the faunal assemblage is undoubtedly related to two factors — increased production in the water column and a decrease in the burial of food materials at the sediment surface by mineral sediment accumulation. The decline in the organic carbon:total nitrogen ratio from an average of 10.19 throughout the Pre-Hopewell Period to an average of 10.09 in the early ? part of the Hopewell Period indicates organic production was increasing throughout the interval. The increased productivity probably is attributable to the developing Hopewell culture. The general decline in the Erosion Index, extending from the latter part of the Pre-Hopewell Period into the early ? parts of the Hopewell, indicates that burial by mineral sediment accumulation was becoming less of a problem. This is also reflected in the decline in the organic matter:organic carbon ratio throughout the same period, from an average of 2.25 to 2.18. The lowered ratio indicates that organic materials arriving at the sediment surface were more readily available to the chironomid community and were not being buried unutilized. Accumulation of available food stocks is further revealed by the organic matter:organic carbon ratio in the large amount of diagenetically immature organic material trapped at 139.5 cm. The Erosion Index shows that the material was buried by a relatively heavy influx of fine mineral sediments between 139.5 and 137.5 cm. The beginning of the accumulation event that trapped the material is readily apparent in the response of the faunal assemblage. Fauna that react positively to the accumulation of mineral sediment such as *Micropsectra* spp., *Harnischia curtilamellata* (Mall.), and *Heterotrissocladius changi* Sæth. increased in abundance. Fauna that are sensitive to the accumulation of fine mineral sediments such as *Chironomus* spp. declined.

Zone III (319–714 A.D.)

Roughly equivalent to the Algonkian Period, Zone III was comparatively less eutrophic than Zone II. According to the faunal assemblage from 114.5 cm, the period was ranked weakly oligotrophic on the basis of the presence of *Nanocladius (Nanocladius)* cf. *incomptus* Sæth. and *Nanocladius (Nanocladius)* cf. *distinctus* (Mall.), which appeared in limited numbers. The presence of a single specimen of *Abiskomyia* Edw. suggests the interval should possibly be ranked even more oligotrophic. *Pagastiella* cf. *ostansa*

(Webb) reached its maximum abundance during this period. Designation of the type as an indicator of weak oligotrophy is marginally different from Sæther's (1975b: 3132) designation of a primarily moderately oligotrophic type, and is more in line with the trophic preference assigned to the European *P. orophila* Edw. The trend to increasing oligotrophy, marked by the faunal assemblage, began in the late ? stage of the Hopewell Period, where the organic carbon:total nitrogen ratio increased to an average of 10.10, and continued into the Algonkian Period, where the ratio reached an average of 10.17. The process of oligotrophication begun in the late ? stage of the Hopewell Period was initiated by the accumulation of fine mineral sediments, shown by the Erosion Index. The sediments effectively buried any organic food materials accumulated in the surface sediments, or gleaned from the water column, and rendered it increasingly unavailable to the chironomid community. This is apparent in the increase in the organic matter:organic carbon ratio (Table 24) which reached an average of 2.55, if the large amount of organic matter buried at 139.5 cm is included, or 2.19 if it is not. The trend initiated at this stage continued into Zone III where the organic matter:organic carbon declined to 2.16 average and the organic carbon:total nitrogen ratio increased to 10.17. The steady state of the Erosion Index indicates a lack of any human activity in the area which might have influenced the bay during the period. The withdrawal of cultural influence during the Algonkian Period probably aided and sustained the return to the more oligotrophic conditions initiated in the later stages of the preceding period.

Zone IV (714–1669)

The process of oligotrophication continued into Zone IV. According to the faunal assemblage, the zone (which roughly represents the Iroquois Period) was ranked moderately oligotrophic. The characteristic taxa, *Stictochironomus* and *Nanocladius (Nanocladius)* cf. *distinctus* (Mall.), were present at 89.5 cm. Stated to be associated with the very early stages of a *Phaenopsectra* lake in Europe (Lundbeck 1936: 322–326, sub *Sergentia*), the North American contemporary of *Stictochironomus* is believed to favor an even more oligotrophic situation (Sæther 1975b: 3127). Sæther (1977: 30) similarly reported *Nanocladius (Nanocladius)* cf. *distinctus* (Mall.) from the moderately oligotrophic areas of Lake Winnipeg. The continued process of oligotrophication is again related to sedimentation and food availability, but in a slightly different manner. The increase in the organic carbon:total nitrogen ratio to an average of 10.24 demonstrates the process reached its maximum during the Early Ontario and Convergence or Middle Ontario Iroquois stages. Although this fact coincides with the two periods of most intense fine sediment accumulation, and undoubtedly implicates sedimentation processes in the trend, another factor may be involved. The fact that the Erosion Index failed to mark the beginning of the Iroquois Period suggests that the early Iroquois communities were small and tended to be established well back from navigable waterways for defensive purposes. This intentional avoidance of rivers and streams as sites for community development probably accounts for the fact that the Iroquois culture in the early stages of development had such little impact on the trophic status of the bay, as shown by the high organic carbon:total nitrogen ratio. The chironomid community at 89.5 cm was directly influenced by this decline in productivity of the bay, as well as by the fact that the greater proportion of carbon material reaching the sediments was fully combusted ash material of little nutritional value. The presence of increasing amounts of this material (a by-product of the slash-and-burn land-clearing techniques of Iroquois agriculture) is readily apparent in the declining organic matter:organic carbon ratio, which reached averages of 2.09 and 2.06 in the Early Ontario and Convergence or Middle Ontario Iroquois stages, respectively., The trend continued into the Late Ontario Iroquois Stage where the ratio dropped to an average of 2.04, but reversed dramatically during the Abandonment Stage where the ratio increased suddenly to 2.26. The sudden increase in the ratio undoubtedly reflects the entrapment of diagenetically immature organic material at the sediment surface by the sudden influx of fine mineral sediments during the Abandonment Stage of the Iroquois Period. The trapped organic materials probably were produced by the increased productivity, indicated by the decline in the organic carbon:total nitrogen ratio during the Late Ontario Iroquois and Abandonment stages to 10.22 and 10.18, respectively. The increase in productivity undoubtedly reflects the larger numbers and bolder cultural mien of populations inhabiting the area, during the Late Ontario Iroquois Stage. The large-scale retreat of the southern Ontario Iroquois away from the bay led to the influx of fine mineral sediments monitored by the Erosion Index, and the entrapment of immature organic materials during the Abandonment Stage.

Zone V (1669–1784)

The increase in productivity begun in the latter phases of the Iroquois Period is evident in the more eutrophic faunal assemblage of Zone V. The zone outlines the French Period and was ranked weakly oligotrophic on the basis of the fauna from 64.5 cm. Particularly pertinent in the assemblage was the presence of *Monodiamesa depectinata* Sæth. and *Stictochironomus*. The latter species, as discussed above, is a strong indicator of moderately oligotrophic conditions, whereas the former tends to favor slightly more eutrophic conditions. The marked increase in the abundance of *Chironomus* spp. similarly favors the more eutrophic interpretation. The increase in productivity is reflected in the organic carbon:total nitrogen ratio that continued to decline throughout the period, from an average of 10.12 during the active French Stage to 10.05 in the Abandonment Stage. The fact that organic carbon concentrations (Fig. 27) were able to remain more or less constant during the period, in spite of the increasingly rapid rate of mineral sediment accumulation, demonstrates that organic production was indeed increasing. The organic materials of nutritional value stemming from increased production apparently were being fully utilized by the benthic communities, because the organic matter:organic carbon ratio remained at the level of fully combusted carbon throughout the period. The ratio was lowest during the initial stages of the period where it averaged only 1.97, and increased only marginally to 2.01 during the Abandonment Stage.

Zones VIa, b (1784–1822)

The trend to more eutrophic conditions continued into Zone VI. Zones VIa (1784–1803) and VIb (1803–22) were ranked slightly oligotrophic on the basis of the faunal assemblage from 49.5 cm. The sharp increase in the abundance of the genus *Chironomus* Meig., begun in the preceding zone, continued into Zone VI, whereas *Einfeldia insolita* gr. sp. *1* reappeared again. The presence of a single specimen of *Heterotrissocladius* sp. *B* Sæth., an acknowledged strongly oligotrophic type (Sæther 1975a: 26), at the beginning of the transition period marking the change from a sublittoral–upper profundal habitat to a truly profundal habitat, presages the process of oligotrophication encountered in succeeding zones and marks the beginning of the development of unstable environmental conditions in the bottom habitat. The trend to more eutrophic conditions marked in the faunal assemblage is also apparent in the organic carbon:total nitrogen ratio. The ratio declined throughout the period from 10.00 to 9.89 in zones VIa and b, respectively. This interpretation is supported by Fig. 27, which shows organic concentrations were maintained in spite of the increasing rate of accumulation of sediment materials. The organic matter:organic carbon ratio, which remained more or less constant at 2.00 and 2.02 in zones VIa and b, respectively, suggests that little organic material of nutritive value was retained in the sediments.

Zone VIc (1822–38)

The increasing instability in the bottom habitat in Zone VIc is readily apparent in the faunal assemblage of 44.5 cm. The trend to increasing eutrophy, marked by the decrease in the organic carbon:total nitrogen ratio to 9.77, is reflected in the increase in abundance of the genus *Chironomus* Meig. (probably *Chironomus atritibia* (Mall.)?) and the presence of *Einfeldia insolita* gr. sp. *1*. However, the presence of the oligotrophs *Stictochironomus* and *Pagastiella* cf. *ostansa* (Webb) suggests a more oligotrophic condition. The zone is provisionally ranked weakly oligotrophic on the basis of the latter two taxa, but the possibility of the higher trophic rating of slight oligotrophy suggested by the former two species, is acknowledged by the dotted lines in Fig. 35. The disruptive mechanism influencing the fauna at this stage is clearly identified as the accumulation of fine mineral sediments by the increase in abundance of the mineral–sediment–positive taxa *Micropsectra* spp., *Heterotrissocladius changi* Sæth., and *Harnischia curtilamellata* (Mall.). The ratio organic matter:organic carbon remained more or less constant at 2.03 in Zone VIc.

Zone VIIa (1838–51)

The trend to more oligotrophic faunas in Zone VIc of the Initial Impact Phase was continued in Zone VIIa of the Imbalanced Oligotrophic Phase. The zone was ranked moderately oligotrophic primarily on the basis of *Stictochironomus*. However, the presence of *Abiskomyia* Edw., *Heterotrissocladius* sp. *B* Sæth. of the *maeaeri* group, and *Parakiefferiella* cf. *bathyphila* Kieff. suggests a more oligotrophic ranking, whereas the presence of *Nanocladius (Nanocladius)* cf. *balticus* (Palm.) suggests a more eutrophic ranking. (This "conflicting" fauna characterizes the environmental stress apparent in the zone.) The abundance of the genus *Chironomus* declined markedly while that of *Stempellinella* increased. Brundin (1949: 859) regarded the latter species as a valuable indicator of an oligotrophic profundal environment, poor in humus but rich in oxygen when associated with ferromanganese particles like those found at this level. The trend to the more oligotrophic fauna proceeded in spite of the continued decline in the organic carbon:total nitrogen ratio to 9.62 indicating increased productivity. The sharp increase in the abundance of *Micropsectra* spp., *Heterotrissocladius changi* Sæth., and *Harnischia curtilamellata* (Mall.) signifies that the accumulation of fine mineral sediments suppressed the influence of increased productivity. (This factor is responsible for the collapse of the faunal assemblage so apparent in the community indices (see Section 4.3.1)). The impact of this rapid accumulation is shown by the rapid decline in the concentration of organic carbon (accentuated at 41.5–40.5 cm by the presence of the ferromanganese micronodule horizon) in Fig. 26. The sharp rise in the organic matter:organic carbon ratio from 2.03 to 3.37 indicates that, of the limited amount of organic material arriving at the bottom, the majority was buried intact and remained unavailable to the bottom community. This in no small measure accounts for the increasingly oligotrophic fauna found in Zone VIIa.

Zone VIIb (1851–61)

The trend to oligotrophication marked by the faunal assemblage was maximized in Zone VIIb. The zone was similarly ranked moderately oligotrophic on the basis of *Stictochironomus*. No other forms were found to suggest a more eutrophic interpretation, although *Chironomus* did increase slightly in abundance. *Phaenopsectra* sp. *1* was absent. Although the decline in the organic carbon:total nitrogen ratio to 9.38 indicates productivity continued to increase, the accumulation of fine mineral sediments, which reached a maximum of 9322.69 × 10^{-4} g dry sediment weight·cm^{-2}·yr^{-1} at 36.5 cm, continued to dominate developments in the bottom habitat. This is clearly reflected by the distribution of *Micropsectra* spp., which reached its maximum abundance at 34.5 cm almost coincident with peak sediment accumulation. The dilution effect of the massive accumulation of mineral sediments reduced organic carbon concentrations to a minimum. The continued high organic matter:organic carbon ratio of 2.80 suggests that the organic materials of nutritive value buried in the sediments remained unavailable to the decimated faunal assemblage. The higher ratio in Zone VIIa than in Zone VIIb suggests that the brief cessation in mineral sediment accumulation toward the end of Zone VIc may have allowed an accumulation of organic materials (taken down in the initial influx of sediments in Zone VIIa) in the water column. (It is unlikely the accumulation occurred at the sediment interface because of the faunal composition.) The continued pressure of the sedimentation process in Zone VIIb probably precluded any similar buildup in that zone.

Zone VIIc (1861–86)

The trend to oligotrophication was reversed in Zone VIIc, according to the faunal assemblage at 29.5 cm. The zone, ranked slightly oligotrophic, was characterized by a slight decline in the abundance of *Chironomus*, the appearance of *Saetheria tylus* (Town.), and the reappearance of *Phaenopsectra* sp. *1*. Effects of the rapid drop in the rate of mineral sediment accumulation, which reached a minimum of 403.05 × 10^{-4} g dry sediment weight·cm^{-2}·yr^{-1} at 26.5 cm, are apparent in the rapid decline in the abundance of *Micropsectra* spp. and perhaps in the slight decline of *Heterotrissocladius changi* Sæth. Despite the marked decline, the rate of fine mineral sediment accumulation remained sufficiently rapid, at least in the earlier part of Zone VIIc, to offset any increase in the concentration of organic carbon in the sediments due to the steadily increasing productivity of the water column, marked by the decline in the organic carbon:total nitrogen ratio to 9.10. The organic matter:organic carbon ratio, which remained at 2.80, indicates the bulk of the organic material produced was still being buried unutilized.

Zone VIId (1886–97)

The trend reversed again in Zone VIId, as moderately intense fine mineral sediment accumulation resumed. The zone was ranked weakly oligotrophic in its earlier stages by the presence of *Paracladopelma galaptera* (Town.) at 24.5 cm. However, the marked increase in the abundance of *Chironomus* at 19.5 cm suggests that the rapid transition to mesotrophic conditions began in the latter stages of the zone. The marked decline in the abundance of *Micropsectra* spp., *Heterotrissocladius changi* Sæth., and *Harnischia curtilamellata* (Mall.), in spite of favorable sedimentary conditions, would seem to confirm this interpretation. The accumulation of fine mineral sediments, which increased to 1227.06 × 10^{-4} g dry sediment weight·cm^{-2}·yr^{-1} in the early stages (24.5 cm) but declined slowly throughout the remainder of the zone, was increasingly unable to mask the organic materials arriving from the water column. The increase in the concentrations of organic carbon in the later stages of Zone VIIc continued throughout Zone VIId, despite the resumption in fine mineral sediment accumulation. The high organic matter:organic carbon ratio of 2.74 at 21.5 cm suggests that the greater part of the organic nutritive material remained inaccessible to fauna in the earlier stages of the zone. However, the rapid drop in the ratio to 2.48 at 19.5 cm indicates the material was no longer inaccessible to the fauna. This factor undoubtedly accounts for the changes in faunal type observed in the latter stages of Zone VIId.

Zone VIII (1897–1956)

The trend to more eutrophic conditions was resumed in Zone VIII. The zone was identified as a mesotrophic phase primarily on the basis of the presence of *Phaenopsectra* sp. *1*. The progressive elimination of species, as the processes of eutrophication continued, seriously reduced the numbers of attendant taxa available for interpretation, and the inability to accurately identify those taxa remaining made the definition of biological changes within the zone more difficult. The three subzones in Zone VIII were conservatively ranked according to successive degrees of mesotrophy initially; however, composition of the remaining fauna suggests the trophic state should possibly be even higher. The predominance of the *Chironomus* fauna in relation to *Phaenopsectra* sp. *1* in Zone VIIIa (1897–1909) suggests the zone may have attained a degree of strong mesotrophy. However, the absence of other interpretable taxa severely restricts definition of the zone. The presence of limited numbers of *Heterotrissocladius changi* Sæth., *Micropsectra* spp., and *Phaenopsectra* sp. *1* (in conjunction with very rapidly increasing numbers of *Chironomus*) suggests Zone VIIIb (1909–32) and VIIIc (1932–56) may be slightly eutrophic. (The interpretive value of *Micropsectra* spp. may be overrated in surface sediments; the majority of specimens included in the taxon at this point typically have short blunt spurs on the antennal base, rather than the large curving type more characteristic of *Micropsectra*. These specimens may belong to *Tanytarsus,* an identification more in keeping with the more eutrophic nature of these zones.) The rapid increase in productivity in the bay is reflected in the organic carbon:total nitrogen ratios, which averaged 8.46, 8.09, and 7.68 in zones VIIIa, b, and c, respectively. Effects of increasing productivity, coupled with the steady decline in fine mineral sediment accumulation, are readily apparent in the rapid increase in concentrations of organic carbon in the sediments. The rapid increase in the accumulation of organic materials accounts for the comparatively high organic matter:organic carbon ratio of 2.42 in the sediments. Decreasingly influenced by fine mineral sediment accumulation, the ratio reflects the increase in exposure time of organic materials to natural decomposition processes. However, the ratio still remained well above that for recalcitrant carbon, possibly because the rapid rate of organic matter accumulation in the more recent sediment surface precluded complete diagenesis.

Zone IX (1956–72)

The definition of Zone IX was considerably easier because of the availability of the live samples taken at the time of coring and the documentation provided by Johnson's (1970) faunal lists. Zone IX was ranked moderately eutrophic because of the dominance of *Chironomus* (61.69%), primarily of the *plumosus* type, and *Procladius* species (23.88%) in the faunal assemblage. (The estimate of the *Chironomus* fauna based on the remnant fossil assemblage (30.00%) from the surface of the core is thought to be underestimated, as discussed in Section 2.5.4) Limited numbers of other Chironomini and Tanytarsini taxa and one Orthocladiinae taxon also were found in the surface sediments (Table 13). The presence of *Cricotopus (Cricotopus)* cf. *triannulatus* (Macq.), both in the remnant fossil assemblage from 4.5 cm and the live samples, contradicts the currently accepted opinion that members of Orthocladiinae do not persist in moderately eutrophic waters. (The presence of the same taxon in very eutrophic Pasqua Lake, Sask. (Warwick unpublished data), however, confirms that certain members of the subfamily may persist, albeit in limited numbers, under eutrophic conditions.) The influence of fine mineral sediment accumulation is comparatively minimal in Zone IX, with the result that the influence of increased productivity on the faunal assemblage probably is reaching its maximum at the present time. The increase in productivity is reflected in the decline in the organic carbon:total nitrogen ratio to an average of 7.39. The value 6.8 for the surfacemost sediments approaches the value of 6.5 reported by Bordovskiy (1965: 48) for blue-green algae, known to be prevalent in the Bay of Quinte at the present time. The sharp rise in the organic matter:organic carbon ratio to 2.65 in the surfacemost sediments probably reflects the diagenetically immature nature of organic materials that have collected at the surface–water interface and are undergoing active degradation.

In summary, the changes in trophic status outlined in semiquantitative terms in Fig. 36 show that, within the time frame of the Glenora core, the Bay of Quinte has passed from moderate oligotrophy (TIN 4) to moderate eutrophy (TIN 12). The fact that trophic levels reverted twice in the more recent history of the core to the original state of moderate oligotrophy (TIN 4) characterizing the initial sediments of the pre-Hopewell Period indicates that nutrient supplies derived from the extensive watershed of the bay were sufficient to maintain this baseline condition under natural circumstances. This would account for the absence of typical ultraoligotrophic faunal assemblages (TIN 1) and the comparatively higher level of productivity noted initially in the sedimentary record of the core.

Shifts in the productivity of the bay above this baseline level are clearly linked to cultural developments. The increase in trophic level to slightly oligotrophic conditions (TIN 6) in the older sediments was undoubtedly connected with the growth and development of the Hopewell culture, while the increase in the more recent sediments marks the beginnings of European involvement in the area. (The increase in the French Period to weakly oligotrophic conditions (TIN 5) probably began as early as the Late Ontario Iroquois Stage of the Iroquois Period, when considerable numbers of native people resided in the area.) Increases in the trophic level were severely repressed during the periods of heavy mineral sediment accumulation, but once this accumulation began to recede trophic levels increased with startling rapidity. From the last period of major fine mineral sediment accumulation (Table 24, Zone VIId), where trophic levels were held at weak oligotrophy (TIN 5), the trophic level of the Bay of Quinte, even estimating conservatively, advanced rapidly to the moderately eutrophic conditions (TIN 12) found in the bay at the present time. If this rate of increase continues, ultraeutrophic conditions (TIN 15) will probably soon be reached in the Bay of Quinte.

4.3.4. HABITAT ORIGINS OF THE FAUNA

An evaluation of habitat origins (Fig. 37) demonstrates that redeposition was not a critical factor in the analysis of faunal assemblages from the Glenora-B core. The majority (90.18%) of the total fauna were true deepwater inhabitants, whose remains could legitimately be expected in the deepwater sediments, whereas the remains of only 6.34% of the fauna originated elsewhere. The greater proportion of the extraneous fauna (3.65%) belonged to littoral species with planktonic life stages. The mobility of this planktonic stage undoubtedly accounts for the group's proportionately high distribution in the deepwater sediments. By comparison, true littoral taxa (the next most abundant redeposited group) formed only 1.85% of the total fauna. Even this estimate may be in excess, because *Orthocladius* spp. *1* and *4*, included in the estimate, may represent true but rare deepwater forms. Taxa from lotic and terrestrial or semiterrestrial habitats made up only 0.60 and 0.24% of the total fauna, respectively. The predominance of the remains of true deepwater taxa in the sediments implies that the thanatocoenosis can be used to analyze the structure of the chironomid communities without seriously compromising the interpretation of the core, and that changes within the structure of these communities probably truly reflect changes in quality of the aquatic environment.

The presence of redeposited fauna, rather than seriously compromising the interpretation of environmental changes within the deepwater biocoenosis, may provide some insight into events and processes affecting the tributary streams, rivers, and shorelines outside the immediate boundaries of the primary habitat. The abrupt disappearance of lotic species from the sedimentary record (Fig. 37), particularly those of *Eukiefferiella*, is interpreted as a reflection of the alterations imposed on the running-water habitats of streams emptying into the Bay of Quinte. The increase in the abundance of terrestrial or semiterrestrial taxa in the deepwater sediments (Fig. 37) is coincident with the involvement of European culture in the area, and is believed to reflect increased activity along the immediate shorelines of the bay. Although based only on an imperfect record, the presence of such fauna may provide an additional dimension to the interpretation of external forces that influence the bay itself.

4.3.5 FAUNAL DEFORMITIES

The presence of deformed chironomid larvae in the most recent sediments indicates that domestic sewage and mineral sediments are not the only forms of pollution impinging on the Bay of Quinte. Deformed larvae, characterized by twisted, gnarled, asymmetrical teeth in the mentum and mandibles and the thickened cuticle of body and head capsule walls, are thought to be caused by industrial or agricultural pollutants (Brinkhurst et al. 1968: 22; Hamilton and Sæther 1971: 368). Increase in the incidence of deformities from 0.09% in the pre-European sediments to 1.06% at 4.5 cm (1951) and 1.99% in the 1972 chironomid population from the Glenora site is strong evidence that problems connected with these pollutants are developing in the Bay of Quinte. The incidence of deformities in the bay at the present time is higher than that (1.14%) re-

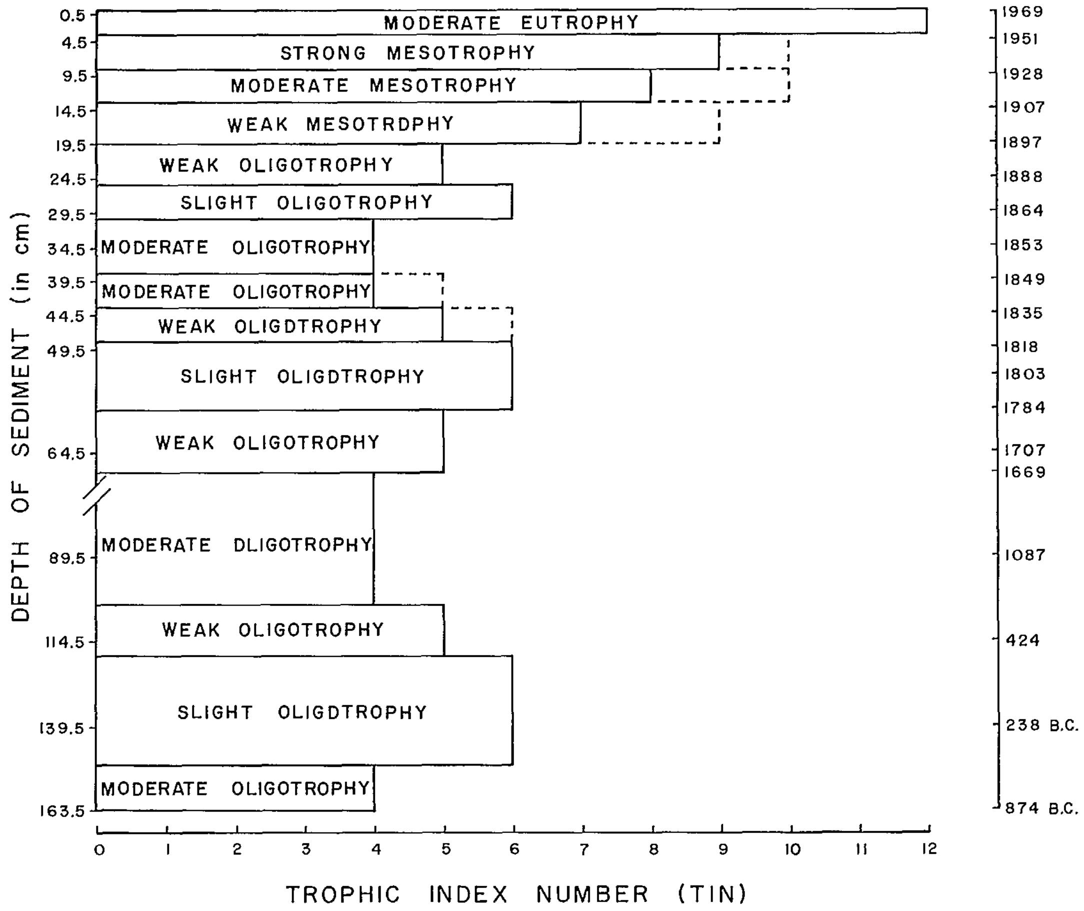


FIG. 36. Summary of trophic stages in the history of the Bay of Quinte as assessed from the Chironomidae thanatocoenosis. The more conservative estimates of trophic response are indicated by solid lines. Composition of the chironomid community, however, suggests that the degree of trophic response may have been greater than the more conservative estimates would indicate. Broken line extensions of the solid line bars demontrate the possible upper limits assessed from the faunal response to trophic change.

ported from lakes Okanagan and Skaha (Sæther 1970: 10).

4.4 Productivity, Sedimentation, and Faunal Responses

4.4.1. INTERACTION BETWEEN SEDIMENTATION AND PRODUCTIVITY

The process of oligotrophication was apparent twice in the faunal assemblages from the core. The initial reversion to more oligotrophic conditions following the slight oligotrophy (TIN 6) of the Hopewell Period was probably because there were markedly fewer people in the area to provide trophic stimulation during the subsequent Algonkian Period and early stages of the Iroquois Period. Without the artificial support of human presence, trophic levels declined to moderate oligotrophy (TIN 4) (the seemingly natural trophic level for the Bay of Quinte at this stage of its development) through a process of natural nutrient deprivation.

The second reversion to more oligotrophic conditions following the slight oligotrophy (TIN 6) marking the early stages of British colonization apparently was induced through the effects of rapidly accumulating fine mineral sediments, and

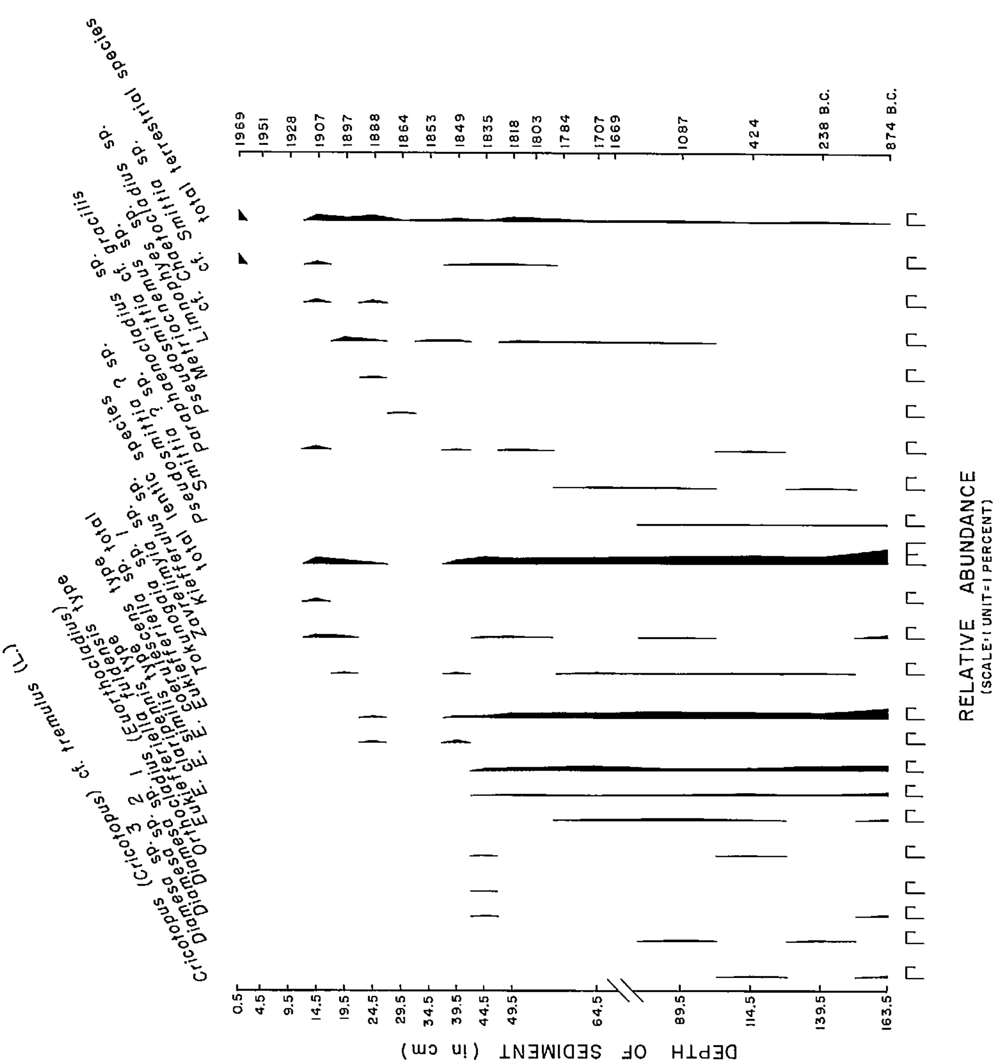


FIG. 37. Relative abundance of taxa from lotic habitats and terrestrial or semiterrestrial habitats expressed as functions of sediment depth.

occurred in spite of increasing productivity in the water column. Although the suppression effect on the fauna was greatest during the period of most rapid accumulation in sedimentation Zone VIIb (Fig. 32), the effect was apparent as early as Zone VIc, and noticeably apparent again with the resumption of sediment accumulation in Zone VIId.

The process of oligotrophication in both cases appears (Table 25) to be a function of the rate of accumulation, the type of material accumulating, and the proportion of the fine mineral sediment fraction. In Zone VIIb the rapid rate of accumulation (41.34 mm·yr^{-1}) was clearly the predominant factor in the process, whereas in Zone VIId, where the rate of accumulation was considerably less (5.05–5.07 mm·yr^{-1}), the proportionately greater fraction of fine mineral sediments was the more significant factor. In both cases, the sediments accumulating were predominantly fine montmorillonite clay mineral materials. In contrast, the sediments marking the accumulation event of Zone II were mainly CaCO$_3$ materials originating from the limestone

Table 25. Comparison of sedimentation regimes influencing the faunal assemblages.

				Sediment size (Proportions in %)		
Sediment zone	Sediment depth (*cm*)	Accumulation rate (*mm·yr*$^{-1}$)	Sediment type	Silt (4–8.5 ϕ)	Clay (> 8.5 ϕ)	Clay (> 10.50 ϕ)
Zone VIId	19.5	5.07	Montmorillonite	22.00	78.00	67.00
	24.5	5.05	Montmorillonite	26.98	73.02	60.32
Zone VIIb	35.5	41.34	Montmorillonite	36.73	62.32	45.11
	36.5	41.34	Montmorillonite	41.86	56.14	36.64
Zone II	134.5	0.38	$CaCO_3$-base limestone with some clays	57.73	42.27	15.47
	139.5	"	"	52.00	45.81	22.67
	144.5	"	"	54.19	45.81	18.44

basin of the bay with only smaller amounts of clay mineral materials included. The accumulation process, which was neither rapid (0.38 mm·yr^{-1}) nor proportionately high in fine sediment content, appears to have had a minimal inhibitory effect on the development of slightly oligotrophic conditions (TIN 6) during the period. In summary, the two basic aspects involved in the processes of oligotrophication marked in the changes in the faunal assemblages from the Glenora core were the inhibition of productivity through nutrient deprivation and the inhibition of productivity through mineral sediment accumulation.

4.4.2 FAUNAL RESPONSES TO PRODUCTIVITY-SEDIMENTATION INTERACTIONS

The involvement of the chironomid fauna in the interrelationship between the two basic aspects involved in oligotrophication and eutrophication processes is shown in the discrepancy between the trophic profiles determined from faunal assemblages and productivity indices (Fig. 38), and may be summarized in the expression:

$$\underset{\substack{\text{faunal}\\ \text{indices}}}{\text{TROPHY}} = \underset{\substack{\text{productivity}\\ \text{indices}}}{\text{TROPHY}} - \text{mineral sediment accumulation}$$

Trophic levels estimated on the basis of the faunal assemblages closely approximate those determined from the organic carbon:total nitrogen ratio in the older sediments, where the accumulation of mineral sediments is slow and its inhibitory effects minimal. The faunal assemblage responded initially to the increase in productivity during the Hopewell Period by developing a slightly oligotrophic community (TIN 6), but reverted to a more oligotrophic type when productivity declined through the Algonkian and Iroquois periods. The reversion ultimately to the moderately oligotrophic chironomid community (TIN 4) characterizing the Iroquois Period[4] probably occurred in response to the decline in the supply of particulate food materials produced in the water column. This interpretation is suggested by the marked decline in abundance of omnivores such as *Chironomus* during this period.

Trophic levels, estimated in terms of faunal indices, declined in spite of the fact that productivity indices monitored in the more recent sediments indicated continued increases in productivity in the water column. There is little doubt that the repression of trophic expression within the chironomid communities was effected through the massive accumulation of mineral sediments. Their influence probably was exerted through the dilution of organic material concentrations, through the physical burial of organic food materials which rendered them unavailable to the chironomid community, and through direct interference with the feeding activities and physiology of the greater proportion of the chironomid community. The influence of increasing clay min-

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[4] Estimate of moderate oligotrophy, based on the faunal assemblage from 89.5 cm, probably applies more appropriately to the Early Ontario and Convergence or Middle Ontario Iroquois stages when population numbers were comparatively low and the tendency was to build communities well back from navigable waterways. Both factors would tend to reduce the amount of nutrient materials introduced into the aquatic environment. The larger populations of the Late Ontario Iroquois Stage were probably instrumental in initiating the weakly oligotrophic conditions characteristic of the French Period.

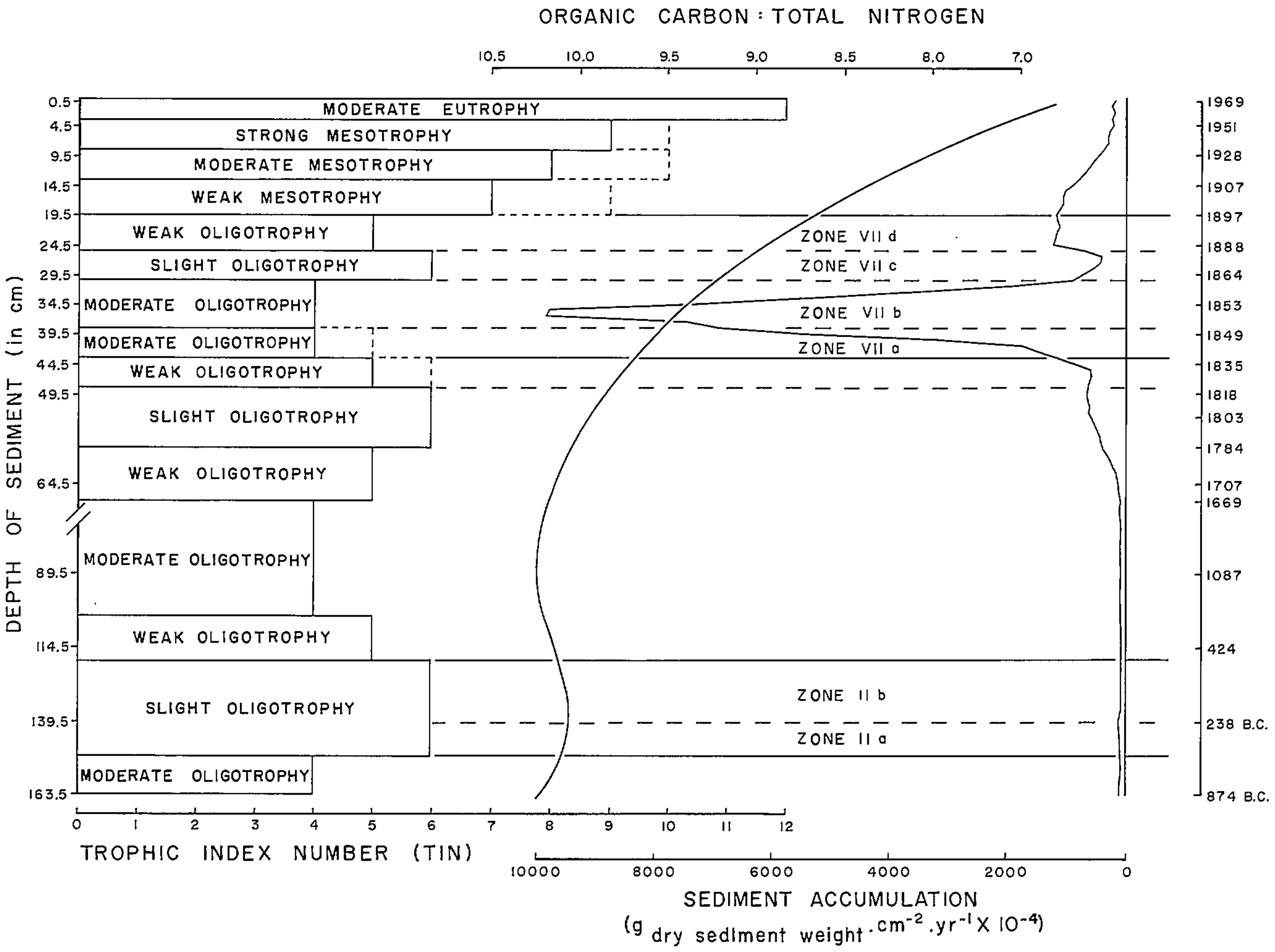

FIG. 38. Influence of mineral sediment accumūlation on trophic status measurements, based on productivity indices and chironomid communities.

eral sediment accumulation on food availability, measured in terms of organic carbon concentrations, is demonstrated in Fig. 39.

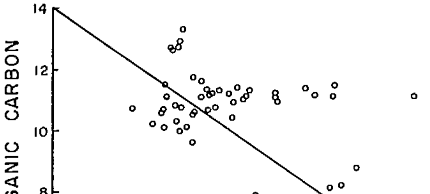

FIG. 39. Percentage organic carbon vs. percentage clay-size mineral sediments.

The chironomid community was able to respond to the processes of eutrophication again, once the restraints of mineral sediment accumulation began to be alleviated. In the most recent sediments, the trophic levels estimated on the basis of faunal assemblages again closely approximate those determined from chemical productivity indices.

Response of the chironomid fauna to the interaction between productivity and sedimentation in the Bay of Quinte is expressed in general terms[5] in the *Chironomus*–Tanytarsini type 7 dichotomy (Fig. 40). The original Chironomini-dominated fauna of sedimentation Zone VI (primarily of *Chironomus* spp. and *Polypedilum (Tripodura) simulans* group) was replaced in Zone VII by a Tanytarsini-dominated fauna (composed primarily of *Micropsectra* spp. and Tanytarsini type 7, including specimens resembling the *Tanytarsus* sp. *C.* and/or *Paratanytarsus* figured by Hofmann (1971b: 48, 50)). Not only was the supply of organic food materials in the sediments reduced through dilution in Zone VII, but the food materials present were buried intact and probably remained unavailable to the chironomid community. The reversion to the "more oligotrophic" chironomid fauna occurred, therefore, in part at least, because of the impoverished condition of the sediments.

The situation in the more recent sediments is the reverse. As the accumulation of mineral sediments declined in Zones VIII and IX, and the amount of organic materials introduced to the sediments increased, the Tanytarsini-dominated fauna was replaced by a Chironomini-dominated fauna, most likely in response to the increased availability of food materials. The more modern Chironomini-dominated fauna, however, differed from its older counterpart, as it was composed almost entirely of the genus *Chironomus*, instead of a mix of Chironomini genera as in the older sediments. In conclusion, the availability, or the nonavailability, of food materials has a definite bearing on the composition of the chironomid community.

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[5] Only major components of the fauna are used to illustrate the shift in faunal-type dominance.

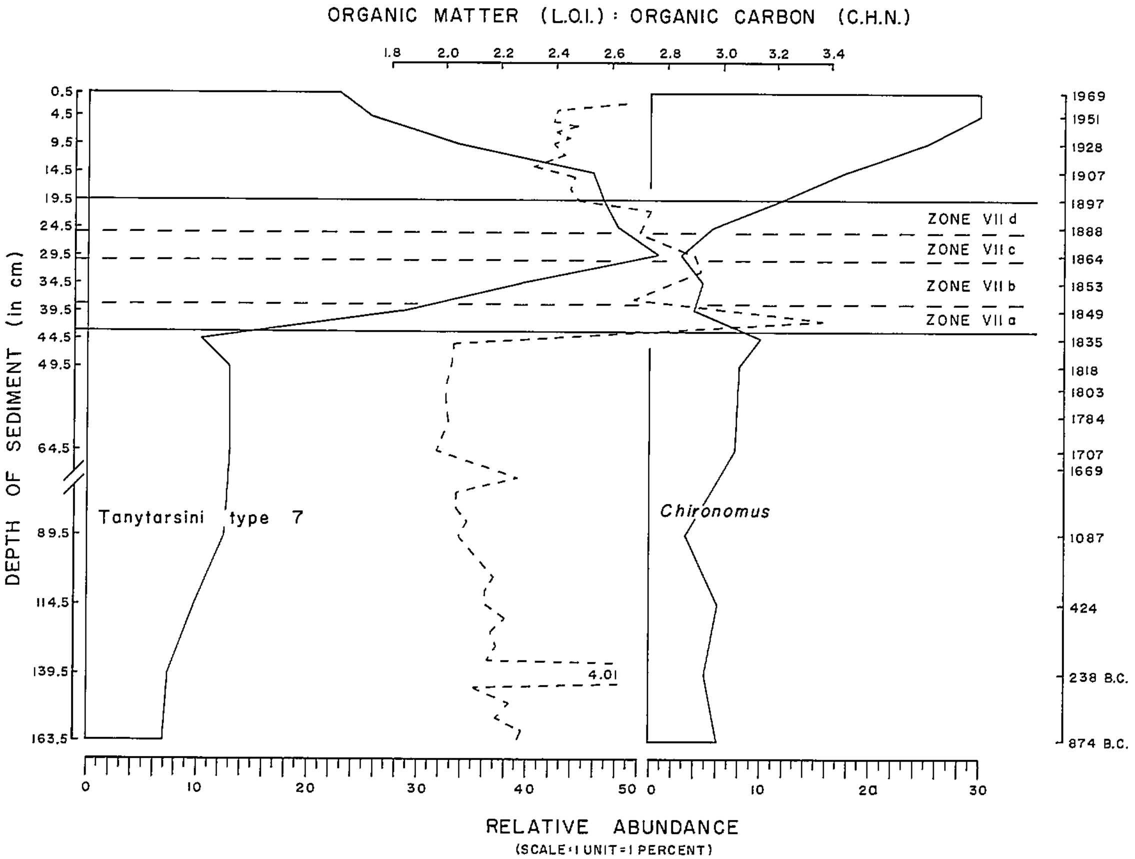

FIG. 40. The influence of mineral sediment accumulation on the *Chironomus*–Tanytarsini type 7 dichotomy. Oscillations in faunal dominance between two primary chironomid taxa are a result of the interplay between sedimentation and eutrophication processes. The Chironomini, as typified by the *Chironomus* profile on the right-hand side, respond primarily to eutrophication processes. When eutrophication processes are suppressed by the accumulation of mineral sediments, a more oligotrophic Tanytarsini fauna, typified by the Tanytarsini type 7 profile on the left-hand side predominates. The organic matter:organic carbon profile (broken line, center) suggests that the more oligotrophic fauna is formed because of the unavailability of food materials buried by rapidly accumulating mineral sediments. After mineral sediment accumulation declines and food materials become available again, the Tanytarsini type 7 fauna is replaced by *Chironomus* as the predominant fauna.

5. GENERAL DISCUSSION

5.1 Overview

Man, especially European man, has had, and is having, a profound impact on the Bay of Quinte and its watershed. Characterization of the benthic habitat of the Glenora site, both by core analysis and live sampling, shows that conditions in the aquatic environment have changed markedly in the recent history of the bay. An evaluation of the present-day benthic community at the site clearly rank the habitat trophic status as moderately eutrophic (Johnson 1970). In contrast, the chironomid remnant fauna found in the older portions of the core sediments was an oligotrophic fauna. Although aboriginal societies clearly had an influence on these oligotrophic assemblages, massive changes in the faunal assemblages clearly link the transition to present-day conditions with the arrival of European colonists, and the development of a modern society in the bay area today.

The influence of colonization on the aquatic habitat involved two major processes — sedimentation and eutrophication. The erosion of mineral sediments concomitant initially with land-clearing activities of a rapacious lumber industry, and latterly with poor agricultural practices, instituted a process of oligotrophication to the aquatic habitat that led to the development of a fauna characteristic of more oligotrophic conditions. The process of oligotrophication proceeded in spite of increasing amounts of nutrients that entered the water column from a growing population. The suppression of eutrophication processes continued while the accumulation of fine mineral sediments was rapid. As the accumulation of these materials began to slow, however, the process of eutrophication, decreasingly inhibited by the sterilizing effects of sedimentation processes and promoted by a rapidly expanding human population, proceeded at an increasingly rapid rate until the present conditions were reached. The fauna that characterized the older oligotrophic conditions was initially supplanted by fauna characterizing more oligotrophic conditions, then a fauna characteristic of an environment in which mineral sediments were accumulating, and finally by a fauna characteristic of eutrophic conditions. The acceleration imposed on the transition from an oligotrophic to an eutrophic environment through man's influence may, in part at least, be responsible for the fact that the intervening mesotrophic fauna did not develop proportions similar to those normally found in mesotrophic lakes.

The presence of a proportionately large number of deformed larvae in the most recent sediments suggests that factors other than sedimentation and eutrophication processes are also influencing the aquatic environment. Hamilton and Sæther (1971: 368) suggested that similar deformities in chironomids from Lake Erie and the Okanagan lakes were probably indicative of the presence of industrial and/or agricultural contaminants in the environment.

5.2 Scientific Implications and Relevance to Other Studies

5.2.1 CONCLUSIONS RELATIVE TO ORIGINAL PROSPECTUS

A number of the questions posed in the original prospectus may now be answered. Although the major changes in the chironomid community structures could be directly related to the development of European culture in the Bay of Quinte area, the chironomid community was apparently sufficiently sensitive to reflect the effects of aboriginal cultures predating the European. The chironomid succession in the sediments did not follow the same orderly sequence of events outlined in the classical succession from oligotrophy to eutrophy, but demonstrated that the process of oligotrophication, both natural and event-induced, could occur. Culturally induced eutrophication processes were shown to accelerate the time scale involved in the sequence of succession. In comparison with the natural eutrophication of Schöhsee, West Germany, which took from 8200 to 8500 yr according to Hofmann (1971a: 7), the Bay of Quinte became eutrophic within the period of European involvement in the area — a span of only 2 to 3 centuries. If the oligotrophication effects of fine mineral sediment accumulation are taken into account, the transition from the artificially maintained weak oligotrophy of Zone VIId to moderately eutrophic conditions of the present only took about 80 yr. Although all major stages in the succession from oligotrophy to eutrophy were represented, the acceleration forced on the system is apparent in the fact that the mesotrophic *Phaenopsectra* fauna did not develop to proportions normally found in mesotrophic lakes. This same factor accounts for the fact that some other subdivisions of mesotrophy and eutrophy were not well documented in the sedimentary record. The influence of mineral sediment pollutants undoubtedly affected the chironomid community directly and was responsible, in part, for the decline in numbers of species and their abundance in the more modern sediments. Deterioration in environmental conditions due to the depletion of dissolved oxygen as a result of domestic waste pollution was undoubtedly also involved. The increased incidence of deformities in the most recent chironomid communities is evidence that industrial and/or agricultural pollutants are also becoming a problem in the bay. The long-term aspects of the study clearly demonstrate that the process of oligotrophication can occur if the pressures forcing eutrophication are alleviated.

5.2.2 An Overall Assessment of Man's Impact

In retrospect, the major impacts on the Bay of Quinte from the development of a European-type culture were exerted through changes in sedimentation patterns and trophic regimes. The introduction of massive amounts of erosion products into the bay as a result of deforestation by the lumber industry, and the continuation of the process to a lesser degree by agricultural endeavors, led to extensive changes in the character of bottom habitat of the bay. The profound effect of the accumulation of mineral sediments on plant life characterizing the presettlement sublittoral–upper profundal habitat, whether through the inhibition of light penetration or physical burial, led to the alteration of an entire bottom habitat to a true profundal type. For a time this accumulation of mineral sediments suppressed the effects of increasing amounts of domestic wastes from an expanding population. As the accumulation of mineral sediments began to wane, the repressed processes of eutrophication proceeded to develop at an accelerated rate. The presence of deformed chironomid specimens in the most recent sediments indicates that another serious, and perhaps more sinister, problem of industrial and/or agricultural contamination of the aquatic environment is becoming increasingly important.

Changes in the Bay of Quinte have already had serious consequences for society. Decline of the valuable commercial fishery documented in the succession of fish populations by Christie (1973: 48) was undoubtedly due in large measure (Fig. 41) to the deterioration in quality of the aquatic environment of the bay. The collapse of the salmon fishery between 1830 and 1840 correlates directly with the disappearance of species of *Eukiefferiella* from the sedimentary record. *Eukiefferiella* species are stream forms characteristic of fast-flowing, well-oxygenated water (Lehmann 1972: 348), and their disappearance from the more recent sediments links the collapse of the fishery to the destruction of these streams. The massive accumulation of erosion materials in the system as a result of the far-reaching deforestation in this period undoubtedly led to the destruction of the salmon's food base and spawning grounds and, ultimately, to the collapse of the salmon fishery.

The collapse of lake whitefish stocks may similarly be related to the effects of eutrophication processes. The timing of the lake whitefish collapse in 1955 (Hurley and Christie 1977: 1855) coincides well with the transition from strongly mesotrophic to moderately eutrophic conditions in the Bay of Quinte. The transition, dated 1956, marks a major, rapid advance in the eutrophication of the bay that may have proven too drastic for the whitefish population. The appearance of increasing numbers of deformed chironomid specimens at about this time may similarly implicate industrial and/or agricultural contaminants in the decline of whitefish stocks. The other changes in fish communities documented by Christie are probably also related to alterations in the aquatic environment by these processes.

5.2.3 Previous Investigations

The reversion to a more "oligotrophic" fauna in response to the accumulation of mineral sediments documented in the Bay of Quinte by the *Chironomus*–Tanytarsini type 7 dichotomy (Fig. 40) is apparent in the results of a number of reservoir studies. Nursall (1952: 400–404) noted the reversion in Barrier Reservoir, Alta.; the original Chironomini-dominated pioneer fauna (initially

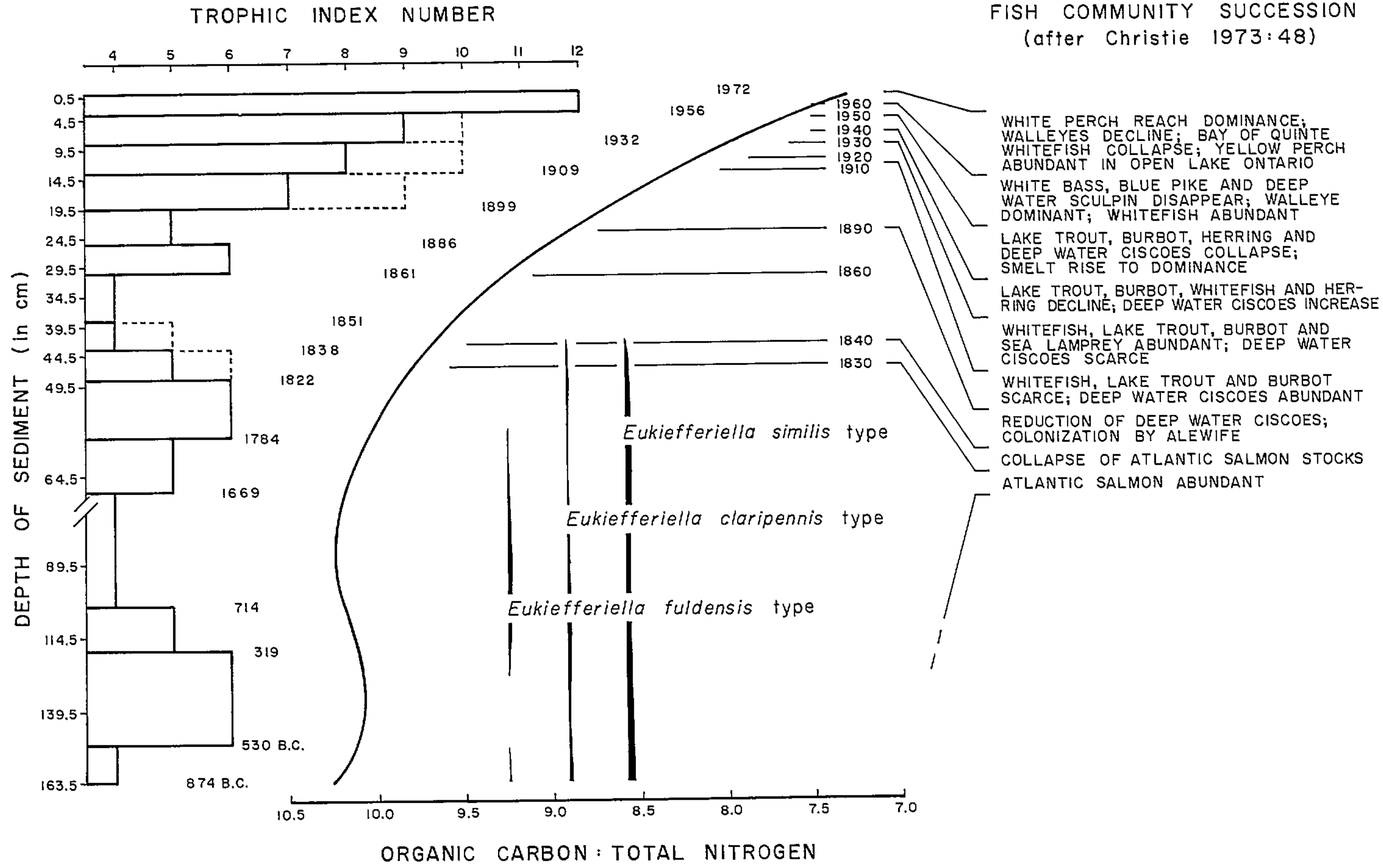

FIG. 41. Correlation between fish succession and trophic change in the Bay of Quinte. Trophic change is expressed in terms of the chironomid community (left-hand side) and the C:N ratio (middle). The outline of fish succession is after Christie (1973: 48). The *Eukiefferiella* species represent the stream habitat.

"*Pentapedilum*" with successive additions of other Chironomini later) reverted to a more oligotrophic Tanytarsini-dominated fauna when the leaf-litter layer (which had initially covered the reservoir floor upon filling in 1947 and which had supported the initial populations of Chironomini) was buried by extensive accumulations of soft, gray clay–alluvial sediments (introduced by the heavy spring runoff in 1948) and yellowish clay materials (washed from the reservoir walls the following spring after water-level regulation). Nursall (1952: 405) concluded that the rapid trophic change shown by the succession of chironomid communities was due to interference by the accumulation of these sediments, and that the interference acted on the physical, chemical, and biological processes within the reservoir to increase the tendency towards oligotrophy.

Paterson and Fernando (1970: 214) recorded a similar sequence of events in the newly created Laurel Creek Reservoir in southern Ontario, where the original *Chironomus–Glyptotendipes*-dominated pioneer fauna was gradually replaced by a *Tanytarsus–Micropsectra*-dominated fauna. Paterson and Fernando (1970: 226) stated that the 13-fold increase in the average standing crop of the latter fauna by 1968 was probably the product of progressive siltation of the basin, which rendered the bottom habitat more favorable to this group. Despite the predominantly littoral nature of the shallow-water reservoir, effects of the artificial oligotrophication of the bottom environment, induced through the progressive accumulation of mineral sediments on the chironomid communities of the Laurel Creek Reservoir, were similar to those exerted on the deepwater chironomid communities of the Bay of Quinte.

Effects of drawdown in more mature regulated reservoirs produce similar results in chironomid communities in the zone immediately below the drawdown limit. In a reappraisal of Barrier Reservoir 13 yr after Nursall's (1952) initial study, Fillion (1967: 9) found that, although the Chironomini again predominated in the deepwater habitat, the Tanytarsini were markedly dominant in the zone just below the exposed sediments of the drawdown zone, where fluctuating water levels kept the bottom environment disrupted and unstable through the constant introduction of fine minerogenic sediment material. Like the Tanytarsini type 7 in the present study, *Tanytarsus* sp. formed the greater proportion of the Tanytarsini found by Fillion in the silt-ridden intermediate zone of the reservoir.

In a comprehensive study, Grimås (1961: 233) documented the shift from a Chironomini-dominated fauna to a Tanytarsini–Orthocladiinae-dominated fauna after the regulation of oligohumic, oligotrophic Lake Blåsjön in northern Sweden. Grimås (1961: 191, 233) noted that the greatest faunal changes occurred in the part of the littoral zone immediately below the drawdown limit where ". . . great quantities of eroded materials, primarily of minerogenic origin . . ." were deposited offshore as new beach lines were established. However, similar faunal changes were also noted down into areas of the upper profundal, where significant amounts of mineral sediments had also penetrated. Although Grimås (1961: 222) attributed the changes in the chironomid communities to lower environmental temperatures, the marked similarity shown in Table 26 between the chironomid fauna found to favor environments in the Bay of Quinte, where mineral sediments were accumulating relatively rapidly, and those detailed by Grimås (1961: 205) strongly suggests that mineral sediment accumulation, and not temperature, was the major factor promoting the changes observed in the Lake Blåsjön chironomid communities. Grimås' (1961: 205) own observation that the upper limit for the dominance of *Heterotrissocladius subpilosus* had been lowered from 10 meters to 20 meters in spite of the fact that the species is affected by neither drying up nor freezing in, also suggests that a factor other than temperature was involved in the faunal changes. In the Bay of Quinte, the changes in the chironomid community structure associated with the accumulation of mineral sediments occurred in deep water (22 m), where temperature fluctuations would be minimal.

Similar shifts in faunal dominance recorded in a number of other studies demonstrate the widespread response of chironomid communities to the accumulation of mineral sediments. Bryce (1962: 49–50) documented the repeated involvement of changes in sedimentation patterns in the reversals between *Chironomus*- and *Tanytarsus*-dominated faunas in sediments of Malham Tarn and Tarn Moss, England. Although Bryce associated the reversion from a *Chironomus*-dominated fauna to a *Tanytarsus*-dominated fauna from Zone III to IV in Tarn Moss sediments to ". . . the change from deposition of clay to calcareous material . . .," he attributed the increasing dominance of *Tanytarsus* in zones V and VIa to the ". . . increasing shallowness of this part of the Tarn." The fact that the same *Tanytarsus–Chironomus* reversion occurred in the deep waters of the Bay of Quinte, and in both deepwater and shallow-water habitats in other studies (above), suggests that neither water depth nor temperature change was the major force promoting the changes in the chironomid community

TABLE 26. Comparison of response of chironomid taxa to the increased accumulation of mineral sediments. Categories after Grimås (1961: 204). Category I: species specially favored by the regulation. Category II: species that on the whole retain their position. Category III: species altogether eliminated by the regulation or abundance decreases.

Category	Lake Blåsjön (Grimås 1961: 205)	Bay of Quinte
I	*Constempellina brevicosta*	*Stempellinella*
	Abiskomyia virgo	*Abiskomyia*
II	*Calopsectra gregarius* (sub *Tanytarsus gregarius*)	Tanytarsini type 7 (comprising specimens resembling the *Tanytarsus* spec. C and/or *Paratanytarsus* figured by Hofmann (1971b: 48.50))
	Paratanytarsus hyperboreus	
	Paratanytarsus penicillatus	
	Micropsectra groenlandica	*Micropsectra* spp.
	Parakiefferiella bathophila	*Parakiefferiella* cf. *bathyphila*
	Psectrocladius fennicus	*Psectrocladius* type 3
	Acricotopus thienemanni	–
	Cricotopus alpicola	–
	Heterotrissocladius grimshawi	*Heterotrissocladius changi*
	–	Genus near *Heterotrissocladius*
	–	*Harnischia curtilamellata*
III	*Heterotrissocladius subpilosus*	Numerous taxa absent

structure of Tarn Moss. The continued trend to *Tanytarsus* dominance, therefore, may be reinterpreted as indicating an acceleration of mineral sediment accumulation, which continued through Zone VIa and eventually led to the filling in of that portion of the Tarn. The continued dominance of *Tanytarsus* in Zone VIIb of the Malham Tarn core (the more modern sequences were not available in the cores from Tarn Moss because of formation of the raised bog) suggests that the accumulation of mineral sediments extended well into this period.

Bryce (1962: 51) attributed the reversion from a *Tanytarsus*-dominated fauna to a *Chironomus*-dominated fauna in the more recent sediments of Zone VIII to the normal successional change of a deeper lake to slightly greater mesotrophy. This reversion, rather than suggesting an increase in trophy, may be interpreted to reflect the decreased subordination of normal productivity processes to the influence of mineral sediment accumulation. Although perhaps not a good comparison (in that trophic changes are involved), the reversion in the Glenora sediments from a Tanytarsini type 7-dominated fauna back to a *Chironomus*-dominated fauna in sedimentation zones VIII and IX (Fig. 40) occurred as the accumulation of mineral sediments declined. In oligotrophic Barrier Reservoir, Fillion (1967: 9) found that the Tanytarsini-dominated fauna of the deepwater habitat documented by Nursall (1952: 405) had similarly reverted to a *Chironomus*-dominated fauna, but without any attendant change in trophy. The reversion in this case was probably related to the fact that, during the period between the two studies, the basin morphometry stabilized and progressively less mineral sediment was washed from the reservoir walls into the deeper water zones. As the accumulation of mineral sediment declined, the greater availability of food materials arriving at the sediment surface led to a "more eutrophic" *Chironomus*-dominated fauna. The situation in Malham Tarn probably was more closely akin to that in Barrier Reservoir in that the fauna responded to a decrease in mineral sediment accumulation, which led to an increase in the availability of existing food stocks rather than any marked change in the productivity of the lake. The balance of the chironomid populations in Malham Tarn during Zone VIII suggests this interpretation.

The influence of mineral sediment accumulation was apparent again in the most recent sediments of Malham Tarn, where there was another reversion to a *Tanytarsus*-dominated fauna. Bryce (1962: 51) attributed the change in the fauna to the building of a dam on the Tarn that raised the water level and caused the redistribution of mineral sediments into the deepwater environment as erosion established new beachlines.

The presence of similar shifts in faunal dominance in lakes of varying trophic status demonstrates that the influence of sedimentation processes can override the influence of eutrophication processes on chironomid communities. In Blelham Tarn, England, Harmsworth (1968: 234, sub *Sergentia)* noted that the transition from a *Phaenopsectra*-dominated fauna in the older sediments to the *Chironomus*-dominated fauna in the more recent sediments (marking the progress of the tarn to more eutrophic conditions) was repeatedly punctuated by reversions to apparently more oligotrophic faunas characterized by the dominance of *Tanytarsus*. The fact that the reversions, which were probably similarly prompted by periods of fine mineral sediment accumulation, occurred during periods of both *Phaenopsectra* and *Chironomus* dominance demonstrates that the influence of mineral sediments that initiate oligotrophication processes is equally operative under mesotrophic and eutrophic conditions.

Although not as well documented, Goulden (1964a: 35, sub *Sergentia)* noted similar replacements of *Chironomus*- and *Phaenopsectra*-dominated faunas in the sediments of cores from Esthwaite Water, England. The sequence of changes in the dominant fauna appears roughly similar to those documented by Harmsworth (1968: 234) in the more recent sediments of Blelham Tarn — a fact that is not surprising as the two lakes are only some 6 km apart. With further refinement, these changes in the fossil chironomid assemblages may prove useful in correlating the effects of basin-orientated events in the development of the two lakes.

Hofmann (1971a: 50) similarly attributed the extensive displacement of *Chironomus* larvae from the present-day sediments of the lower profundal of eutrophic Schöhsee, West Germany, to the deposition of clay materials. The displacement was caused by mineral sediments introduced to the lake in the 1930s as a result of the construction of an embankment on the north shore[6]. Although he did not specify the taxa involved, Hofmann referred to the remaining population as a ". . . peculiar chironomid population . . ." composed of individual species that ". . . could only be considered as relicts . . ." as their population densities were extremely low and ". . . none of them lived there under optimal conditions." In retrospect, what Hofmann possibly observed was an imbalanced fauna similar to that observed in the Glenora sediments, but differing in that it represented an *imbalanced eutrophic fauna* rather than an *imbalanced oligotrophic fauna* as in the Bay of Quinte.

Similarity between the sequences of dominant faunas in the Bay of Quinte and Schöhsee cores suggests that the latter may have also undergone a process of oligotrophication connected with the accumulation of minerogenic sediments early in its developmental history. According to Hofmann (1971a: 53), the *Lauterbornia–Sergentia* community characteristic of the Preboreal and Boreal stages was followed by a *Tanytarsus–Sergentia* community in the Atlantic Stage, and then by a *Calopsectra–Tanytarsus–Sergentia* community during Subboreal I and II stages. In the Bay of Quinte, the sequence leading to the sediment-induced oligotrophication was similar; prior to the deposition event the fauna was dominated by Tanytarsini type 1 (comprised of specimens resembling the *Lauterbornia coracina* figured by Hofmann (1971b: 47)), but during the deposition event the fauna was dominated by Tanytarsini type 7 (comprised of specimens resembling the *Tanytarsus* sp. *C* and/or *Paratanytarsus* figured by Hofmann (1971b: 48,50)). Except for the period of most rapid accumulation, *Phaenopsectra* was present prior to and during the deposition event. Development of "sediment faunas" during the Atlantic and Subboreal I and II stages, suggested by the parallel, occurred during the climatic amelioration when temperatures rose to their highest levels (2–3°C above current mean July temperatures) and water levels subsequently declined to a minimum. Although there is the possibility that a decline in nutrient input as a result of lowered runoff was involved, the apparent oligotrophication in the fauna probably resulted from the resuspension of recalcitrant organic materials and mineral sediments from inshore zones, and their redeposition in deeper waters as water levels lowered and the beach line retreated. (The effect is the same as reservoir regulation, but in reverse.) Although Hofmann (1971a: 44) described these sediments as ". . . more nutritive gyttja sediments . . ." the Glenora study suggests that organic material in the Schöhsee sediments may not have been physically available or in a condition suitable for food for the chironomid community.

A number of facts support the hypothesis of a reversion period prompted by changes in the sedimentation regime of Schöhsee. *Procladius,* a genus that appears to be favored by mineral sediment accumulation in the Glenora core, reached its maximum during the Atlantic and Subboreal I stages. *Calopsectra* reached a maximum in the littoral zone (Core I) during the low-water period

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[6] Ungemach (1960: 183–186, quoted by Hofmann 1971a: 50) compared the chemistry of the "old autochthonous gyttja" sediments to the overlying clay mineral sediments and reported that the organic carbon content was reduced from 5.2% in the older sediments to 3.4% in the more recent clay sediments. In comparison, the accumulation of clay mineral sediments diluted organic carbon concentrations from 11.17% to 2.37% at one point in the Glenora core.

of the Boreal II Stage in a manner similar to the response of *Tanytarsus* sp. communities immediately beneath the drawdown zone documented by Fillion (1967: 9) in Barrier Reservoir. Gams (1927: 327) reported that the chironomid succession in the sediments of Lunzer Obersee, West Germany, did not follow the classical sequence outlined in lake-type theory, because of the interjection of several sediment type changes beginning in Zone IV (Younger Dryas) and continuing up to Zone IX (Subboreal I). Lundqvist (1927: 52), in a demonstration of postglacial succession from oligotrophy to eutrophy based on the macroscopic structure of lake sediments, noted that sand and clay sediments of the earliest, coldest periods (Dryas) were overlain by gyttja sediments of various kinds. The maximum development of the latter deposits occurred in the late Boreal to early Atlantic stages and were followed by changes in the sedimentation patterns (i.e. the later Atlantic and Subboreal I and II stages), which Lundqvist regarded as ". . . climatically determined regressions." If the similarity between the chironomid successions in the Glenora and Schöhsee cores is indeed due to the same basic mechanism — albeit one induced by human endeavor and the other through climatic change — this will add another dimension to Hofmann's already impressive work.

Frey (1955: 152) reported two distinct periods of Tanytarsini dominance in the chironomid assemblages from the sediments of meromictic Längsee, Austria, the presence of both of which may be reinterpreted in relation to the response of the group to mineral sediment accumulation. The initial assemblage of *Eutanytarsus* at 24 m, which Frey (1955: 153) interpreted as evidence for an extreme stage of oligotrophy in the lake's history, may be reinterpreted as the fauna resident during the "stabilization phase" in the development of the lake's basin. During its initial formation, soils that eroded from the basin's perimeter as beachlines were established would be deposited in the deeper water habitat at a fairly rapid rate, but as time progressed and the basin's morphometry stabilized, the rate of accumulation would decline. In Längsee, the light gray calcareous silts, which appeared immediately above the varved clays overlying the glacial moraine, probably represent the materials deposited during the latter stages of the "stabilization phase." The remains of the *Eutanytarsus* community preserved in them probably developed in response to an environment where mineral sediments accumulated at a relatively rapid rate. The idea that the *Eutanytarsus* community represents a response to mineral sediment accumulation, rather than trophic conditions, is supported by the fact that no significant community of other chironomid types developed in the succeeding zones after the accumulation of mineral sediments had ceased to be the dominant controlling factor. Without the repressive effects of mineral sediment accumulation, the *Eutanytarsus* fauna was rapidly phased out in favor of other species capable of utilizing the limited amount of food materials available in the succeeding oligotrophic, fine detritus-gyttja sediments. The second *Eutanytarsus* fauna developed immediately prior to the onset of meromixis in the transition zone (21.90–21.40 m) between fine detritus-gyttja and reduced gyttja sediments. The fauna most likely developed in response to the introduction of "clay" mineral sediments that appeared suddenly, and that are virtually absent in the underlying laminated gyttja. Frey (1955: 151) attributed the introduction of the clays to the clearing of land during the first agricultural period. The mechanism and response fostering development of the second *Eutanytarsus* fauna in Längsee was, in all accounts, similar to those initiating the same response in the Bay of Quinte.

The influence of mineral sediment accumulation on the relationship between estimates of trophic condition based on faunal and productivity indices is also apparent in Megard's (1964: 529) study of Dead Man Lake, New Mexico. The conflicting presence in the sediments of an oligotrophic Tanytarsini–Orthocladiinae assemblage, in a lake where carbon assimilation presently exceeds 3 $g \cdot m^{-2} \cdot day^{-1}$, led Megard (1964: 542) to conclude that ". . . oxygen concentration, not trophic level, regulates the chironomid fauna . . . " and further that ". . . the inconsistency between the productivity of Dead Man Lake and its chironomid fauna by no means destroys the validity of classifying lakes on the basis of the Chironomidae . . ." but means ". . . the lake classification system applies only to deep stratified lakes." In view of the responses of the Chironomidae to mineral sediment accumulation demonstrated in the Bay of Quinte and other studies, the presence of an apparently oligotrophic Tanytarsini–Orthocladiinae-dominated fauna in Dead Man Lake suggests that the effects of the lake's productivity have been masked by the influence of mineral sediment accumulation processes. The interpretation of an unstable bottom environment, prone to periods when extensive amounts of fine mineral sediments are deposited, is supported by the repeated reversions to Tanytarsini–Orthocladiinae-dominated faunas outlined in Megard's (1964: 536–537) faunal profiles. In particular, Core A demonstrates that the number of reversions increased markedly in more recent sediments compared to older sediments, where the Tanytarsini predominated almost exclusively. The suggestion of a sedimentation-prone environment is strengthened by Megard's (1964: 531) description of the surrounding watershed soils and basin characteristics, the composition of the core sediments, and the fact that the extensive *Chara* beds noted in the summer of 1959 were absent in 1961. The abrupt disappearance of the *Chara* beds suggests burial by accumulations of mineral sediments, whereas the presence of alluvial fans at the mouths of streams entering the lake indicates spring runoffs have sufficient energy to introduce proportionately high suspended sediment loads into the lake. According to Megard (1964: 531) ". . . whatever inhibited the vegetation, the phenomenon was regional, widespread and presumably the result of weather earlier in the season." It is highly probable, therefore, that the processes of sedimentation are operating in Dead Man Lake to mask the effects of high productivity, and the chironomid fauna is responding to the more dominant factor.

In conclusion, the ramifications of mineral sediment accumulation on the expression of trophic status displayed by chironomid communities, and probably benthic communities in general, appear to be widespread. It is not apparent whether the effects of mineral sediment accumulation act on the lake productivity in general or are confined more to the chironomid community; it is apparent, however, that considerably more attention must be given to sedimentation processes when interpreting faunal communities in cores or living situations.

5.3 Social and Ethical Implications and Relevance

> *For several thousand million years, the ecosphere has been developing into an extremely complex organization of different forms of life in close interaction with each other. The elaborate mechanisms that have enabled the ecosystem to develop . . . have been disrupted by man's activities. In his gross presumption, he has sought to replace them with devices causing dereliction and confusion, which rather than seek to satisfy the countless competing requirements of the ecosphere, have been geared to the satisfaction of petty, short-term, anthropocentric ends.*
>
> Goldsmith et al. 1972: 27

This Bulletin, in essence a 2800-year environmental impact assessment, documents a few of the more obvious relationships between man, his institutions and activities, and the Bay of Quinte ecosystem. There is something both frightening and ominous in the implications and the prospects it suggests for mankind. It is frightening to realize the magnitude of the disruptions evident in the Bay of Quinte ecosystem, and the rate at which these disruptions have come about. The study clearly demonstrates man's ability to seriously alter this environment, and the remarkably short span of time involved brings into question the ability of the bay to sustain itself in the face of continued insults. Alterations, unwittingly induced through changes in sedimentation and eutrophication processes, have seriously degraded the quality of the natural resources of the bay. This is particularly distressing at a time when the value of these resources is only now beginning to be appreciated. At a time, too, when human health problems are being increasingly linked to environmental contaminants, the evidence for industrial and/or agricultural contamination in the bay assumes a more ominous and sinister meaning. Although the linkages may be tenuous, one cannot help feeling that the same factors causing the marked increase in the incidence of deformities among larval organisms in the bay may be involved in the increased incidence of serious medical problems, such as cancer, in our own societies.

The disruption of the interrelationships between various levels of life in the bay with one another and with their surroundings has been documented above. However, another level of complexity is also apparent in the interrelationship between global affairs and the aquatic ecosystem of the Bay of Quinte. Commoner (1976: 1) described the complex interactions among the three basic systems — the ecosystem, the production system, and the economic system — that, together with the social or political order, govern all human activity. What is surprising is that the sediments of a lake could contain such clear evidence of these same complex interactions and on a scale involving international affairs. Who would have imagined that Napoleon's blockade of the Baltic Sea in the Continental System would lead the British government to institute the Differential Duties that made it profitable to harvest Bay of Quinte white pine for masts and spars for the Royal Navy. That this activity in turn would lead to erosion in the watershed and increased sedimentation would never have occurred to Napoleon, the British, or probably even the men who harvested the virgin pines. It is even more unlikely that anyone could have contemplated the degree of disruption these events would have on the life support systems of the bay. Although meant in a slightly different context, Vallentyne's (1978: 353) statement that

". . . participants in slow processes of major change are rarely aware of the extent to which change has taken place around them, and even less to the extent to which their behaviour as individuals and groups has accommodated to that change . . ." is applicable. Only in the extended analysis of hindsight, where the juxtaposition of time can be evaluated, can the degree to which political and economic events and decisions, which were made in other parts of the world and have influenced the ecosystem, be brought into focus. The extent of the disruption of the Bay of Quinte ecosystem provides a clear example of the urgent need to develop a better understanding of the workings of environmental processes, and to modify human behavior with respect to the environment before its limits are exceeded. Short-term actions of limited perspective must be replaced by intelligent long-term planning and initiative if the human species is to survive.

> *It would be well to bear in mind that the present of today was the future of yesterday and that it is what it is because of the human actions, the human decisions of yesterday. Therefore the future will be what we make it.*
>
> John W. Dafoe
> (Pratt 1976: 13)

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APPENDIX 1. SAMPLE PREPARATION AND ANALYSIS

1.1 Core Color Descriptions

Each core was described prior to sectioning according to wet sediment color, using a Munsell Soil Color Chart. Descriptions were made by comparing the sediment color as seen through the 1.6–mm perspex core liner wall to a moistened color chip.

The color of dry, finely ground sediment from each centimeter interval of the Glenora-B core was estimated after sectioning. Descriptions based on the Munsell Soil Color Charts were made against dry color chips.

1.2 Core Chronology

1.2.1 POLLEN METHODS

Weighed sediment samples of 1 cc volume for pollen analysis were taken at consecutive 1 cm intervals throughout the top 55 cm of the core, and at every fifth centimeter interval throughout the remainder of the core. Four additional samples through the 58–62 cm interval were also taken to define more clearly the effects of the Abandonment Stage between the French and British periods. The samples were submitted to Dr J. H. McAndrews, Royal Ontario Museum, Toronto, Ont., for analysis, and subjected to standard concentration techniques with KOH, HF, and acetolysis solution. The samples through the ferromanganese micronodule horizon were additionally treated with hot HNO_3 after HF to remove the pyrite-type minerals. The sediment matrix of each sample was washed through a 12-μ sieve, the concentrate stained with safranin, mixed with silicone oil, and weighed. The oil–concentrate mixture was reweighed after each slide was made to determine the aliquot on the slide. Normally a measured portion of each prepared slide was examined until pollen of a minimum 200 woody plants was identified. However, this sum was increased for the four special samples to enhance the confidence placed on the results. The pollen of woody plants (trees and shrubs) was used to determine the basic sum for the calculation of pollen percentages. Herbs, indeterminate and unknown pollen percentages were calculated as percentages of the basic sum (Faegri and Iversen 1964: 134). Pollen concentrations per mg wet sediment were calculated according to the method of Traverse and Ginsburg (1966: 427). The nomograms presented by Maher (1972: 87) were used to compute the 95% confidence limits for the pollen data.

1.2.2 CESIUM-137 METHOD

Samples of fresh sediment from the first 20 consecutive sediment intervals of the Glenora-C core were spread evenly in small petri dishes and dried at 65°C. The dried sample "cakes" were orientated on the gamma ray spectrometer and the gamma emission activity counted, on the average, for 24 h. The efficiency of the gamma counter was 0.016; 2.2 disintegrations per minute were equivalent to one picocurie. All cesium-137 determinations were conducted by G. Kipphut, Lamont-Doherty Geological Observatory, Palisades, N.Y.

1.2.3 LEAD-210 METHOD

Samples of fresh sediment were taken from the 1.5, 3.5, and 6.5 cm intervals and from every fifth centimeter interval from 8.5 to 48.5 cm, as well as three additional samples from 25.5, 26.5, and 27.5 cm. All samples were dried to constant weight at 80–95°C and a known volume (80 ml) of 6 N hydrochloric acid was added to each, along with known amounts of polonium-208 and nonradioactive lead. The sediment–acid mixtures were then heated (80°C) for 1 h to leach the sample lead and the polonium-208 and nonradioactive yield tracers from the sediment. The sediment was removed by centrifugation and the supernatant brought to 1.5 N acidity. A copper disc (diameter 22 cm) was placed in the beaker and the solution heated (70–80°C) for 1.75 h to deposit the polonium on the copper disc. The activity of the disc was then measured on an alpha-spectrometer. All lead-210 determinations were carried out by G. Kipphut, Lamont-Doherty Geological Observatory, Palisades, N.Y.

Apparent sedimentation rates based on the differential measurement of supported and unsupported lead-210 were calculated according to the following relationship:

$$\text{sedimentation rate} = \frac{-\pi}{2.3\ m}$$

where π is the decay constant for Pb-210 (3.12×10^{-2} yr^{-1}), m is the slope of the line, and 2.3 the log conversion.

1.2.4 CARBON-14 METHOD

Carbon-14 determinations were conducted on combined bulk sediment samples from intervals between 31 and 36 cm, 55 and 58 cm, 113 and 116 cm, and 158 and 161 cm. The sediment matrix was removed initially after dissolution in HCL. Organic humic acid compounds were then removed from the concentrate with boiling KOH and the nondissolved residue used for the radiocarbon measurement. The measurement was conducted on the refined organic concentrate to avoid the uncertainties introduced by the sediment matrix (Shotton 1972: 460). All carbon-14 measurements were carried out by T. H. Peng, Lamont-Doherty Geological Observatory, Palisades, N.Y.

The date of formation of the organic material was calculated by the relationship:

$$C^{14}/C^{12}\ \text{today} = C^{14}/C^{12}\ \text{formation} \times e^{-\lambda}\ t$$

where λ is the decay constant for carbon-14 (8030 yr) and t = time.

Age alteration caused by the depression of the C^{14}:C^{12} ratio by the presence of a contaminant in a sample was computed from the relationship:

$$e^{-t_{M/8030}} = fe^{-t_{C/8030}} + (1-f)e^{-t_{S/8030}}$$

where t_S is the true age of the sample, t_C the age of the contaminant, f the fraction of carbon contributed by the contaminant, and t_M the apparent age of the contaminated sample (Broecker and Kaufman 1965: 539).

1.2.5 THE EROSION INDEX

The Erosion Index was calculated for each consecutive 1-cm interval throughout the top 70 cm of the core and for every fifth centimeter interval for the remainder of the core as follows:

$$\text{E.I.} = \frac{\%\ \text{clay-sized fraction} > 10.50\ \phi}{\%\ \text{total clay-sized fraction}\ (> 8.5\ \phi)} \times 100$$

The precision attained in the measurement of the sediment particle size distribution in half phi size increments by the Sedigraph Particle Size Analyzer was 0.5–1.0%.

1.3 Core Physical Parameters

1.3.1 GRAIN SIZE ANALYSIS

Distribution of the fine sediment fractions in the silt-clay size range was measured at each centimeter level of the Glenora-B core on a Sedigraph 500 Particle Size Analyzer (Micromeritics Corporation, Norcross, Georgia) according to the procedure of Duncan and Rukavina (1972). Precision attained by the Sedigraph grain-size analyzer is in the range 0.5 to 1.0% (Duncan and Rukavina 1972: 82). Description of particle size distribution in the sediments using moment measures was accomplished by SEDAN, a computer program for sediment particle size analysis (Coakley and Beal 1972).

Distribution of the coarse fractions associated with the ferromanganese micronodule horizon was determined by sieving, as the particle size range of this material was outside the size range capacity (0.1–100 μ) of the Sedigraph analyzer. The coarse fraction was separated into quartz and ferromanganese micronodule fractions by dissolving away the latter fraction with hot HCL and reweighing. No determinations of the actual size ranges of the coarser fractions were attempted. The fine sediment distribution from the Sedigraph analysis was correspondingly corrected to take into account the coarse sediment material.

1.3.2 IGNITION MEASUREMENTS

Measured volumes (1 cc) of fresh sediment from selected levels (every centimeter from 0.5 to 9.5 cm, every second centimeter from 11.5 to 21.5 cm, every fourth centimeter from 25.5 to 49.5 cm, every fifth centimeter from 54.5 to 159.5 cm, and the 163.5 cm interval) in the Glenora-B core were used to determine wet weight, dry weight (48 h at 40°C), loss on ignition (30 min at 550°C), and loss on combustion (30 min at 950–1000°C). The temperature used to determine dry weight (40°C) is somewhat lower than that (65–100°C) traditionally used by most authors. Planktonic studies indicate that the higher temperatures result in considerable loss of organic matter (Shaw 1959: 321; Lovegrove 1966: 435; Dr F. P. Healy, L. Henzel personal communication); the lower temperature was used, therefore, to retain the organic matter fraction intact.

1.3.3 SEDIMENT ACCUMULATION

The annual accumulation of sediment was calculated on the basis of the relationship between sediment density and the sedimentation rate. Sediment densities, or dry weights of sediment per unit volume, were determined at selected levels (see Section 1.3.2). Densities at levels not measured were interpolated. Sedimentation rates were also interpolated, but the procedure was slightly more involved. Because each experimentally determined sedimentation rate involved the average for the interval measured, the experimental rate was placed at the midpoint of the interval. Sedimentation rates between any two such experimentally determined rates were then interpolated. For example, as shown in Table 27, the sedimentation rate for the interval between 23.5 and 18.5 cm, which was measured by the lead-210 method as 5.07 mm·yr⁻¹, was placed at the midpoint of the interval at 21.0 cm. Similarly the sedimentation rate between 18.5 and 13.5 cm (5.19 mm·yr⁻¹) was centered at the midpoint of the interval at 16.0 cm. Sedimentation rates for each level median were then interpolated between these two measurements. The procedure was slightly modified for the surface sediments. The sedimentation rate for the surface interval between 13.5 and 0 cm (calculated as an average rate 2.15 mm·yr⁻¹) was centered in the usual manner at 6.75 cm, and the sedimentation rates for the level medians between this point and 16.0 cm, the midpoint of the preceding interval, interpolated. The average figure of 2.15 mm·yr⁻¹ was then used for the sedimentation rate for the level medians between 6.75 cm and the surface. Because of the methodology adopted, the actual measured sedimentation rates only infrequently appear in the consecutive sedimentation rate scale determined through interpolation; the exceptions, generally, are the four consecutive levels measured by the lead-210 method between 25.5 and 28.5 cm.

TABLE 27. Example of method used to extrapolate sedimentation rates for intermediate sediment intervals.

Depth interval (*cm*)	Sediment depth (*cm*)	Sedimentation rate (by Lead-210)	Interpolated sedimentation rate (*mm·yr⁻¹*)
13–14	13.5		4.37
	14.0		
14–15	14.5		4.70
	15.0		
15–16	15.5		5.03
	16.0	5.19	
16–17	16.5		5.18
	17.0		
17–18	17.5		5.16
	18.0		
18–19	18.5		5.13
	19.0		
19–20	19.5		5.10
	20.0		
20–21	20.5		5.08
	21.0	5.07	
21–22	21.5		5.06
	22.0		
22–23	22.5		5.06
	23.0		
23–24	23.5		5.05

1.4 Core Chemical Parameters

The following analyses were performed each centimeter interval for the first 70 cm and every fifth centimeter interval thereafter: total carbon, total nitrogen, inorganic carbon, and phosphorus. Total carbon and nitrogen were measured (two replicates, minimum) on a Carlo Erba Model 1100 CHN Element Analyzer. Inorganic carbon was determined (in triplicate) on a modified Fisher Hamilton Model 29 Gas Partitioning Chromatograph according to Stainton's (1973: 1442) gas stripping procedure. Phosphorus was measured colorimetrically (in triplicate) on a Technicon Auto Analyzer II using a modified particulate phosphorus method (Stainton et al. 1974: 67). Precisions for the two latter analyses are given in Stainton (1973: 1443) and Stainton et al. (1974: 67). An independent check of the phosphorus sequence between 45 and 70 cm was conducted by J. D. H. Williams, Canada Centre for Inland Waters, Burlington, Ont., using the method of Harwood et al. (1969: 418).

Chemistry of the ferromanganese micronodules was determined on material washed by the KOH-PO_4 method employed for subfossils (see Section 1.5.2.1). Samples were concentrated by sluicing to remove organic debris and heavier materials, mainly quartz grains (Vallentyne 1961: 294), then sorted by hand under a stereomicroscope to provide a pure sample analysis.

The micronodules were digested in nitric acid and 50% hydrogen peroxide by U.V. irradiation for 4 d. The sample was then brought up to volume with demineralized water and aliquots of the stock solution used for analysis. Sodium and potassium were measured by flame emission; all other analyses were done by atomic absorption. Micronodule chemistry was carried out by A. Lutz and F. A. J. Armstrong, Freshwater Institute, Winnipeg, Man.

1.5 Core Biological Parameters

Sixteen sediment intervals from the major historical periods embraced by the Glenora-B core were selected for exhaustive analysis. Eleven intervals were chosen to represent the period from the date of the first British colonization to the present — the period of greatest activity and greatest change — while single sample intervals were selected to represent the French, Iroquoian, Algonkian, Hopewellian, and Pre-Hopewellian periods. The fauna recovered from each sampling interval was maximized, within the constraints of time and effort, to provide as large a data base as possible.

1.5.1 General Methodology

Sediment samples of known volume (3 cc) were deflocculated in 8% KOH at low temperature (30–32°C) for several days. The sediment matrix was then removed by sieving through a fine-mesh (93 μ) sieve. The material retained in the sieve, including chironomid head capsules, was washed in a basic solution of trisodium orthophosphate and rinsed through a fine-mesh sieve again. After dehydration through a series of ethanol baths, the material retained in the sieves was searched under a stereomicroscope (generally at 25 ×) for head capsules and other macroinvertebrate material. All specimens were mounted in euparol on glass slides.

Sorting efficiency was checked by resorting the samples after the initial sorting, pooling the results, and calcualting the efficiency of the first sorting. Checks by the author indicated a sorting efficiency between 97 and 98%.

All identifications were made by a compound microscope. Measuring and reconstruction procedures were carried out under oil immersion, with the aid of a Wild M20 equipped with a drawing tube.

1.5.2 Detailed Methodology

A detailed description of the equipment and methodology used in sample preparation, sorting, and speciman mounting is provided as a guide for those interested in the techniques developed in the Glenora study.

1.5.2.1 *Sample preparation* — Chironomid head capsules, although made of virtually indestructible chitin, have a fine infrastructure that can easily be lost if samples are mishandled during the preparatory stages. Gentle moderation is stressed in the techniques described below, especially with respect to water spray velocity, heating, and chemical treatment. Cleanliness should also be stressed to avoid cross-contamination.

The following equipment is required:

1) Sampling syringe (5 cc disposable plastic syringe with tip removed at the 1-cc mark).
2) Small sieves (25-ml pill vials (Rigo Plasticlear snap cap vials available through The Richards Glass Co., Toronto). Bottom of vial removed and replaced with #15 Nitex screen cemented into place with plastic modeller's cement).
3) Large sieve (250 ml polystyrene jar (available Twin City Plastics, 1227 Hennepin E. Ave., Minneapolis, Minn. 55414). Bottom screened as above.
4) Combination hot-plate stirrer (Magne-4 Mod. No. 4820-2 4-unit magnetic stirrer with hot plate from Cole-Parmer Instrument Co., Chicago, Ill. 60648).
5) Nitex #15 mesh (mesh opening = 93 μm available from B. & S. H. Thompson & Co. Ltd., 236 Montpellier Blvd., Montreal, Que. H4N 2G3)).
6) Ointment jars (30-ml low-form flint glass jars available from O. H. Johns Scientific, Toronto, Ont.).
7) Sample vials (10-ml (19 × 65 mm) allergy vials available as above, Cat. No. 12550).
8) 30-ml beaker (Pyrex Brand No. 1000, small sieves nest closely inside for decanting purposes).
9) Ethanol (99% and 75%)
10) Potassium hydroxide (pellet form).
11) Tri-sodium orthophosphate(crystalline form $Na_3Po_4{\cdot}12H_2O$).
12) Small flat spatulas.

The most efficient method developed for cleaning sediment samples is outlined below:

1) Measure a 3-cc (or other suitable sample volume) sample of wet sediment in a sampling syringe, and eject it into a 30-ml ointment jar. Use the fine end of a spatula to tamp the sediment into the syringe, to ensure air bubbles are not present and the measure is accurate.
2) Fill the jar to 25 ml with filtered water. (A screen of #15 Nitex was used to filter all water supplies to avoid cross-contamination.)
3) Add potassium hydroxide pellets (5 or 6) for approximately 8% solution, mix thoroughly.
4) Digest sample at low heat (30–32°C) for 2–3 d (not critical). Leave lids loosely in place to prevent evaporation. (Caution: do not tighten lids.)
5) Pour digested sample into large-sieve screen (rinse all contents from ointment jar thoroughly) and gently flush the fine mud through the screen with filtered water.
6) Carefully concentrate and back-flush retained materials from the large sieve into a small beaker. Fill with filtered water to 25 ml (care must be taken to ensure the transfer is quantitative).
7) Add a small quantity (approx 0.1 g) of orthophosphate crystals and 1–2 potassium hydroxide pellets.
8) Heat, with continuous stirring, at 60°C for 30 min on the combination hot-plate stirrer.
9) Pour the washed sample from the beaker into a small sieve and flush gently with filtered water. The washing liqueur of a clean sample will be clear; if, however, the sample still appears cloudy (Step 8), a third washing may be desirable. The importance of proper cleaning will be appreciated when the sample is sorted.
10) To rewash, flush the sample from the small sieve back into its beaker and repeat steps 6–9.
11) Pass the sample in the small-sieve screen successively through baths of 75, 95, and 99% ethanol.
12) Back-flush the clean dehydrated sample from the small sieve into a sample vial with 99% ethanol.
13) Label, stopper, and store.

Several points on sample preparation should be noted. The temperatures mentioned should be adhered to fairly closely as higher temperatures tend to deform and bleach chitinous structures. Measurements can seriously be affected by heat deformation. Cleaning materials such as d-mannitol and commercial detergents seriously bleach chitin, making sorting and identification difficult. Sediment dispersal with ultrasonic sound is harsh and should be avoided. Hofmann (1971a) found 10% HCL to be a useful cleaning agent in sediments rich in calcium; unless absolutely necessary its use is not recommended as it tends to soften chitinous structures. Acid-treated material tends to clump, causing subsequent difficulties in sorting. Subfossil materials may be separated from heavy fractions such as sand grains by density separation. Remains suspended in a supersaturated solution may be decanted from a small sieve, nesting in a small beaker of supersaturated potassium iodide solution. This procedure is advocated only when absolutely necessary; it would be better to sort a sample with the heavy fraction present than risk the loss of head capsules, which may be filled with sediment and separate out with the heavy fraction.

1.5.2.2 *Sample sorting* — As in preparing the samples, cleanliness should be stressed both for the sake of accuracy and ease of operation. The equipment required is:

1) Stereomicroscope (Wild M5 stereomicroscope using transmitted light at 25 × magnification).
2) Needle probes (2 No. 40 special, extra fine, smooth broach needles mounted in needle holders (available from The S. S. White Dental Mfg. Co. Philadelphia, Pa.) one hooked probe, one straight).
3) Fine forceps (Melcher, Germany, or Irex, Switzerland).
4) Sorting dishes (Stender dishes 37 × 25 mm, available O. H. Johns Scientific , 219 Broadview Ave., Toronto, Ont.) selected for aberration-free bottoms).
5) Hot plate (adjustable temperature hot plate, available from Canlab, 535 Marjorie St., Winnipeg, Man.)
6) Holding jars (450-ml wide-mouth specimen jars with sealing bakelite lids).
7) Absolute ethanol.
8) Xylene.
9) Eyedropper.
10) Fine rubber band and scissors.
11) Cleaning tissue (T^m Kimwipes).

The sorting procedure is as follows:

1) Transfer a stored sample quantitatively to a sorting dish using a minimum of alcohol. (This may be accomplished by first concentrating the

sample in a small sieve and then back-flushing to a sorting dish.)

2) Place the sorting dish on a hot plate to evaporate the excess alcohol. The temperature of the hot plate should be such to cause reasonably rapid evaporation. (Caution: do not overheat.)
3) Excess alcohol is removed to the point at which the sample material is *just moist*. Close attention is necessary at this point to avoid drying the sample and ruining it. If the sample is removed a few moments before the proper point is reached, the residual heat in the glass dish should be sufficient to reach the desired point, but at a slower rate.
4) At this point, control of the alcohol level becomes important (Pl. 1). The sample is kept just moist by adding alcohol with an eyedropper to the sample material. If too much alcohol is added the fine material will be moved around by convection currents set up by evaporation. The decisive factor in this procedure is the careful control of the alcohol level in the sorting dish. If the material to be sorted is moving it is virtually impossible to search efficiently for subfossil remains.
5) Concentrate the bulk of the material to one side of the sorting dish using a hooked probe and/or drops of alcohol from an eyedropper (Pl . 2).
6) Examine the large area of the sorting dish. Remove any subfossil remains with a hooked probe or fine forceps. Concentrate the extraneous material together in a discard pile (Pl. 3). (Note: frequent, careful additions of alcohol with an eyedropper every few minutes will be necessary to prevent drying. Movement caused by excess alcohol will destroy the continuity of the search pattern.)
7) Place small dikes made of small pieces of rubber band in V-pattern to isolate the discarded material from the remaining unsorted material (Pl. 4).
8) The remaining material is then sorted by drawing very small amounts of material into the open area at the apex of the dikes, where it can be searched and discarded (Pl. 5). Any subfossils found are removed to a separate dish of alcohol; the extraneous material is moved into the protected discard area.

Plate 1.

Plate 2.

Plate 3.

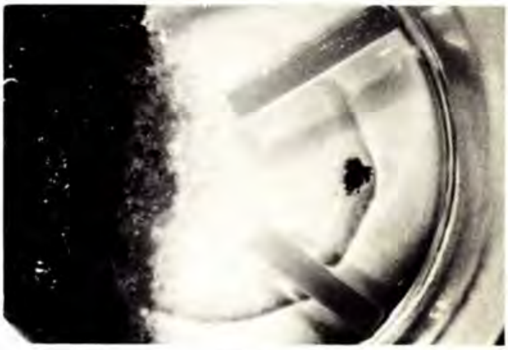


Plate 4.

Plate 5.

Very small specimens are most easily picked out by fine forceps. In this respect it is often easier to pick up a specimen in the meniscus formed between the two points of the forceps, than to actually grasp the specimen directly.

Water accumulation in the absolute ethanol may present a problem. It is detected as a small sticky mass or bead, which makes sorting difficult. The water bead can be isolated by the judicious application of alcohol and sponged up with the corner of an absorbent cloth or tissue.

Forceps and probes should be cleaned frequently in xylene.

If it is necessary to leave a sample during the sorting stage when the alcohol level is so critical, place the sorting dish with the lid on (also the container of specimens already sorted) in a holding jar whose bottom is covered with alcohol (5 mm depth) and seal tightly. The alcohol in the bottom of the holding jar will quickly reach vapor pressure equilibrium and prevent evaporation from the specimen or sorting dishes.

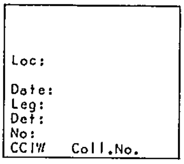
1.5.2.3 Slide preparation — Permanent slides of all subfossil chironomid remains provide a record of the subfossil assemblages found in a core. Required for permanent slides are:

1) Glass slides (plain microscope slides 25 × 75 mm, available from Canlab, 535 Marjorie St. Winnipeg, Man., Cat. No. M6145).
2) Cover slips (chance cover slips No. 1, diameter 10 mm, available from O. H. Johns Scientific Co., 219 Broadview Ave., Toronto, Ont.).
3) Mounting media (Turtox Euparol, Natural, available from General Biological, Inc., 8200 South Hoyne Ave., Chicago, Ill. 60620).
4) Probes and forceps.
5) Ethanol, xylene, toluene (for cleaning purposes).

Procedures are outlined and discussed as follows:

1) Afix label blanks to slides prior to use and allow to dry thoroughly.
2) Clean glass slides and cover slips in xylene or toluene and polish with lens tissue.
3) Transfer a small bead of euparol to a glass slide on the hooked end of a probe (eight specimens are generally placed on a single slide); to properly space each bead of euparol, place a template drawn on a file card beneath the slide indicating the proper spacing. The file card also provides a white background against which specimens show up better. Be careful of the size of bead of euparol applied; too little is better than too much, as more euparol can easily be added after the cover slip is in place.
4) Transfer a specimen from the alcohol with fine forceps. The meniscus between the forceps' tips aid in transferring the specimen to the euparol. (Note: instruments should be kept clean at all times.)
5) Loosen the euparol, as necessary, with a small drop of alcohol and position the specimen ventral side up. If a head capsule has sediment trapped inside, a gentle tapping pressure with the hooked probe across the head capsule may dislodge it (small amounts of alcohol are best applied down the hooked needle from the ferrule rings by gentle shaking).
6) With forceps place a cover slip over the specimen in loose euparol. If the euparol has started to set, a drop of alcohol will loosen the euparol and draw the mounting media neatly out under the cover slip.
7) Apply gentle pressure and a rotary motion to the cover slip to flatten specimen. This will serve to disperse any sediment in the head capsule and expose fine structures to view.
8) Add euparol as necessary to fill any airspaces under the cover slip.
9) Label and dry the slides in a drying oven at 40°C for 2–3 wk.

The labeling system established for the Bay of Quinte study was set up as follows:



Glenora B indicates the core site (Glenora) and identifies the core (B) of a series taken at that site.

3 cc indicates the volume of fresh sediment analyzed in a particular sample.

139–140 indicates the interval (in cm) in the core from which the sample is taken.

G-140 collection number corresponds to core site and level.

7 of 41 identifies this particular slide as the 7th of a total of 41 slides from this level.

iv indicates that this is the fourth replicate of *n* replicates analyzed at this level.

The specimens on each slide are numbered from left to right consecutively, one to four across the top and five to eight across the bottom.

APPENDIX 2. SEDIMENT CHEMICAL–PHYSICAL ANALYSES

Sediment chemistry and grain size analyses: total carbon, organic carbon, inorganic carbon, total nitrogen, total phosphorus (in mg·g dry sediment weight^{-1}), carbon:nitrogen ratio, silt (4–8.5 ϕ), clay (8.5 to > 12 ϕ), fine clay (> 10.5 ϕ), ferromanganese micronodules, and quartz (in percentage).

Sample median (cm)	Total carbon	Organic carbon	Inorganic carbon	Total nitrogen	Total phosphorus	$C_O:N_T$	Silt (%)	Clay (%)	Fine clay (%)	FeMn micro-nodule (%)	Quartz (%)
0.5	–	–	–	–	–	6.800[a]	–	–	–	–	–
1.5	89.222	86.139	3.083	12.578	2.986	6.848	–	–	–	–	–
2.5	86.457	83.684	2.773	10.640	2.497	7.865	–	–	–	–	–
3.5	90.662	88.254	2.408	12.915	1.937	6.833	36.36	63.64	45.45	–	–
4.5	–	–	–	–	–	7.378[a]	24.64	75.36	63.77	–	–
5.5	91.546	89.427	2.119	11.285	1.767	7.924	–	–	–	–	–
6.5	84.096	81.827	2.269	11.294	1.546	7.245	39.29	60.71	42.86	–	–
7.5	84.973	82.752	2.221	10.286	1.460	8.045	38.00	62.00	42.00	–	–
8.5	81.636	79.447	2.189	9.415	1.422	8.438	47.50	52.50	30.00	–	–
9.5	81.240	78.990	2.250	9.397	1.369	8.406	30.77	69.23	53.85	–	–
10.5	76.127	73.922	2.205	9.300	1.395	7.949	31.25	68.75	54.17	–	–
11.5	77.226	75.047	2.179	9.241	1.353	8.121	33.61	66.39	49.58	–	–
12.5	70.022	67.828	2.194	8.541	1.344	7.941	32.56	67.44	51.16	–	–
13.5	76.021	73.781	2.240	9.009	1.328	8.190	40.91	59.09	38.64	–	–
14.5	–	–	–	–	–	8.760[a]	35.00	65.00	48.75	–	–
15.5	70.519	68.322	2.197	7.323	1.298	9.330	28.57	71.43	57.14	–	–
16.5	72.754	70.522	2.232	7.862	1.277	8.970	36.71	63.29	45.57	–	–
17.5	70.006	67.756	2.250	6.675	1.297	10.151	29.41	70.59	55.88	–	–
18.5	70.201	68.088	2.113	7.641	1.309	8.911	29.03	70.97	58.06	–	–
19.5	65.709	63.765	1.944	6.635	1.312	9.610	22.00	78.00	67.00	–	–
20.5	66.037	63.794	2.243	7.015	1.378	9.094	28.45	71.55	54.31	–	–
21.5	59.530	57.234	2.296	7.873	1.343	7.270	35.48	64.52	46.77	–	–
22.5	62.550	60.440	2.110	6.215	1.383	9.725	37.04	62.96	48.15	–	–
23.5	56.571	54.721	1.850	6.266	1.381	8.733	33.33	66.67	50.00	–	–
24.5	–	–	–	–	–	8.453[a]	26.98	73.02	60.32	–	–
25.5	54.635	52.880	1.755	6.470	1.562	8.173	38.18	65.82	50.63	–	–

[a] interpolated

APPENDIX 2. *(continued)* Sediment chemistry and grain size analyses: total carbon, organic carbon, inorganic carbon, total nitrogen, total phosphorus (in mg·g dry sediment weight^{-1}), carbon:nitrogen ratio, silt (4 to 8.5 φ), clay (8.5 to > 12 φ), fine clay (> 10.5 φ), ferromanganese micronodules, and quartz (in percentage).

Sample median (cm)	Total carbon	Organic carbon	Inorganic carbon	Total nitrogen	Total phosphorus	C_O:N_T	Silt (%)	Clay (%)	Fine clay (%)	FeMn micro-nodule (%)	Quartz (%)
26.5	52.044	50.394	1.650	5.316	1.542	9.480	38.14	61.86	43.22	–	–
27.5	51.505	49.755	1.750	5.300	1.725	9.388	35.40	64.60	46.58	–	–
28.5	46.316	44.244	2.072	6.066	1.626	7.294	38.78	61.22	40.82	–	–
29.5	43.632	42.111	1.521	4.240	1.386	9.932	36.96	63.04	43.48	–	–
30.5	44.426	42.756	1.670	4.468	1.562	9.569	35.38	64.62	47.69	–	–
31.5	46.315	44.502	1.813	4.672	1.771	9.525	38.46	61.54	43.36	–	–
32.5	44.680	42.850	1.830	4.557	1.631	9.403	42.14	57.86	42.86	–	–
33.5	–	–	–	–	–	9.185[a]	38.23	61.70	44.42	0.03	0.04
34.5	–	–	–	–	–	9.294[a]	38.84	60.65	41.69	0.36	0.15
35.5	48.118	46.036	2.082	5.072	1.640	9.076	36.73	62.32	45.11	0.68	0.27
36.5	47.159	44.888	2.271	4.801	1.520	9.350	41.86	56.14	36.64	1.28	0.72
37.5	55.454	53.022	2.432	5.983	1.624	8.862	41.06	56.45	37.84	2.02	0.47
38.5	–	–	–	–	–	8.963[a]	41.35	55.62	45.99	2.53	0.50
39.5	–	–	–	–	–	9.064[a]	28.47	63.53	48.65	5.12	2.88
40.5	26.129	24.847	1.282	2.711	1.292	9.165	22.63	64.41	53.72	7.70	5.26
41.5	24.819	23.714	1.105	2.322	1.359	10.213	30.64	57.39	43.54	1.44	10.53
42.5	65.816	63.601	2.215	6.488	1.359	9.803	33.19	63.18	49.59	0.65	2.98
43.5	112.991	110.108	2.883	10.639	1.300	10.349	44.48	54.92	31.19	0.15	0.45
44.5	–	–	–	–	–	10.138[a]	42.50	57.00	37.27	0.17	0.33
45.5	115.584	112.177	3.407	11.299	1.357	9.928	40.64	59.06	39.39	0.20	0.10
46.5	108.550	104.641	3.909	10.959	1.265	9.548	49.87	49.86	28.50	0.15	0.12
47.5	–	–	3.825	–	1.260	–	43.40	56.60	35.85	–	–
48.5	114.909	111.077	3.832	11.366	1.334	9.773	45.35	54.65	32.56	–	–
49.5	119.593	115.339	4.254	14.775	1.257	7.806	38.78	61.22	40.82	–	–
50.5	119.102	114.452	4.650	11.068	1.364	10.341	41.98	58.02	37.04	–	–
51.5	116.125	111.678	4.447	10.657	2.200	10.479	38.96	61.04	41.56	–	–
52.5	116.132	111.761	4.371	10.852	1.971	10.299	53.01	46.99	21.08	–	–
53.5	115.565	111.075	4.490	10.852	1.419	10.235	53.57	46.43	19.29	–	–
54.5	113.884	109.433	4.451	10.804	1.549	10.129	50.00	50.00	23.02	–	–
55.5	116.540	112.025	4.515	11.158	1.260	10.040	52.69	47.31	21.51	–	–
56.5	117.234	112.493	4.741	11.293	1.423	9.961	52.29	47.71	22.02	–	–
57.5	119.351	114.441	4.910	11.793	2.104	9.704	49.54	50.46	26.61	–	–
58.5	118.291	113.502	4.789	11.079	1.468	10.245	48.19	51.81	28.92	–	–
59.5	112.256	107.466	4.790	10.611	1.494	10.128	61.11	38.89	9.26	–	–
60.5	107.577	103.302	4.275	10.525	1.200	9.815	56.25	43.75	24.11	–	–
61.5	117.243	113.560	3.683	10.877	1.133	10.440	53.00	47.00	20.00	–	–
62.5	117.708	113.455	4.253	10.874	1.129	10.434	51.54	48.46	23.08	–	–
63.5	115.255	110.654	4.601	10.897	1.336	10.155	48.89	51.11	26.67	–	–
64.5	112.573	107.741	4.832	10.545	1.171	10.217	55.81	44.19	16.28	–	–
65.5	117.582	112.458	5.124	11.070	1.135	10.159	50.54	49.46	23.66	–	–
66.5	117.147	111.695	5.452	10.944	1.149	10.206	48.61	51.39	30.56	–	–
67.5	118.818	112.754	6.064	10.759	1.141	10.480	45.35	54.65	31.40	–	–
68.5	108.064	101.447	6.617	9.704	1.129	10.454	55.17	44.83	17.24	–	–
69.5	122.040	116.563	5.477	12.099	1.155	9.634	53.49	46.51	20.93	–	–
74.5	137.311	133.449	3.862	13.356	1.179	9.992	55.67	44.33	16.49	–	–
79.5	137.701	127.690	4.011	12.498	1.187	10.217	56.13	43.87	12.90	–	–
84.5	133.884	129.605	4.279	12.881	1.167	10.062	55.91	44.09	15.75	–	–
89.5	130.490	127.125	3.365	12.246	1.192	10.381	56.87	43.12	15.00	–	–
94.5	132.399	127.484	4.915	12.256	1.155	10.402	56.85	43.15	15.07	–	–
99.5	122.656	117.619	5.037	11.394	1.167	10.323	54.47	45.53	17.89	–	–
104.5	111.045	105.674	5.371	10.488	1.228	10.076	58.05	41.95	13.79	–	–
109.5	120.051	115.475	4.576	11.726	1.178	9.848	57.47	42.53	13.79	–	–
114.5	115.458	111.056	4.402	10.798	1.166	10.285	57.32	42.68	14.02	–	–
119.5	111.522	107.055	4.467	10.718	1.148	9.988	52.80	47.20	20.50	–	–
124.5	112.988	108.440	4.548	10.949	1.160	9.904	56.44	43.56	17.82	–	–
129.5	110.680	105.712	4.968	10.221	1.129	10.343	54.25	45.75	19.61	–	–
134.5	111.591	107.144	4.447	10.639	1.164	10.071	57.73	42.27	15.47	–	–
139.5	112.698	108.166	4.532	10.467	1.167	10.334	52.00	48.00	16.67	–	–
144.5	111.044	106.388	4.656	10.439	1.165	10.191	54.19	45.81	18.44	–	–
149.5	106.879	101.401	5.478	9.757	1.252	10.393	57.61	42.39	16.31	–	–
154.5	107.797	102.636	5.161	10.239	1.251	10.024	52.15	47.85	11.66	–	–

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[a] interpolated

APPENDIX 2.*(concluded)*Sediment chemistry and grain size analyses: total carbon, organic carbon, inorganic carbon, total nitrogen, total phosphorus (in mg·g dry sediment weight^{-1}) carbon:nitrogen ratio, silt (4 to 8.5 ϕ), clay (8.5 to > 12 ϕ), fine clay (> 10.5 ϕ), ferromanganese micronodules, and quartz (in percentage).

Sample median (cm)	Total carbon	Organic carbon	Inorganic carbon	Total nitrogen	Total phosphorus	C_O:N_T	Silt (%)	Clay (%)	Fine clay (%)	FeMn micro-nodule (%)	Quartz (%)
159.5	102.440	96.609	5.831	9.585	1.256	10.079	55.49	45.51	19.23	-	-
163.5	105.552	100.063	5.489	9.959	1.225	10.047	55.90	44.10	18.46	-	-

APPENDIX 3. SEDIMENT IGNITION ANALYSES

Ignition data for the Glenora-B core: sediment density (g·cm^{-3}) and percent water content, loss on ignition (organic matter), loss on combustion, and mineral content.

Sample median (cm)	Sediment density (g· cm^{-3})	Water content %	Loss on ignition %	Loss on combustion %	Mineral content %
0.5	0.07934	92.3	22.1	3.9	74.0
1.5	0.10732	89.6	22.8	3.6	73.6
2.5	0.09228	91.1	22.2	3.7	74.1
3.5	0.09782	90.2	21.2	4.2	74.6
4.5	0.09613	90.4	21.4	4.2	74.4
5.5	0.12156	88.2	21.4	3.8	74.8
6.5	0.13781	86.2	20.3	4.3	75.4
7.5	0.12239	87.6	19.9	4.3	75.8
8.5	0.13308	86.6	19.5	4.2	76.3
9.5	0.14659	85.9	18.9	4.2	76.9
11.5	0.16723	84.0	18.2	3.9	77.9
13.5	0.17719	81.9	17.1	4.0	78.8
15.5	0.20212	80.7	16.9	4.0	79.1
17.5	0.20491	80.6	16.6	3.7	79.7
19.5	0.22709	79.0	15.8	3.8	80.4
21.5	0.21869	79.5	15.7	3.2	81.1
25.5	0.25121	76.7	14.3	2.2	83.5
29.5	0.27658	74.0	12.2	2.8	85.0
33.5	0.24473	76.4	12.6	2.6	84.8
37.5	0.24928	77.6	14.2	2.3	83.5
41.5	0.48006	60.6	8.0	1.5	90.5
45.5	0.16932	83.0	22.8	3.8	73.4
49.5	0.20680	80.4	23.3	3.7	73.0
54.5	0.21283	79.7	21.9	3.9	74.2
59.5	0.22954	78.2	21.6	3.8	74.6
64.5	0.19431	81.0	21.2	4.3	74.4
69.5	0.22148	78.6	26.3	2.9	70.8
74.5	0.19168	81.5	27.2	3.2	69.6
79.5	0.21731	79.0	26.0	3.2	70.8
84.5	0.21272	79.0	27.0	2.9	70.1
89.5	0.21023	80.1	26.1	3.3	70.6
94.5	0.21715	79.3	26.6	3.0	70.4
99.5	0.22229	79.1	25.0	3.2	71.9
104.5	0.24851	76.7	23.0	2.6	74.4
109.5	0.21826	79.0	24.8	3.0	72.2
114.5	0.22689	78.0	23.9	3.1	73.0
119.5	0.22087	78.4	23.8	2.8	73.3
124.5	0.22824	78.4	23.6	3.1	73.3
129.5	0.21425	79.2	23.1	3.2	73.7
134.5	0.20511	80.0	23.1	3.0	73.9
139.5	0.30267	71.0	43.4	2.2	54.4
144.5	0.22325	78.6	22.4	2.7	74.9
149.5	0.24184	77.0	22.7	3.0	74.3
154.5	0.22550	77.0	22.5	3.0	74.5
159.5	0.26604	75.7	22.0	3.1	74.9
163.5	0.26900	74.8	22.7	3.1	74.2

APPENDIX 4. NUMBERS OF TAXA AND SPECIMENS IN MAJOR CHIRONOMIDAE GROUPS

Number of taxa (S), average number of specimens per sample (n), and average number of specimens per cm^3 for the major Chironomidae groupings at each interval sampled (stated as a function of sediment depth).

	Sample median (*cm*)															
	0.5	4.5	9.5	14.5	19.5	24.5	29.5	34.5	39.5	44.5	49.5	64.5	89.5	114.5	139.5	163.5
CHIRONOMINAE																
CHIRONOMINI																
Number of taxa	7	17	13	14	15	17	14	16	19	25	25	25	28	29	25	25
Average number specimens per sample	6.6	20.8	14.8	16.3	11.4	23.1	12.6	17.4	20.8	67.6	57.4	70.2	87.4	120.6	87.0	90.1
Average number specimens per cm^3 sediment	2.2	6.9	4.9	5.4	3.8	7.7	4.2	5.8	7.0	22.6	19.3	23.5	29.3	40.3	29.1	30.0
TANYTARSINI																
Number of taxa	5	7	7	6	7	9	9	8	9	10	11	11	11	11	11	12
Average number specimens per sample	5.4	13.9	16.1	28.9	30.8	103.7	108.0	93.2	65.2	82.6	62.7	89.2	90.6	124.9	98.6	96.5
Average number specimens per cm^3 sediment	1.8	4.6	5.4	9.8	10.6	35.2	36.6	32.5	22.4	28.2	21.5	30.1	30.6	42.5	34.1	33.0
ORTHOCLADIINAE																
Number of taxa	4	10	7	11	13	16	11	13	24	31	37	39	35	45	32	32
Average number specimens per sample	0.7	1.6	1.7	2.4	4.7	13.5	14.9	7.5	13.7	27.1	28.4	35.7	36.1	60.7	36.9	38.9
Average number specimens per cm^3 sediment	0.2	0.6	0.7	0.8	1.6	4.7	5.1	2.6	4.7	9.3	9.7	12.1	12.6	20.3	12.4	13.2
PRODIAMESINAE & DIAMESINAE																
Number of taxa	–	–	–	–	–	–	–	–	1	2	1	1	1	–	2	2
Average number specimens per sample	–	–	–	–	–	–	–	–	0.2	0.5	0.2	0.1	0.2	–	0.5	0.9
Average number specimens per cm^3 sediment	–	–	–	–	–	–	–	–	0.1	0.2	0.1	< 0.1	0.1	–	0.2	0.3
TANYPODINAE																
Number of taxa	2	7	6	9	6	9	10	8	12	17	15	12	14	15	13	17
Average number specimens per sample	1.0	4.0	2.3	4.3	3.3	8.0	8.2	7.7	9.0	40.7	34.7	42.2	59.7	62.0	56.0	48.5
Average number specimens per cm^3 sediment	0.3	1.3	0.8	1.4	1.1	2.7	2.7	2.6	3.0	13.6	11.6	14.1	19.9	20.7	18.7	16.2

APPENDIX 5. PERCENTAGE COMPOSITION OF MAJOR CHIRONOMIDAE GROUPS

Percentage composition (100p) of major Chironomidae groupings and their 95% confidence limits (lower and upper) for each interval sampled (stated as a function of sediment depth). Confidence limits and nomenclature according to Mosimann (1965).

	Sample median (*cm*)															
	0.5	4.5	9.5	14.5	19.5	24.5	29.5	34.5	39.5	44.5	49.5	64.5	89.5	114.5	139.5	163.5
CHIRONOMINAE																
CHIRONOMINI																
lower	35.53	45.69	35.19	26.51	18.04	12.68	6.70	10.66	15.46	27.68	27.86	26.97	29.00	30.23	28.18	29.73
100 p	48.18	51.50	41.59	31.02	22.33	15.33	8.73	13.31	18.81	30.63	31.08	29.48	31.67	32.57	30.80	32.42
upper	61.06	57.27	48.29	35.93	27.30	18.42	11.30	16.49	22.70	33.74	34.49	32.12	34.47	35.00	33.55	35.23
TANYTARSINI																
lower	27.31	29.05	39.25	50.94	56.28	66.24	71.60	70.91	55.64	35.04	31.30	35.05	30.36	31.98	33.35	32.85
100 p	39.09	34.34	45.79	56.05	61.81	70.01	75.26	74.81	60.25	38.18	34.63	37.75	33.06	34.35	36.10	35.61
upper	52.29	40.05	52.48	61.04	67.05	73.53	78.59	78.34	64.68	41.42	38.11	40.53	35.88	36.80	38.94	38.47
ORTHOCLADIINAE																
lower	1.87	2.45	3.58	3.01	6.62	7.29	8.29	4.22	9.88	10.56	13.12	13.19	11.76	14.59	11.31	12.28
100 p	5.45	4.25	6.07	4.76	9.39	9.36	10.53	5.94	12.65	12.58	15.54	15.11	13.65	16.39	13.15	14.21
upper	14.85	7.28	10.11	7.44	13.16	11.95	13.28	8.31	16.06	14.93	18.31	17.25	15.80	18.36	15.24	16.39
PRODIAMESINAE & DIAMESINAE																
lower	–	–	–	–	–	–	–	–	0.04	0.06	0.02	< 0.01	0.02	–	0.05	0.11
100 p	–	–	–	–	–	–	–	–	0.23	0.22	0.13	0.04	0.09	–	0.18	0.31
upper	–	–	–	–	–	–	–	–	1.27	0.81	0.75	0.40	0.51	–	0.65	0.85
TANYPODINAE																
lower	2.87	6.95	3.94	5.78	4.23	3.78	3.91	4.22	5.88	15.98	15.99	15.57	19.21	14.88	17.55	15.33
100 p	7.28	9.91	6.55	8.17	6.47	5.30	5.48	5.94	8.06	18.39	18.62	17.62	21.53	16.69	19.77	17.45
upper	17.27	13.95	10.69	11.42	9.78	7.39	7.63	8.31	10.96	21.07	21.57	19.88	24.04	18.67	22.19	19.79

APPENDIX 6. CHIRONOMIDAE FAUNA DISTRIBUTIONS

Total rated numbers of specimens from intervals sampled in the Glenora-B core sediments.

	Sample median (*cm*)															
	0.5	4.5	9.5	14.5	19.5	24.5	29.5	34.5	39.5	44.5	49.5	64.5	89.5	114.5	139.5	163.5
CHIRONOMINI																
Chironomus	16.5	85.0	53.5	65.5	37.5	34.0	16.0	24.5	17.5	88.5	60.0	92.0	35.5	90.5	55.5	68.5
Dicrotendipes	4.0	19.5	8.5	7.5	5.5	17.5	9.0	20.0	19.0	22.5	18.5	41.5	61.0	52.5	41.0	54.0
Microtendipes	1.0	10.0	3.0	7.5	4.5	9.5	4.0	0.5	3.0	9.5	13.0	15.0	31.0	38.5	15.5	26.5
Gen. nr. *Microtendipes* sp. *1*	–	–	–	–	–	–	–	–	1.0	–	1.0	1.0	2.0	4.0	3.5	2.0
Gen. nr. *Microtendipes* sp. *2*	–	–	–	–	–	–	–	–	–	1.0	–	–	–	–	–	–
Paratendipes	2.0	3.0	1.0	4.0	5.0	8.0	2.5	3.0	5.0	10.5	8.0	7.0	4.0	9.0	10.0	12.0
Polypedilum (Polypedilum) convictum (Walk.), or *obtusum* Town.	–	–	–	–	1.0	1.0	–	–	–	–	1.0	–	2.0	2.0	–	–
P. (Polypedilum) fallax gr.	–	1.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–
P. (Polypedilum) cf. *aviceps* Town.	–	–	–	–	–	–	–	–	–	3.0	4.0	3.5	4.0	11.0	6.0	–
P. (Polypedilum) cf. *ophioides* Town.	–	–	–	1.0	1.0	1.0	–	2.0	–	11.0	–	–	–	–	–	–
P. (Pentapedilum) cf. *sordens* v.d. Wulp	–	–	–	–	–	–	–	–	–	0.5	0.5	–	2.0	1.5	0.5	1.0
P. (Pentapedilum) cf. *tritum* (Walk.)	–	–	–	–	–	–	–	–	–	–	1.0	2.0	4.0	3.0	3.0	4.0
P. (Tripodura) simulans Town., *halterale* (Coq.), or *digitifer* Town.	–	2.0	2.5	6.5	–	4.5	1.0	5.0	12.5	58.5	51.5	76.0	83.0	115.5	90.5	86.5
P. (Tripodura) scalaenum (Schrank), *parascalaenum* Beck, or *albinodus* Town.	–	–	–	–	–	–	–	–	–	–	–	–	–	2.0	–	–
Glyptotendipes	1.0	2.5	5.0	3.5	1.0	1.5	3.5	2.0	0.5	–	1.0	4.0	2.0	6.5	–	–
Cryptochironomus	–	2.0	–	1.0	0.5	4.5	1.0	1.0	4.0	7.0	8.0	13.0	12.0	12.5	6.5	9.5
Parachironomus sp. *1*	–	–	3.0	2.0	2.0	3.0	3.0	0.5	2.0	5.5	11.0	13.0	12.5	18.0	13.5	9.0
Parachironomus sp. *2*	–	–	–	–	–	–	–	–	–	–	–	–	1.0	–	–	0.5
Parachironomus ? sp.	–	3.0	6.0	8.0	4.0	–	2.0	1.5	1.0	–	–	4.0	–	1.0	4.0	2.0
Cladopelma	–	5.0	1.5	–	1.0	1.0	–	–	4.0	12.5	21.5	30.5	29.5	37.5	32.0	30.0
Harnischia curtilamellata (Mall.)	–	–	–	–	1.0	3.0	4.0	3.0	3.5	2.0	1.0	4.0	5.5	2.0	3.5	4.0
Harnischia sp. *1*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0
Pseudochironomus	–	–	–	0.5	–	1.0	–	1.0	0.5	8.0	4.5	9.0	10.5	11.5	13.5	10.5
Endochironomus	–	5.5	2.5	4.0	2.5	0.5	1.5	1.5	0.5	–	–	–	0.5	0.5	1.0	–
Phaenopsectra sp. *1*	–	1.0	1.0	2.0	–	–	1.0	–	1.5	2.0	3.5	6.5	5.0	6.5	6.5	7.0
P. ("Phaenopsectra") sp. *2*	–	–	–	–	–	–	–	–	–	3.0	2.0	1.0	–	1.0	–	–
Stictochironomus	–	–	–	–	–	–	–	1.0	1.0	1.0	–	1.0	1.0	–	–	–
Tribelos	–	–	–	–	–	–	–	–	–	–	–	–	2.0	–	–	–
Cryptotendipes	–	2.0	–	–	–	1.0	–	2.0	2.0	8.5	3.0	6.0	11.0	21.5	10.0	6.5
Paralauterborniella nigrohalteralis (Mall.)	1.0	–	–	–	–	0.5	–	–	4.0	4.0	6.0	3.0	6.5	4.5	5.0	3.0
Lauterborniella	–	1.0	–	–	1.0	–	–	–	–	6.0	4.0	10.5	12.5	19.0	14.0	14.0
Xenochironomus (Xenochironomus) xenolabis (Kieff.)	–	1.0	–	–	–	–	–	–	–	1.0	3.0	4.5	3.5	2.0	6.0	1.5
X. (Xenochironomus) sp. *1*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0	–
Pagastiella cf. *ostansa* (Webb)	–	–	–	–	–	–	–	–	–	2.0	–	1.0	3.0	5.0	2.0	1.0
Einfeldia insolita gr. sp. *1*	1.0	1.0	1.0	–	–	–	–	–	–	1.0	1.0	–	–	–	2.0	–

APPENDIX 6 *(continued)* Total rated numbers of specimens from intervals sampled in the Glenora-B core sediments.

	Sample median (*cm*)															
	0.5	4.5	9.5	14.5	19.5	24.5	29.5	34.5	39.5	44.5	49.5	64.5	89.5	114.5	139.5	163.5
E. insolita gr. sp. *2*	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0	–	2.0
E. pagana gr. sp. *1*	–	1.0	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–
Paracladopelma galaptera (Town.)	–	–	–	–	–	1.0	–	–	–	–	–	–	–	–	–	–
Saetheria tylus (Town.)	–	–	–	–	–	–	1.0	–	–	–	–	–	–	–	–	–
Beckiella tethys (Town.)	–	–	–	–	–	–	–	1.0	–	–	–	–	–	–	–	–
Demicryptochironomus	–	–	–	–	1.0	–	–	–	–	–	–	–	–	1.0	–	2.0
Kiefferulus	–	–	–	1.0	–	–	–	–	–	–	–	–	–	–	–	–
Stenochironomus	–	–	–	–	–	–	–	–	–	1.0	1.0	1.0	1.0	–	–	–
Chironomini unknown sp. *1*	–	–	–	–	–	–	1.0	–	1.0	1.0	1.5	2.0	2.0	2.0	2.0	2.5
Chironomini unidentified	–	–	–	–	0.5	–	0.5	–	0.5	1.0	1.5	1.0	2.0	1.5	1.0	–
TANYTARSINI																
Constempellina	–	–	–	1.0	2.0	3.5	3.0	2.0	4.0	10.0	11.0	30.0	37.5	44.5	30.5	27.5
Stempellinella	–	1.0	1.0	–	1.5	4.5	6.0	7.0	12.5	12.0	7.5	12.0	12.5	26.5	12.5	19.5
Stempellina	–	0.5	0.5	–	–	1.0	2.0	2.0	1.5	6.0	5.0	3.0	1.5	5.5	1.5	1.0
Micropsectra	1.0	6.5	3.0	–	16.0	51.5	53.0	95.5	74.0	46.0	13.0	21.0	20.5	41.0	50.5	41.0
Tanytarsini type 1	3.0	7.0	14.5	16.5	13.5	44.5	42.5	36.0	16.5	97.5	77.5	158.5	97.5	160.5	157.5	156.5
Tanytarsini type 2	1.0	1.0	1.0	5.0	4.5	1.5	2.5	–	2.0	4.0	0.5	3.0	4.5	4.0	7.5	6.5
Tanytarsini type 3	4.0	9.0	4.5	10.5	3.0	16.0	19.0	23.5	14.5	48.0	27.5	48.5	37.0	44.0	29.5	42.0
Tanytarsini type 4	–	–	–	1.0	–	2.0	2.0	1.0	7.0	13.0	9.5	10.0	7.0	18.0	16.0	10.5
Tanytarsini type 5	–	–	–	–	–	–	–	–	–	–	2.0	–	1.0	2.0	1.0	1.0
Tanytarsini type 6	–	–	–	–	–	–	–	–	–	3.0	1.0	3.0	5.0	8.0	5.0	2.0
Tanytarsini type 7	12.5	72.0	72.0	168.5	144.5	290.5	302.0	206.0	129.0	91.0	96.5	156.0	138.5	145.5	83.0	77.5
Tanytarsini type 8	–	–	–	–	–	–	–	–	–	–	–	1.0	–	–	–	1.0
Tanytarsini type unidentified	–	–	1.5	3.5	6.0	7.5	7.5	17.5	8.0	8.0	7.5	6.0	4.5	11.0	14.5	10.0
ORTHOCLADIINAE																
Heterotrissocladius changi Sæth.	–	0.5	0.5	–	2.5	13.5	11.5	10.0	7.0	6.0	2.0	5.5	5.0	9.0	10.0	4.5
Heterotrissocladius sp. *B* Sæth.	–	–	–	–	–	–	–	–	1.0	–	1.0	–	–	–	–	–
Gen. nr. *Heterotrissocladius*	–	–	–	1.0	5.5	9.5	30.0	5.5	14.5	12.0	14.5	18.5	20.0	21.5	20.5	16.5
Parakiefferiella cf. *bathyphila* Kieff.	–	–	–	–	–	–	–	–	1.0	0.5	2.0	5.0	2.5	6.5	5.0	–
Parakiefferiella sp. *1*	–	1.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Parakiefferiella sp. *2*	–	1.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Parakiefferiella sp. *3*	–	–	–	–	–	–	–	–	1.0	1.0	1.0	–	1.0	2.0	1.0	–
Psectrocladius cf. *septentrionalis* Chern.	–	–	–	–	–	–	–	–	–	–	1.0	–	–	–	–	–
P. (Psectrocladius) type *1*	–	–	–	–	–	–	–	1.0	–	–	2.0	1.0	1.5	3.0	2.5	1.0
P. (Psectrocladius) type *2*	–	3.0	2.0	–	0.5	1.0	0.5	2.5	1.5	6.0	7.0	9.0	10.5	23.0	8.0	7.5
P. (Psectrocladius) type 3	–	–	–	–	3.0	1.0	3.0	1.5	–	5.0	4.5	7.0	7.5	8.5	2.5	8.0
P (Allopsectrocladius) sp.	–	–	–	–	–	–	–	–	–	–	–	1.0	–	–	–	–
Eukiefferiella fuldensis type	–	–	–	–	–	–	–	–	–	–	–	1.0	2.5	1.0	–	1.0
E. similis type	–	–	–	–	–	–	–	–	–	1.5	2.0	4.5	2.5	4.0	4.5	5.5
E. claripennis type	–	–	–	–	–	–	–	–	–	0.5	1.0	0.5	1.0	3.0	1.0	3.0

APPENDIX 6 *(continued)* Total rated numbers of specimens from intervals sampled in the Glenora-B core sediments.

	Sample median (*cm*)															
	0.5	4.5	9.5	14.5	19.5	24.5	29.5	34.5	39.5	44.5	49.5	64.5	89.5	114.5	139.5	163.5
E. coerulescens type	–	–	–	–	–	1.0	–	–	1.0	–	–	–	–	–	–	–
Brillia longifurca type	–	2.0	–	3.0	2.0	3.5	–	1.0	8.5	17.0	13.0	27.0	16.0	33.0	12.0	28.0
Synorthocladius semivirens Kieff.	–	0.5	–	1.0	–	–	–	0.5	1.0	12.0	11.0	21.0	15.5	21.0	9.0	13.0
Corynoneura sp. *1*	–	–	–	1.0	1.0	3.0	–	1.0	2.0	14.0	10.0	12.0	11.0	23.0	14.0	9.0
Corynoneura sp. *2*	1.0	1.0	4.0	4.0	9.0	9.0	6.0	3.0	4.0	6.0	12.0	10.0	7.0	14.0	9.0	4.0
Corynoneura sp. *3*	–	–	–	–	–	–	1.0	–	–	1.0	3.0	4.0	2.0	5.0	4.0	1.0
Corynoneura sp. *4*	–	–	–	–	–	1.0	–	–	2.0	1.0	1.0	–	3.0	6.0	2.0	3.0
Corynoneura sp. *5*	–	–	–	–	–	–	–	–	–	2.0	3.0	4.0	3.0	3.0	5.0	3.0
Hydrobaenus spp.	0.5	0.5	1.0	0.5	–	1.0	1.0	1.0	–	1.0	1.0	5.5	3.5	5.0	3.0	4.5
Zalutschia cf. *lingulata* Sæth.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2.0
Limnophyes sp.	–	–	–	–	1.0	1.0	–	1.0	1.0	–	1.0	1.5	1.0	–	–	–
Tokunagaia sp.	–	–	–	–	0.5	–	–	–	0.5	–	–	1.0	0.5	2.0	1.0	–
Epoicocladius flavens (Mall.)	–	–	–	–	–	–	–	–	2.0	1.0	–	0.5	–	–	1.0	–
Cricotopus (Cricotopus) cf. *tibialis* (Meig.)	–	–	–	–	–	–	–	–	–	–	–	–	1.0	–	0.5	1.0
C. (Cricotopus) cf. *fuscus* (Kieff.)	–	–	–	–	–	–	–	–	–	–	–	1.0	–	–	–	–
C. (Cricotopus) cf. *algarum* (Kieff.)	–	–	–	–	–	–	–	–	–	–	–	–	–	2.0	2.5	1.5
C. (Cricotopus) cf. *pirifer* Hirv.	–	–	–	–	–	–	–	–	0.5	1.5	0.5	–	–	3.0	–	–
C. (Cricotopus) cf. *tremulus* (L.)	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0	–	1.0
C. (Cricotopus) cf. *slossonae* Mall.	–	–	–	–	–	–	–	–	–	0.5	0.5	2.5	3.5	3.0	–	–
C. (Cricotopus) cf. *annulator* Goetgh.	–	–	–	–	–	–	–	–	–	0.5	0.5	3.0	–	0.5	3.5	2.5
C. (Cricotopus) cf. *triannulatus* (Macq.)	–	1.0	–	1.5	0.5	2.5	–	–	2.0	4.0	0.5	–	–	4.0	–	–
C. (Cricotopus) cf. *cylindraceus* (Kieff.)	–	–	–	–	–	–	–	–	–	1.5	1.5	6.0	7.0	2.0	5.5	4.0
C. (Cricotopus) cf. *patens* Hirv.	–	–	–	–	1.0	2.5	–	–	0.5	1.0	0.5	2.0	–	–	–	–
C. (Cricotopus) nr. *patens* Hirv.	–	–	–	–	–	–	–	–	–	1.0	2.5	1.0	0.5	2.0	2.0	5.0
C. (Cricotopus) cf. *flavocinctus* (Kieff.)	–	–	–	–	–	–	–	–	–	–	–	2.0	3.5	2.0	3.5	5.0
C. (Cricotopus) cf. *albiforceps* (Kieff.)	–	–	–	–	–	2.0	1.0	–	0.5	2.5	1.0	–	–	1.0	2.0	–
C. (Cricotopus) bicinctus (Meig.)	–	–	–	–	0.5	–	–	1.0	0.5	1.0	1.5	3.0	–	1.0	–	–
C. (Cricotopus) cf. *vierriensis* Goetgh.	–	–	–	–	–	–	–	–	–	–	–	–	–	3.0	–	–
C. (Cricotopus) nr. *vierriensis* Goetgh.	1.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
C. (Cricotopus) spp. unidentified	–	–	–	–	–	–	–	–	–	–	–	1.0	–	–	–	–
Cricotopus (Isocladius) sp. *1*	–	–	–	–	–	–	–	1.0	–	–	–	–	–	–	–	–
C. (Isocladius) sp. *2*	–	–	–	1.5	–	–	–	–	–	–	–	–	–	–	–	–
C. (Isocladius) sp. *3*	–	–	1.0	–	–	–	3.5	–	–	–	1.5	1.5	–	–	–	–
C. (Isocladius) sp. *4*	–	–	–	–	–	–	–	–	–	–	–	1.0	–	–	–	–
C. (Isocladius) sp. *5*	–	–	–	–	–	–	–	–	–	–	1.0	–	1.5	–	–	–
C. (Isocladius) sp. *6*	–	–	–	–	–	–	–	–	–	–	1.0	–	–	0.5	–	–
C. (Isocladius) sp. *7*	–	–	–	–	–	–	–	–	–	–	–	1.0	2.0	–	–	1.5
C. (Isocladius) sp. *8*	–	–	–	–	–	–	–	–	–	–	–	1.0	–	–	–	–
Paraphaenocladius sp.	–	–	–	1.0	–	–	–	–	0.5	–	1.0	–	–	2.0	–	–
Nanocladius (Nanocladius) cf. *distinctus* (Mall.)	–	–	–	–	–	–	–	–	–	–	–	–	0.5	0.5	–	0.5
N. (Nanocladius) cf. *balticus* (Palm.)	–	–	–	–	–	–	–	–	1.0	–	–	–	–	–	–	–
N. (Nanocladius) cf. *incomptus* Sæth.	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0	–	–

APPENDIX 6 *(continued)* Total rated numbers of specimens from intervals sampled in the Glenora-B core sediments.

	Sample median (*cm*)															
	0.5	4.5	9.5	14.5	19.5	24.5	29.5	34.5	39.5	44.5	49.5	64.5	89.5	114.5	139.5	163.5
Abiskomyia sp.	–	–	–	–	–	–	–	–	1.0	–	–	–	–	1.0	–	–
Metriocnemus sp.	–	–	–	–	–	1.0	–	–	–	–	–	–	–	–	–	–
"*Paracladius*" cf. *triquetra* Chern.	–	–	–	–	–	–	–	–	–	2.0	–	–	–	–	–	–
cf. *Paracladius* sp.	–	–	–	–	–	–	–	–	–	0.5	–	–	1.0	0.5	–	–
cf. *Smittia* sp.	0.5	–	–	1.0	–	–	–	–	0.5	1.5	1.5	–	–	–	–	–
Smittia ? sp.	–	–	–	–	–	–	–	–	–	–	–	0.5	1.0	–	1.0	–
Pseudosmittia cf. *gracilis* Goetgh.	–	–	–	–	–	–	1.0	–	–	–	–	–	–	–	–	–
Pseudosmittia ? sp.	–	–	–	–	–	–	–	–	–	–	–	–	0.5	1.0	0.5	0.5
cf. *Chaetocladius* sp.	–	–	–	1.0	–	1.5	–	–	–	–	–	–	–	–	–	–
Gen. nr. *Paracricotopus*	–	–	–	–	–	–	–	–	–	–	1.0	2.0	1.0	3.0	5.5	3.0
Orthocladius spp.	–	1.0	1.0	–	1.5	–	1.0	–	–	3.0	3.5	6.5	5.0	9.0	2.0	10.5
Orthocladius sp. *1*	–	–	–	–	–	–	–	–	–	–	–	2.0	1.0	1.0	1.0	3.0
Orthocladius sp. *2*	–	–	–	–	–	–	–	–	–	–	–	–	–	2.5	–	1.0
Orthocladius sp. *3*	–	–	–	–	–	–	–	–	–	–	–	1.0	–	1.0	–	–
Orthocladius sp. *4*	–	–	–	–	–	–	–	–	–	–	1.0	1.0	1.0	1.0	3.0	–
O. (Euorthocladius) sp.	–	–	–	–	–	–	–	–	–	1.0	–	–	–	1.0	–	–
cf. *Orthocladius* sp. *1*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0
cf. *Orthocladius* sp. *2*	–	–	1.0	–	–	–	–	–	–	–	–	–	–	–	–	–
Orthocladiinae unidentified	–	0.5	2.5	1.0	0.5	2.5	2.0	1.0	1.5	2.5	2.5	2.5	5.0	0.5	1.5	2.5
TANYPODINAE																
Apsectrotanypus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0
Thienemannimyia gr. sp. *3*	–	–	–	–	–	–	–	–	–	–	1.0	–	1.0	1.0	–	–
Coelotanypus	–	–	–	–	–	–	–	–	–	1.0	–	–	2.0	1.0	–	1.0
Tanypus cf. *neopunctipennis* Subl.	–	–	–	–	–	–	–	–	–	3.0	1.0	–	–	–	1.0	2.0
Tanypodinae sp. *3*	–	–	–	–	–	–	–	–	–	1.0	–	–	–	–	–	–
Thienemannimyia gr. sp. *2*	–	–	–	–	–	–	–	–	1.0	3.0	6.0	10.0	12.0	7.0	9.0	5.0
Tanypodinae spp.	–	–	–	–	–	–	–	–	2.0	23.0	21.0	28.0	44.0	19.0	31.0	18.0
Procladius (abnormal) sp. *1*	–	–	–	–	–	–	–	–	1.0	–	–	–	–	–	–	–
Tanypodinae sp. *2*	–	–	–	–	–	1.0	–	–	–	1.0	1.0	–	–	–	–	1.0
Thienemannimyia gr. sp. *1*	–	–	–	1.0	–	–	–	–	–	–	1.0	–	–	1.0	3.0	–
Zavrelimyia sp.	–	–	–	1.0	1.0	–	–	–	–	1.0	1.0	–	1.0	–	–	3.0
Tanypodinae sp. *1*	–	–	–	1.0	–	–	1.0	–	1.0	1.0	1.0	3.0	1.0	5.0	2.0	2.0
Ablabesmyia (Karelia) peleensis (Wall.)	–	–	–	1.0	1.0	7.0	6.0	1.0	4.0	32.0	40.0	45.0	62.0	61.0	35.0	35.0
Procladius (abnormal) sp. *2*	–	–	1.0	–	–	–	–	–	–	–	–	–	–	–	–	–
Labrundinia cf. *pilosella* (Loew)	–	1.0	–	–	–	1.0	1.0	1.0	–	19.0	16.0	28.0	22.0	35.0	28.0	24.0
Procladius (Procladius) cf. *culiciformis* (L.)	–	3.0	–	–	3.0	4.0	2.0	7.0	3.0	1.0	1.0	3.0	5.0	4.0	1.0	3.0
P. (Procladius) cf. *freemani* Subl.	–	4.0	2.0	1.0	2.0	2.0	3.0	2.0	4.0	2.0	1.0	3.0	1.0	2.0	–	4.0
P. (Procladius) cf. *denticulatus* Subl.	–	4.0	1.0	2.0	–	2.0	3.0	3.0	2.0	5.0	–	2.0	6.0	1.0	4.0	1.0
Procladius (Psilotanypus) cf. *bellus* (Loew)	2.0	7.0	4.0	6.0	–	1.0	3.0	3.0	1.0	15.0	8.0	12.0	8.0	9.0	14.0	14.0
Procladius (immatures)	2.0	8.0	5.0	14.0	9.0	5.0	7.0	8.0	12.0	40.0	26.0	65.0	59.0	80.0	67.0	67.0
cf. *Procladius* (immatures)	–	1.0	1.0	3.0	4.0	9.0	4.0	6.0	4.0	10.0	14.0	10.0	15.0	20.0	24.0	10.0
cf. *Procladius (Psilotanypus) bellus* (Loew)	–	–	–	–	–	–	2.0	–	1.0	5.0	–	2.0	–	2.0	5.0	3.0

APPENDIX 6 *(continued)* Total rated numbers of specimens from intervals sampled in the Glenora-B core sediments.

	Sample median (*cm*)															
	0.5	4.5	9.5	14.5	19.5	24.5	29.5	34.5	39.5	44.5	49.5	64.5	89.5	114.5	139.5	163.5
PRODIAMESINAE & DIAMESINAE																
Monodiamesa depectinata Sæth.	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	–	–
Potthastia longimanus Kieff.	–	–	–	–	–	–	–	–	1.0	–	1.0	–	–	–	1.0	2.5
Diamesa sp. *1*	–	–	–	–	–	–	–	–	–	1.0	–	–	–	–	–	–
Diamesa sp. *2*	–	–	–	–	–	–	–	–	–	1.0	–	–	–	–	–	1.0
Diamesa sp. *3*	–	–	–	–	–	–	–	–	–	–	–	–	1.0	–	1.0	–

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