



HAL
open science

Chironomids (Diptera) in river floodplains: their status and potential use for palaeoenvironmental reconstruction purposes

Emmanuel Gandouin, Evelyne Franquet, Brigitte van Vliet-Lanoë

► To cite this version:

Emmanuel Gandouin, Evelyne Franquet, Brigitte van Vliet-Lanoë. Chironomids (Diptera) in river floodplains: their status and potential use for palaeoenvironmental reconstruction purposes. *Archiv fur Hydrobiologie*, 2005, 162 (4), pp.511-534. <10.1127/0003-9136/2005/0162-0511>. <hal-02958930>

HAL Id: hal-02958930

<https://hal.science/hal-02958930v1>

Submitted on 7 Oct 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

GANDOUIN E., E. FRANQUET, & B. Van VLIET-LANOE
2005. Chironomids (Diptera) in River Floodplains: their Status and Potential Use for Palaeoenvironmental Reconstruction Purposes. *Archiv für Hydrobiologie* 162: 511-534.

Abstract: The chironomid subfossils from a single sediment core in the floodplain of the Aa river (Saint-Omer basin, Northern France) were analysed. This study was a pioneering attempt to use sedimentary chironomid assemblages and lithostratigraphic analysis to reconstruct the palaeoenvironment and the past hydrodynamic conditions in a river system during the mid-Holocene period. In this paper, a chironomid subfossil typology is proposed, based on the current scientific knowledge about the present distribution of chironomid species through the cross-section of a floodplain (from lotic to more lentic habitats). A hydrological status is attributed to 27 subfossil chironomid taxa (limnophilous taxa and rheophilous taxa) from the Saint-Omer sediment sample. Based on these chironomid hydrological statuses and in regard with the lithostratigraphic data, the dynamics of chironomid subfossil assemblages showed the occurrence of some fluctuations between periods with lower (lentic periods SMch-1, SMch-3 and SMch-5) and higher (lotic periods SMch-2 and SMch-4) Aa river discharge rates during the Late-Atlantic and Subboreal periods. The lotic periods were correlated with several climatic events known to have occurred during these periods in Europe. Several hypotheses are put forward and discussed, as to the potential relationships between the levels of precipitation and the hydrological conditions in the Saint-Omer basin. Although chironomid analysis in river systems is still in its developmental phase, the conclusions drawn from the present findings on subfossil chironomids show that these can provide a useful tool for palaeoenvironmental reconstruction purposes.

Introduction

Many palaeoecological studies designed to reconstruct the climatic history of continental regions are focusing on the composition of lake sediments. These sediments are often sampled in mountain lakes with small drainage basins, where relatively few anthropic disturbances or physical constraints (e. g. geomorphologic forcing, hydrological variability, tectonic movement) occur. However, studying only these sediment records may lead to underestimating the physical constraints exerted by the habitat on biological communities and may distort our picture of palaeoenvironments. It is therefore important to explore methods of studying habitats of other kinds.

Alluvial plains are sedimentary sites which can yield useful palaeoecological information (AMOROS & VAN URK 1989). Most palaeoenvironmental studies of these habitats have focused on ecological restoration aspects (BROWN 2002). The geomorphologic approach has been mainly used to determine past climatic conditions in alluvial plains (e. g. GROSSMAN et al. 2001). It would now be useful to develop biological models which could be used along with the geomorphologic approach.

Among the invertebrate faunal groups colonising aquatic environments in alluvial plains, the Chironomidae (Diptera) play a key role; chironomids colonise habitats of all kinds from the main channels to the most isolated, temporary aquatic environments (WILSON 1980). Chironomids are abundant in freshwater sediments, where they are often the predominant macroinvertebrate taxon. KLINK (1989) has reported, for example, that this group accounts for 90 % of the entire macroinvertebrate population in the Lower Rhine region. Chironomids have been widely used as palaeoecological indicators in lake environments. The latest findings in the field of chironomid ecology and the development of transfer function tools now make it possible to obtain a more accurate picture of palaeo-temperatures (e. g. BROOKS & BIRKS 2000, HEIRI et al. 2003), total phosphorus (LOTTER et al. 1998) and past levels of eutrophication (FRANCIS 2001). Previous studies on palaeo-assemblages of chironomids have been based on the identification of fossil larval head capsules. The chitinous remains of larvae are relatively well preserved in sediment (HOFMANN 1986).

In order to test the use of chironomid analysis in river floodplains, a sedimentary core from the Saint-Omer marsh (downstream floodplain of the Aa river, Northern France) was collected. In the first part of this study, based on the data available so far on the status of chironomid Diptera in river floodplains (FRANQUET 1996, GARCIA & LAVILLE 2001), it was proposed to draw a picture of the palaeoenvironment and hence of the past hydrodynamic conditions pertaining in the Aa river (JUNK et al. 1989, WARD & STANFORD 1995). The structure of habitats and chironomid assemblages depends on the level of connection between the main channel and the various parts of the floodplain,

and hence on the intensity, frequency and duration of the floods. Since a direct relationship has been found to exist between precipitation, river discharge and flood events (AMOROS & PETTS 1993, KIELY 1999, RÎMBU et al. 2002), it may be possible in a subsequent stage to deduce what climatic changes occurred during the period under consideration (VANDENBERGHE 1995). This should enable us to determine whether the use of chironomids is an efficient tool for palaeoecological river reconstruction purposes.

Study site

The Saint-Omer basin, which is also known as the “Audomarois marsh”, is located in the Pas-de-Calais region of Northern France (Fig. 1), in the Aa river catchment. The Saint-Omer basin is subdivided into two asymmetrical parts. The first, upstream part belongs to the Palaeocene formations, which open into the “Sables d’Ostricourt” and the downstream Ypresian clay (second part) typical of Flanders (WATERLOT 1957). On its north-western edge, the basin extends into the chalk and the Palaeocene clay. The basin forms a low platform before joining the marsh itself (which has a peat substratum). The northern edge, on the contrary, forms a steep “cuesta” consisting of Eocene clay. To the south-east, there is a gap of only 30 m between the Aa river catchment and that of the River Lys. The Saint-Omer basin has a single, 1-km wide outlet, near Watten (Fig. 1), consisting of a tectonic alignment of various Cretaceous and Palaeogenic reliefs with a covering layer of Neogenic material. The river slope along the basin is very low, amounting to only around 0.1‰.

The characteristics of this site, including its geographical situation, its subsidence, the topography and the carbonate contents of the catchment basin (giving a eutrophic, productive habitat where problems associated with acidification rarely arise), make it an excellent sediment trap, which is potentially suitable for obtaining long-term sediment records. In Watten, at the downstream end of the basin, a pleniglacial formation possibly attributable to the early Weichselian period has been sampled at a depth of -23 m N. G. F. (“Nivellement Général de la France” which gives the standard zero altitude level) (SOMMÉ et al. 1994).

Because of its very low altitude, the basin served as an estuary during the Calais and Dunkirk transgressions. During the Subboreal period, the functional processes at work in the Saint-Omer system were of the fluvial type (VAN DER WOUDE & ROELVELD 1985). This site was therefore used here to test whether chironomid Diptera might constitute appropriate material for palaeoenvironmental reconstructions.

Material and methods

Field work

Core sampling was carried out in the cultivated Saint-Momelin marsh (Fig. 1). A piston corer with a core diameter of 10 cm was used to perform the extractions. Extending

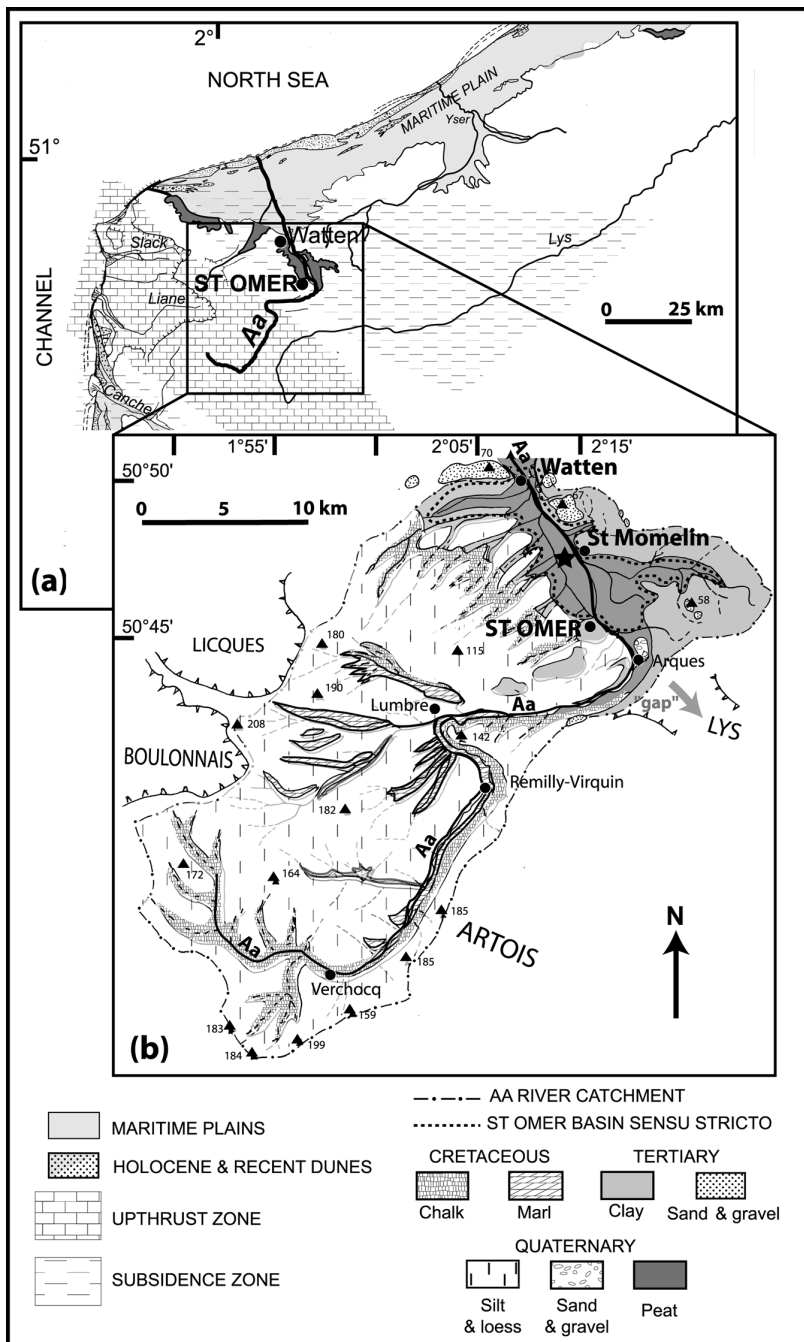


Fig. 1. (a) Location of the Saint Omer basin (North of France). (b) drainage basin of the river Aa and coring site (black star). The Saint-Omer basin sensu stricto is delimited by a dotted line.

from the surface to a depth of 18 m, the Saint-Momelin sequence consisted of one series of thirteen 1-m cores and three shorter ones ranging between 9 m and 12 m in length (from 900 to 968 cm, 1000 to 1080 cm and 1100 to 1140 cm). A lack of sediment was due to the fact that in most cases, the sandy sediment could not be sampled with the piston corer. Only the data obtained on the parts of the cores originating from depths of 605 cm to 1045 cm will therefore be presented in this paper.

Chronology and stratigraphy

Conventional radiocarbon dating of peat samples after acid/alkali/acid washes was used to determine the age of the sediment at 4 points on the Saint-Momelin cores (corresponding to depths of 600–604, 800, 900 and 1025–1030 cm). The calibrated age ranges obtained were based on the INTCAL98 calibration curve, using the intercept method (STUIVER et al. 1998). In order to infer the age of the various regions in the chironomid assemblage diagram, a linear interpolation was used to calculate the sedimentation rates (R_s) between two calibrated radiocarbon dates (obtained on the part of the core analysed).

Nevertheless, this method has some limitations. One of the problems which arises is the discontinuity of the sedimentation, especially during instantaneous events such as strong flooding episodes (e. g. sudden sandy sedimentation occurring just after the rupture of a natural levee). During these lithological changes, it is very unlikely that the sedimentation rates remained constant. This discontinuity probably leads to some uncertainty in the linear interpolated radiocarbon dating. However, this method is the only one available for dating palaeoecological records. Cautiousness will be necessary when making correlations between the chironomid data obtained at Saint-Omer and other palaeoecological events described in the scientific literature. In order to minimize the dating uncertainties, sandy sedimentation (10–13 cm collected at a depth of about 7 m) resulting from occasional flood events was not taken into account in the sedimentation rate calculations.

Chironomid subfossils

Thirty-eight samples of sediment weighing 150 to 500 g were collected at depths ranging from 600 to 1045 cm. Given the low concentrations of chironomid head capsules present in the sediment, it was necessary to use both HOFMANN's (1986) and COOPE's (1986) methods. At sample preparation the sediment was deflocculated in a boiling 10 % KOH solution for 10 minutes. The solution was then sifted through a 100 μ m mesh sieve, and kerosene flotation was then used to concentrate the chironomid subfossils in each sample. The floating fraction was then decanted and removed in a sieve similar to that used previously. The residue was washed with detergent and back-

washed into a beaker in 90 % alcohol, in which it was stored. Head capsules were sorted out with fine tweezers and mounted with resin, ventral side up, on glass slides before being identified under a stereomicroscope at a magnification of 40× and 60×. Whole head capsules and fragments containing more than half of the mentum were counted as one head capsule. Fragments that were exactly half of a head capsule were counted as one half, and all fragments consisting of less than half of the mentum were rejected. A mean number of 78 head capsules per sample were counted (n min = 59 capsules, n max = 121), totalling 2959 head capsules in the 38 samples collected at different depths. QUINLAN & SMOL (2001) have recently stated that counts of 50 head capsules should provide realistic estimates of environmental conditions.

The identification criteria used were based on descriptions by BRYCE (1960), BRYCE & HOBART (1972), CRANSTON (1982), FERRARESE & ROSSARO (1981), RIERADEVALL & BROOKS (2001), ROSSARO (1982), SCHMID (1993), WALKER & BRODERSEN (1997), and WIEDERHOLM (1983). Several unpublished documents and slides from the Natural History Museum of London were also consulted. In most cases, head capsules were identified to the genus level, and in some rare cases, to the species level. It was occasionally necessary to classify the taxa in fairly broad taxonomic categories, because the morphological characteristics of different genera were too similar for more precise identification to be possible (e.g. *Eukiefferiella/Tvetenia*, *Cricotopus/Orthocladius/Paratrichocladius*, *Corynoneura/Thienemanniella* and *Parametriocnemus/Paraphaenocladius*). When the head capsules were damaged, the individuals were classified at the family, sub-family or tribe level, followed by the term “unidentified” (for example, Tanytarsini unidentified).

Chironomid habitat preferences

At present, the Saint-Omer basin is strongly affected by human activities, which makes it difficult to find any habitats with functional fluvial processes. It was impossible to find any modern chironomid assemblages here in order to determine the habitat preferences of the chironomids (chironomid hydrological statuses) on a qualitative gradient across the floodplain. We therefore based our deductions on the hypothesis that the ecology of the chironomids sampled in the Saint-Omer basin is similar to that of the chironomids studied in cross-sections of the Garonne (GARCIA & LAVILLE 2001) and Lower Rhône (FRANQUET 1996) river floodplains. A more general reference work on the ecology of chironomids (WIEDERHOLM 1983) was also used. The chironomid taxa identified at Saint-Omer were sub-divided into the following three ecological categories:

- Taxa associated only with “oxbows or temporarily connected side arms” (lentic habitats);
- Taxa associated only with “the main channel or connected side arms” (lotic habitats);
- The “other chironomids” category includes taxa which could not be exactly identified and taxa with a distribution which is either unknown or not related to the flow rate of the current. This third category did not provide any valuable ecological information, but it was used to compute percentages and to assess the relative weights of the first two categories.

In palaeoecology, chironomid head capsules are usually identified at the genus level. It was therefore necessary in our palaeoecological investigations to assign a genus to one ecological category, by taking the most frequently occurring category among the species of this genus. These required approximations, which might have biased the interpretation of the palaeoecological data if a single genus contained several species with different ecological patterns. In order to minimize any risk of such a bias, we always took care to base conclusions on assemblages of taxa (genera) rather than on one particular taxon (genus). In addition, working on assemblages of taxa yields a second advantage. If the ecology of one taxon may have evolved, it is very unlikely that the ecology of several taxa may have done so in the same way at the same time (according to the “principle of actualism”).

Data analysis

The software program GpalWin (GOEURY 1997) was used to store the data and produce the diagram of the subfossil chironomid communities. Multivariate analyses were carried out using the ADE-4 software program (THIOULOUSE et al. 1997). A cluster analysis of the coordinates obtained from a correspondence analysis (BENZECRI 1973) based on the Euclidean distance and the Wards criteria was performed to highlight the major changes in the chironomid assemblages. With this method, it was possible in the first stage to associate each sample with a particular group of chironomid taxa (one faunal unit). In the second step, taking into account the position of each sample in the core stratigraphy (chronological position), several groups of samples representing temporal zones with a homogeneous faunal content were identified. This method was used successfully in a study by GANDOUIN & FRANQUET (2002) and it seems to be very similar to the Constrained Single Link Method (BIRKS & GORDON 1985). Taxa that accounted for less than 5 % of the total chironomids at all levels were not included in the analyses.

Results

Chronology and stratigraphy

The calibrated radiocarbon ages ranged between 3385 cal. BP and 6840 cal. BP (Table 1). The mean rate of sedimentation observed at depths of between 9 and 6 m ($d = 3$ m) was $10.5\text{--}11$ yrs cm^{-1} . The kinds of sediments most frequently encountered (Fig. 2 a) were of continental types, such as peat sediments (at depths of 964 to 825 cm), charophytic peat sediments (depths 825 to 705 cm and 655 to 600 cm) and gyttja sediments (freshwater mud characterized by abundant organic matter) (depth 690 to 655 cm). The blackish-brown sediments had a spongy appearance. They were often composed of submerged plant debris which were only partly decomposed. The organic sediments also contained leaves, twigs and tree-trunks (depth 690 to 640 cm) in some places. They sometimes contained fine layers of sand (depths 915–905 cm and 700–

Table 1. ^{14}C dates assigned to sediments from Saint-Momelin. The calibrated age ranges were based on the INTCAL98 calibration procedure, using the intercept method (STUIVER et al. 1998). All measurements were performed on bulk sediment with a conventional radiocarbon dating procedure.

Depth (cm)	Laboratory identification code	Material	$^{13}\text{C}/^{12}\text{C}$ ratio	Conventional ^{14}C Age (uncal. BP)	cal. BP	cal. BC
600	Hv - 24814	Peat	-29.7 ‰	3265 ± 70	3565–3385	1615–1435
800	Beta - 161064	Peat	-29.0 ‰	4850 ± 70	5720–5460	3770–3510
900	Beta - 161063	Peat	-30.0 ‰	5830 ± 100	6870–6410	4920–4460
1025	Hv - 24813	Peat	-30.0 ‰	5880 ± 80	6840–6635	4890–4685

710 cm). From 800 to 750 cm depth, a pulsating system with an alternating pattern of variably pale (variably organic) sediment layers was encountered. Lastly, in the basal part of the core, there were layers of other materials such as decanted peat (redeposited organic flotsam) reflecting the occurrence of sediment disturbances (at depths of 1050 to 960 cm) which were not analysed here. Part of this peat, located at depths of 964 to 1000 cm, was lost during the core sampling procedure.

Chironomid distribution

A total number of 85 taxa were identified in the 38 core samples collected (Table 2). The correspondence analysis and the hierarchical classification procedure yielded three groups of taxa (Fig. 3). On the factorial plane F1-F2 (accounting for 28.8 % of the total inertia), the samples collected from depths of 1045 to 805 cm and the 675 cm sample contained group A (faunal unit A), which mainly consisted of the taxa *Tanytarsus* spp., *Chironomus* spp., *Cladotanytarsus mancus* group 1, *Dicrotendipes* spp. and *Procladius choreus*. The samples collected from depths of 795 to 735 cm, 685 cm, 668 to 648 cm, 635 cm and 625 cm contained group B1 (faunal unit B1), which was characterised by *Polypedilum* spp., *Eukiefferiella/Tvetenia*, *Apsectrotanypus trifascipennis* and *Symposiocladius lignicola*. The samples collected from depths of 725 to 705 cm, 642 cm and 615 to 605 cm yielded group B2 (faunal unit B2), which was mainly characterised by *Microtendipes* spp. Based on these three groups of assemblages and their distribution along the depths, the chironomid diagram was subdivided into five successive temporal zones (Fig. 2b), SMch-1 to SMch-5. Each of these temporal zones contained successive samples with similar faunal compositions.

Habitat preferences and dynamics of the Chironomidae assemblages

Fifteen of the 85 taxa identified were assigned to the category of chironomids associated only with oxbows or temporarily connected side arms (lentic habi-

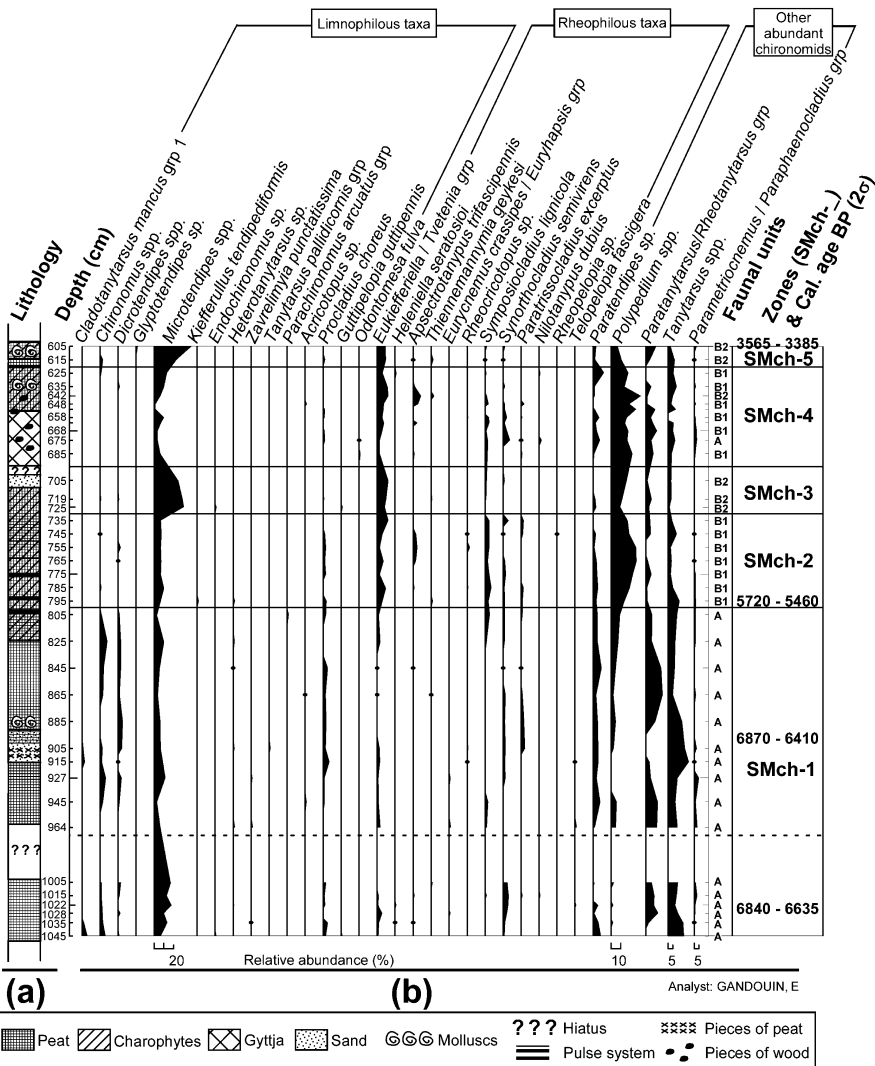


Fig. 2. (a) Core stratigraphy (lithology). (b) Simplified diagram of chironomid assemblages in the Saint-Omer Basin showing relative abundances (%) of chironomid taxa (the dots on the vertical lines indicate < 1% occurrence) versus depth (cm). The faunal units (A, B1 and B2), zones described in the text (SMch-1 to 5) and calibrated age B.P. (2σ) are shown on the right. The diagram section under the horizontal dotted line was a litho-stratigraphic unit composed of decanted peat (organic flotsam) reflecting the occurrence of sediment disturbances.

Table 2. List of chironomid taxa observed in the Saint-Omer cores. The chironomid coding system used for the Correspondance Analysis is given in bold.

Taxa	Taxa
<i>Ablabesmyia</i> JOHANNSEN sp.	<i>Heterotrissocladius scutellatus</i> WALKER group
<i>Macropelopia</i> THIENEMANN sp. Mapel	<i>Kiefferullus tendipediformis</i> GOETGHEBUER
<i>Ablabesmyia</i> JOHANNSEN/ <i>Trissopelopia</i> KIEFFER group	<i>Krenopelopia</i> FITTKAU sp.
<i>Ablabesmyia anilis</i> LINNAEUS	<i>Larsia</i> FITTKAU sp.
<i>Ablabesmyia longistyla</i> FITTKAU	<i>Limnophyes</i> EATON sp. Limn
<i>Acricotopus</i> KIEFFER sp.	<i>Metricnemus</i> VAN DER WULP sp.
<i>Apsectrotanytus trifascipennis</i> ZETTERSTEDT	<i>Micropsectra</i> KIEFFER sp. Mic
Apsect	<i>Microtendipes</i> KIEFFER spp. Micdps
<i>Baeoetenus</i> SAETHER sp.	<i>Nanocladius</i> KIEFFER sp. Nacl
<i>Brillia longifurca</i> KIEFFER Blong	<i>Nilotanytus dubius</i> MEIGEN Nilo
<i>Brillia modesta</i> MEIGEN Bmod	<i>Odontomesa fulva</i> KIEFFER
<i>Chaetocladius</i> KIEFFER sp.	Orthoclaadiinae unidentified Ortind
Chironomidae unidentified	<i>Paratanytarsus</i> THIENEMANN & BAUSE/ <i>Rheotanytarsus</i> THIENEMANN & BAUSE group Pat/Rta
Chironomini unidentified Chmind	<i>Parachironomus arcuatus</i> GOETGHEBUER group
<i>Chironomus</i> ZETTERSTEDT spp. Chmus	<i>Paracladius conversus</i> WALKER sp. Paconv
<i>Cladopelma lateralis</i> GOETGHEBUER	<i>Paracladopelma</i> HARNISCH/ <i>Cyphomella</i> SAETHER group
<i>Cladotanytarsus mancus</i> WALKER group Cldm1	<i>Paracladopelma campolabis</i> KIEFFER group
<i>Conchapelma melanops</i> FITTKAU	<i>Paracladopelma nais</i> TOWNES Pnais
<i>Conchapelopia</i> FITTKAU/ <i>Telopelopia</i> ROBACK/ <i>Thienemannimyia</i> FITTKAU group Co/tel/thi	<i>Paralauterboniella nigrohalteralis</i> MALLOCH Panig
<i>Constempellina</i> BRUNDIN sp. Costp	<i>Paramerina</i> FITTKAU spp. Parina
<i>Corynoneura coronata</i> EDWARDS Crcor	<i>Parametricnemus</i> GOETGHEBUER/ <i>Paraphaenocladius</i> THIENEMANN group Pm/Pph
<i>Corynoneura lacustris</i> EDWARDS Crlac	<i>Paratanytarsus</i> THIENEMANN & BAUSE sp. Patat
<i>Corynoneura scutellata</i> WINNERTZ group Crcsut	<i>Paratendipes</i> KIEFFER sp. Partend
<i>Corynoneura</i> WINNERTZ spp. Corsp	<i>Paratrissocladius excerptus</i> WALKER Prtex
<i>Corynoneura</i> WINNERTZ/ <i>Thienemanniella</i> KIEFFER group Co/Th	<i>Phaenopsectra flavipes</i> MEIGEN Phafla
<i>Cricotopus</i> VAN DER WULP/ <i>Orthoclaadius</i> VAN DER WULP/ <i>Paratrithoclaadius</i> SANTOS ABREU group Criort	<i>Phaenopsectra</i> KIEFFER sp.
<i>Cryptochironomus</i> KIEFFER sp.	<i>Polypedilum</i> KIEFFER spp. Pol
<i>Demicryptochironomus</i> LENZ sp.	<i>Procladius choreus</i> MEIGEN Proclld
<i>Dicrotendipes</i> KIEFFER spp. Dic	<i>Prodiamesa olivacea</i> MEIGEN Prodoli
<i>Diplocadius cultriger</i> KIEFFER	<i>Psectrocladius</i> KIEFFER spp. Psect
<i>Endochironomus</i> KIEFFER sp.	<i>Rheocricotopus</i> THIENEMANN & HARNISCH sp. Rheo
<i>Eukiefferiella</i> THIENEMANN/ <i>Tvetenia</i> KIEFFER group Eukvt	<i>Rheopelopia</i> FITTKAU sp.
<i>Eurynemus crassipes</i> PANZER/ <i>Euryhopsis</i> OLIVER GROUP	<i>Stempellinella</i> BRUNDIN/ <i>Zavrelia</i> KIEFFER group
<i>Glyptotendipes</i> KIEFFER sp.	<i>Stenochironomus</i> KIEFFER sp. Stench
<i>Guttipelopia guttipennis</i> VAN DER WULP	<i>Symposiocladius lignicola</i> KIEFFER Sympli
<i>Gymnometricnemus</i> GOETGHEBUER/ <i>Bryophaenocladius</i> THIENEMANN group Gy/Bry	<i>Synorthoclaadius semivirens</i> KIEFFER Synort
<i>Heleniella seratosioi</i> RINGE	Tanypodinae unidentified Tanind
<i>Heterotanytarsus</i> SPÄRCK sp. Httan	<i>Tanytarsus</i> sp. C HOFFMANN TspC
<i>Heterotrissocladius</i> SPÄRCK sp.	Tanytarsini unidentified Tind
<i>Heterotrissocladius marcidus</i> SPÄRCK group Htmar	<i>Tanytarsus chinensis</i> KIEFFER Tchyn
	<i>Tanytarsus pallidicornis</i> WALKER group
	<i>Tanytarsus</i> KIEFFER spp. Tanspp
	<i>Telopelopia fascigera</i> VERNEAUX
	<i>Thienemannimyia</i> FITTKAU sp. Thien
	<i>Trissopelopia longimana</i> STAEGER
	<i>Zavrelimyia</i> GOETGHEBUER sp.

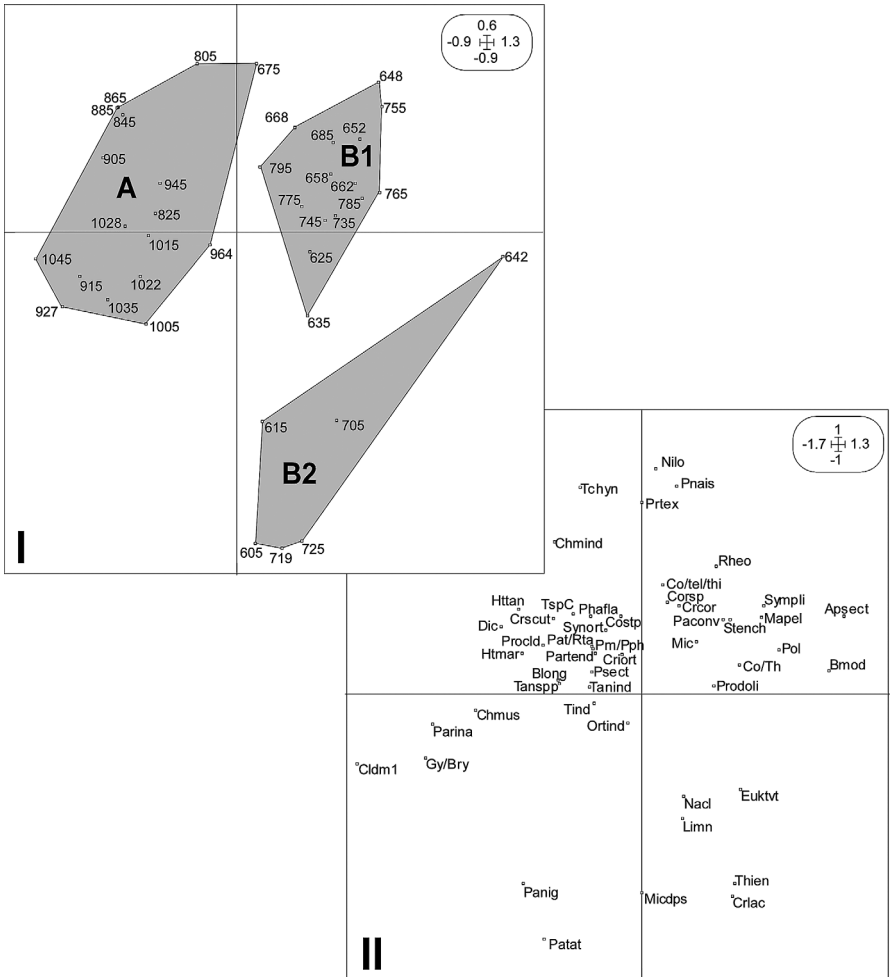


Fig. 3. Factorial plane F1-F2 (accounting for 28.8% of the total inertia) from a Correspondence Analysis of the chironomid remains. (I) Plot along axes F1 and F2 of the 38 levels (depths in cm) analysed. The cluster analysis led to the identification of three faunal groups (A, B1 and B2) (grey areas). (II) Plot along axes F1 and F2 of the 50 taxa jointly identified in the core analysed. The chironomid coding system is given in Table 2.

tats), and twelve with the main channel (lotic habitats) (Table 3). Based on this classification, it is possible to state that faunal unit A is mainly characterised by standing water taxa and that faunal unit B1 is characterised by more rheophilous taxa.

In the first zone, SMch-1 (corresponding to depths of 964 to 805 cm), which contained faunal unit A, the relative abundance of limnophilous taxa

Table 3. Ecological classification of the chironomid taxa identified at Saint-Omer. Altogether 15 taxa were assigned to the category of chironomids associated with “Oxbows or temporarily connected side arms” (lentic zones) and 12 taxa to the “main channel or connected side arms” (lotic zones) category.

Oxbows or temporarily connected side arms	Main channel or connected side arms
<i>Arcicotopus</i> KIEFFER sp.	<i>Apsectrotanytus trifascipennis</i> ZETTERSTEDT
<i>Chironomus</i> ZETTERSTEDT spp.	<i>Eukiefferiella</i> THIENEMANN/ <i>Tvetenia</i> KIEFFER group
<i>Cladotanytarsus mancus</i> WALKER group	<i>Eurycnemus crassipes</i> PANZER/ <i>Euryhapsis</i> OLIVER group
<i>Dicrotendipes</i> KIEFFER spp.	<i>Heleniella seratosioi</i> RINGE
<i>Endochironomus</i> KIEFFER sp.	<i>Nilotanytus dubius</i> MEIGEN
<i>Glyptotendipes</i> KIEFFER sp.	<i>Paratrisocladus excerptus</i> WALKER
<i>Guttipelopia guttipennis</i> VAN DER WULP	<i>Rheocricotopus</i> THIENEMANN & HARNISCH sp.
<i>Heterotanytarsus</i> SPÄRCK sp.	<i>Rheopelopia</i> FITTKAU sp.
<i>Kiefferullus tendipediformis</i> GOETGHEBUER	<i>Symposiocladius lignicola</i> KIEFFER
<i>Microtendipes</i> KIEFFER spp.	<i>Synorthocladus semivirens</i> KIEFFER
<i>Odontomesa fulva</i> KIEFFER	<i>Telopelopia fascigera</i> VERNEAUX
<i>Parachironomus arcuatus</i> GOETGHEBUER group	<i>Thienemannimyia</i> FITTKAU sp.
<i>Procladius choreus</i> SKUSE	
<i>Tanytarsus pallidicornis</i> WALKER group	
<i>Zavrelimyia</i> GOETGHEBUER sp.	
Number of taxa = 15	Number of taxa = 12

was considerably higher than that of rheophilous taxa (Fig. 4). The relative abundance of the limnophilous taxa peaked twice at sediment depths of ca. 927 and 825 cm (peaks C₁ and C₂ in Fig. 4). Zone SMch-1 contained higher proportions of *Tanytarsus* spp. than the other zones. The relative abundances of *Dicrotendipes* spp. and *Chironomus* spp. were fairly consistent throughout the zone. This zone contained litho-stratigraphic groups consisting of peaty flotsam, sandy peat, peat and charophytic peat.

In the zones denoted SMch-2 (at a depth of 795 to 735 cm) and SMch-4 (at a depth of 685 to 625 cm), which were found to contain faunal unit B1, rheophilous taxa were present in much higher proportions than limnophilous taxa. Zone SMch-2 contained higher percentages of *Polypedilum* spp., *Eukiefferiella/Tvetenia* and *Symposiocladius lignicola* than the previous one. Zone SMch-2 was a litho-stratigraphic unit composed of charophytic peat with a pulsating system from 800 to 750 cm. Zone SMch-4 was a litho-stratigraphic unit mainly composed of gyttja and charophytic peat, with many tree-trunks (drift wood).

In zones SMch-3 (725 to 705 cm) and SMch-5 (at a depth of 615 to 605 cm), which contained faunal unit B2, limnophilous taxa were found to be present in greater proportions than in the previous zones, and in distinctly higher proportions than rheophilous taxa: peaks occurred at depths of 725 and 605 cm (C₃ and C₄ in Fig. 4). Zone SMch-3 showed a sharp increase in the percentage of *Microtendipes* spp. The levels of *Microtendipes* spp. then decreased in this zone, in favour of *Polypedilum* spp. This zone was a litho-stratigraphic unit

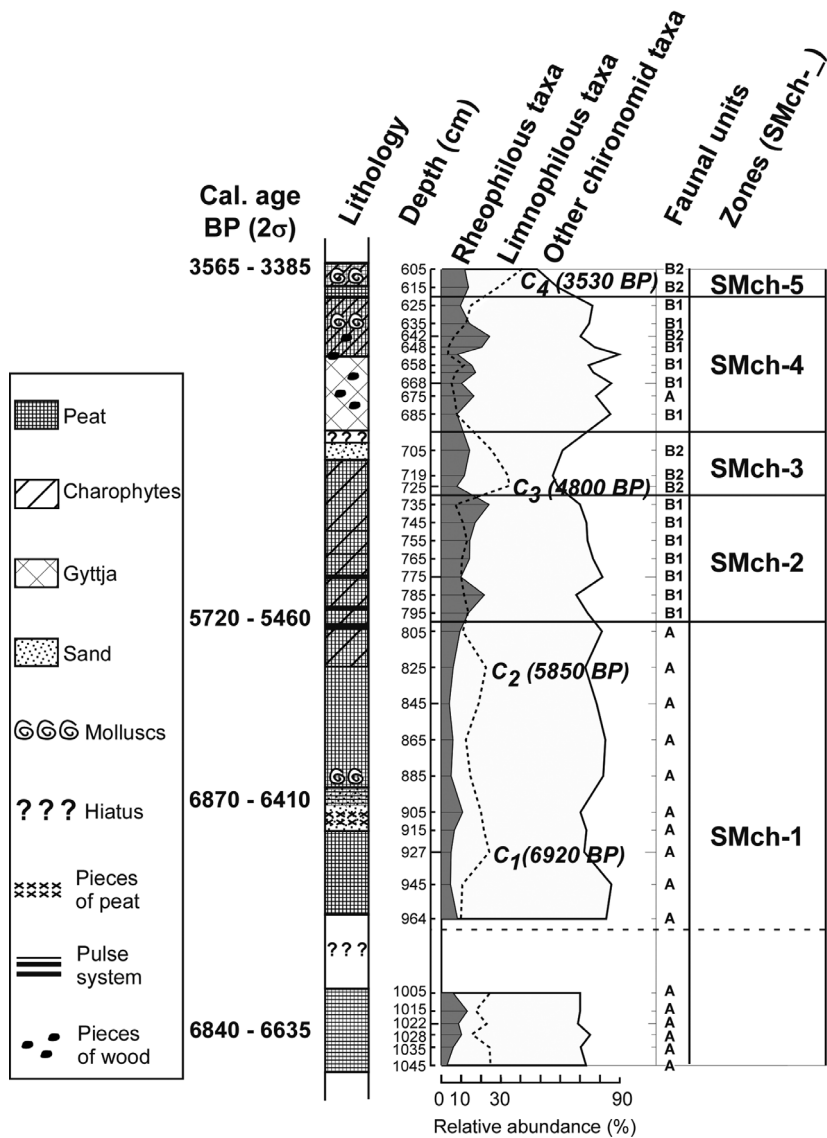


Fig. 4. Relative abundances (%) of groups of rheophilous (12 taxa), limnophilous (15 taxa), and other (58 taxa) chironomid taxa versus depth (cm) (rheophilous taxa are shown in grey and limnophilous taxa in dotted line). Calibrated age B.P. (2 σ) and core stratigraphy are shown on the left, the faunal units (A, B1 and B2) and the zones described in the text (SMch-1 to 5) on the right. C₁ to C₄: peaks of limnophilous taxa. These peaks have been dated (*Italic dates BP*) with the mean rate of sedimentation (Rs) calculated from the calibrated ages (2 σ) obtained on the part of core analysed. The diagram section under the horizontal dotted line was a litho-stratigraphic unit composed of decanted peat (organic flotsam), reflecting the occurrence of sediment disturbances.

composed of a uniformly charophytic peat layer which ended in a fine layer of sandy substrate at a depth of 705 to 700 cm. Zone SMch-5 showed gradually increasing levels of *Microtendipes* spp. This zone was again a litho-stratigraphic unit composed of charophytic peat.

The parts of the core analysed therefore suggest the occurrence of an alternating pattern of lentic and lotic phases, and the time elapsing between the four peaks in the lentic phases (C_1 to C_4) was on the millennial scale (Fig. 4).

Discussion

Palaeoenvironmental implications

The sediment sections analysed here, which were located at a depth ranging from 9 to 6 m (corresponding to radiocarbon dates 6640 ± 230 cal. BP and 3475 ± 90 cal. BP), contained material from parts of the Atlantic and Subboreal periods, based on the chronostratigraphic method developed by MANGERUD et al. (1974). At that time, the sandy Calais sediments were topped by an organic peaty layer not only in all the cores extracted from the floor of the basin itself (VAN DER WOUDE & ROELEVELD 1985) and from the coastal plain (SOMMÉ et al. 1994), but also at other North Sea locations (JELGERSMA 1961, WALLER 1994). This peaty layer reflects the occurrence of a long pause, or even a slight regression, in the rising sea levels which took place during the Holocene, and thus clearly separated the lower Calais from the upper Dunkirk formations. During this long pause, the hydrographic system probably reverted to the classical pattern occurring in the Preboreal and Subboreal periods around the North Sea, consisting of a main fluvial channel meandering through a vast, marshy region (e.g. MOL et al. 2000). The core contents showed traces of a peat-bog located on the edge of the channel. A stratigraphical analysis carried out by GANDOUIN (2003) and based on 20 cores across the Saint-Omer basin has made it possible to reconstruct a weakly meandering river system during the Subboreal period (Fig. 5). The local history of the Saint-Momelin sedimentation (based on the core analysed here) is shown schematically in Fig. 6. Stratigraphical interpretations give an idea of the level of connection between the sedimentation site and the main channel of the river Aa. The relatively uniform sedimentation of the basal part of the core showed that this was a closed system with very rare floods. During this period, lentic chironomid assemblages were present in large numbers (SMch-1 zone). In the next part of the core (from 800 to 750 cm), a pulsating system was observed. This coincides with the increase in the rheophilous fauna (SMch-2 zone) and indicates an increase in the river's influence. During this period, it is possible that due to a river shift, the main channel may have moved closer to the sedimentation site. This process would have made the connexion between the river and the

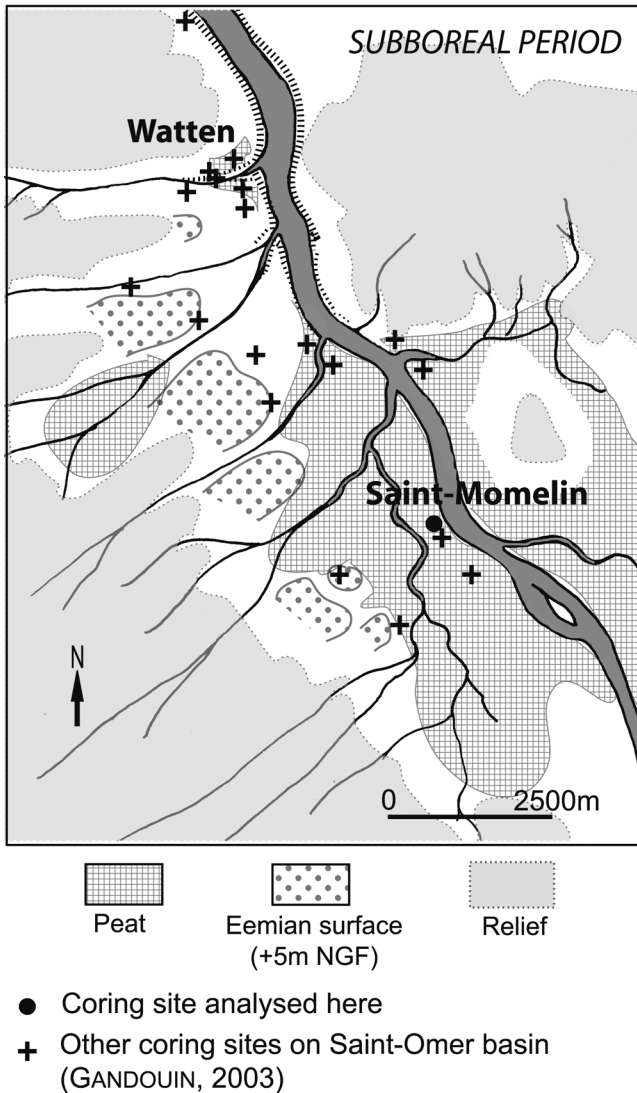


Fig. 5. Geomorphological map of the river Aa in the Saint-Omer basin during the Subboreal period (GANDOUIN 2003). The coring sites used to draw up this map are shown by crosses.

sedimentation site easier. However, during the Subboreal period around the Channel and the North Sea, river systems are known to be stable (ANTOINE et al. 2000, HUISINK 2000). In addition, the very gentle sloping of the basin ought not to have favoured lateral river shifts. A second hypothesis can therefore be put forward. At this period, the frequency and intensity of floods were

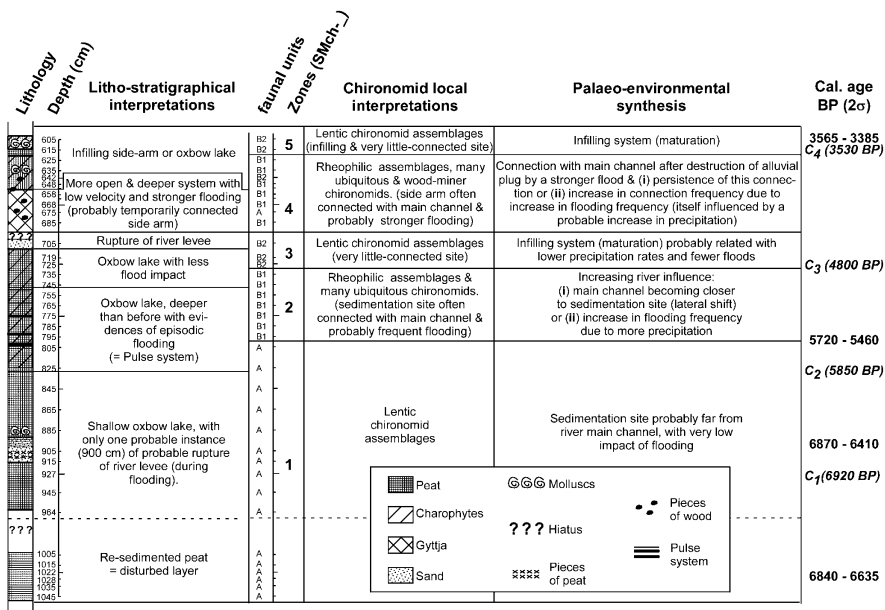


Fig. 6. Correlation between lithology and chironomid data. Core stratigraphy is shown on the left, and the zones described in the text (SMch-1 to 5), the chironomid faunal units and the calibrated age B. P. (2 σ) on the right. C₁ to C₄: peaks of limnophilous taxa. These peaks have been dated (*Italic dates BP*) with the mean rate of sedimentation (Rs) calculated from the calibrated ages (2 σ) obtained on the part of core analysed. The section under the horizontal dotted line was a litho-stratigraphic unit composed of decanted peat (organic flotsam), reflecting the occurrence of sediment disturbances.

increasing. The sedimentation site was probably an oxbow lake which was more frequently and durably flooded, and where submerged macrophytes (Characeae) could settle. This situation persisted up to a core depth of 750 cm (the end of the plusing system). Next, the sedimentation site may have closed up again, probably due to a gradual and natural process of oxbow-lake filling. Lentic chironomid assemblages (SMch-3 zone) could colonize this very closed system. The top of the SMch-3 zone coincides with sandy sediments which indicate the rupture of the river levee during a stronger flooding event. This event transformed the sedimentation site into a deeper and more connected system, probably a temporarily-connected side-arm. The subaquatic sedimentation (gyttja) in this zone indicates that this system persisted during the first part of the SMch-4 zone. Many rheophilous chironomids were able to dominate throughout this zone. The presence of several tree-trunks (pieces of drift wood) in the sediment shows that the impact of flooding was greater during this period. Floods may also have maintained connections (between main

channel and sedimentation site) and the persistence of rheophilous fauna despite the maturation and the filling of the system (in the upper part of the SMch-4 zone with charophitic peat). Lastly, at the top of the subboreal peat, the system closed again, probably forming an oxbow lake containing abundant lentic chironomid assemblages (SMch-5). This may again be attributed to the gradual infilling of the sedimentation site and a decrease in the influence of the river and its floods.

Relevance of the use of the chironomid subfossils in river paleoecological studies

When using river chironomid subfossils for palaeoenvironmental reconstruction purposes, one is confronted with two main problems. The first one is that a large part of the fossil chironomid fauna could not be classified (they fell into the “other chironomids” category), although these taxa accounted for the majority of the fossil assemblages (62 taxa out of 85). This was mainly due to three factors: (i) the identification of the head capsules down to the genus level did not give exact information about the ecological requirements of the species, (ii) literature describing the ecological status of chironomids inhabiting alluvial plains is rare (e. g. FRANQUET 1996, GARCIA & LAVILLE 2001), and the exact ecological status of most of the taxa identified could therefore not be determined, (iii) fluvial environments and alluvial plains are much more complex and dynamic systems than lake environments. This complexity is reflected in the structure of the faunal assemblages and the fossils found may have originated from many landscape units (from lentic to lotic habitats) in the basin. The predominance of unclassified fauna was a potentially biasing factor. Data on river chironomid assemblages must be interpreted more cautiously than those obtained in lakes. However, as described above, a detailed stratigraphical description of the core analysed yielded evidence supporting our hypotheses. It is therefore possible to state here that chironomid data contributed to reconstruct past hydrological changes in the area surrounding the sedimentation site.

The second problem was the simultaneous and abundant presence of larvae of the genus *Polypedilum* along with some rheophilous assemblages. *Polypedilum* is known to often reach abundances of up to 15% of the overall lacustrine chironomid assemblages (e. g. BROOKS & BIRKS 2001, LOTTER et al. 1997). However, in river systems, this genus has been clearly identified as ubiquitous by FRANQUET (1996), including one species in an oxbow lake (*P. cultellatum* GOETGHEBUER), four ubiquitous species (*P. pedestre* MEIGEN, *P. quadriguttatum* KIEFFER, *P. aegyptium* KIEFFER and *P. nebeculosum* MEIGEN found from oxbow to temporarily or permanently connected side arms) and one species in the main channel (*P. sordens* VAN DER WULP). The data obtained by GARCIA &

LAVILLE (2001) also reflect this ubiquitous character. We therefore argue that the genus *Polypedilum* may be considered as an ubiquitous taxa and that its association with some rheophilous assemblages may be an indication that connections occurred between the various compartments of the alluvial plains during flood episodes.

Climatical implications

In spite of the problems above, the present core analysis showed a remarkably regular pattern of alternation between lentic phases (SMch-1, 3 and 5) and more or less predominantly lotic ones (SMch-2 and 4). This alternating pattern may potentially be attributed to the following three processes: (i) the Saint-Omer basin is located in a region of active tectonic control (VAN VLIET-LANOË et al. 2002, MANSY et al. 2003) near the Straits of Dover, where the episodes of opening and closure occurring during the Quaternary era were partly due to tectonic processes. These processes brought about palaeoenvironmental changes in the sedimentary basins, which resulted in flows of detritus (thus raising the level of the basin) and affected the hydrographic networks (VAN VLIET-LANOË et al. 2002). However, the time scales on which these processes occurred (every 10^5 to 10^6 years) were much larger than those recorded here and therefore do not explain the alternating hydrosystem regimes detected at Saint-Omer. (ii) Changes in the sea level (a drop in the sea level increases the slope and the rate of flow of rivers, whereas a rise in the sea level has the opposite effect). However during the period under investigation, no regional variations in the sea level are known to have occurred on a scale to yield conspicuous changes in the slopes. We therefore assume the sea level to have been stable and the coast line to have been fairly distant from the Saint-Omer basin in this part of the Holocene. (iii) Climate could have been the main factor responsible for the changes observed in the hydrological regime of the River Aa. In view of the positive correlation previously observed between precipitation and the rates of flow of waterways (KIELY 1999, RÎMBU et al. 2002) and the fact that the sea was relatively far from the basin at that time, the lotic phases (SMch-2 and 4) may have been the phases when the precipitation levels were greatest, and vice versa for the lentic phases (SMch-1, 3 and 5). In addition, increasing precipitation results in more frequent river floods and watertable flooding. Changes in the river channel and destruction of alluvial plugs lead to the re-opening of oxbow lakes. The high frequency and intensity of flood events was confirmed here by the presence of many pieces of wood in the sediments and by the high relative rates of occurrence of *Symposiocladius lignicola*. Larvae of this species drill into wood debris immersed in running water (WIEDERHOLM 1983). This suggests that the river banks were either immersed for a long time or that the flow rate increased, resulting in the

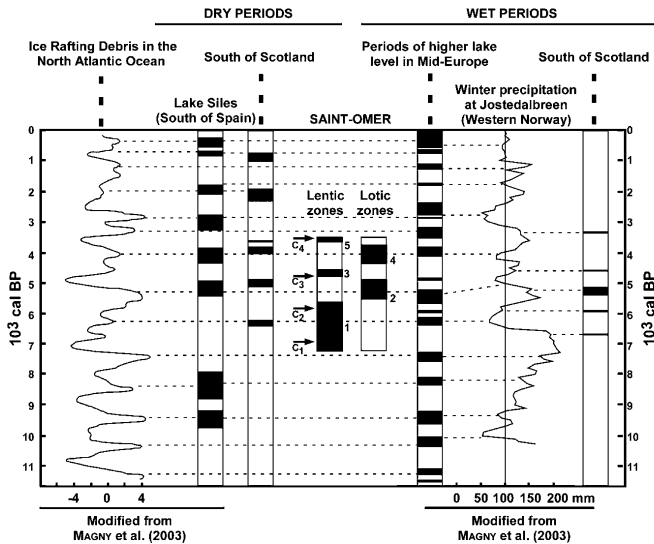


Fig. 7. Comparison between the North-Atlantic Ice Rafting Discharge (IRD) values (BOND et al. 2001) and various hydrological records detected in Europe. Dry periods are in black on the left: South of Spain (CARRIÓN 2002 in MAGNY et al. 2003), South of Scotland (LANGDON et al. 2003) and Saint-Omer (lentic zones: SMch-1, 3 and 5). Wet periods are in black on the right: Saint-Omer (lotic zones: SMch-2 and 4), Mid-Europe (MAGNY et al. 2003), West of Norway (NESJE et al. 2000) and South of Scotland (LANGDON et al. 2003). C₁ to C₄: peaks in the dry periods detected at Saint-Omer [cf. maxima of limnophilous taxa (Fig. 4)]. These peaks and zones have been dated with the mean rate of sedimentation (Rs) calculated from the calibrated ages (2 σ) obtained on the part of core analysed. Estimated dates in cal. BP are [SAINT-OMER (SMch) 1] 7320–5640, (SAINT-OMER 2) 5540–4900, (SAINT-OMER 3) 4800–4590, (SAINT-OMER 4) 4370–3700, (SAINT-OMER 5) 3600–3500, (C₁) 6920, (C₂) 5850, (C₃) 4800 and (C₄) 3530.

erosion of the banks (and in the immersion of the roots and trunks of the riverside vegetation).

Comparisons between our data and those published by MAGNY (2004) (Fig. 7) reveal that the phases of fluctuating humidity observed by the latter author at mid-European latitudes were found to match zones SMch-2 to 5 detected here at Saint-Omer. The humidity profile of SMch-1 is rather more typical of the Northern European latitudes (Fig. 7). This may be due to the fact that the Saint-Omer basin is located between these two latitudes with respect to the North Atlantic atmospheric currents (the Westerlies), as well as to the fact that at the beginning of the drop in the sea level, the resulting retrogressive erosion had not yet completely reached the Saint-Omer basin. This means that water logging and peat growth persisted in the basin, slightly disturbing the climatic signal.

A cyclic pattern on the millennial scale was observed in the present study between peaks C_1 to C_4 in the lentic phases at Saint-Omer, based on the analysis of sub-fossil chironomid assemblages. These peaks (C_1 to C_4) correspond with the minima in the North-Atlantic ice rafting discharge (IRD) curves (BOND et al. 2001) and with the increases in the winter precipitation levels occurring in western Scandinavia (NESJE et al. 2000) (Fig. 7). In addition, lotic phases SMch-2 and 4 seem to correspond with maxima of IRD. Our results therefore seem to be agree with the working hypothesis put forward by MAGNY et al. (2003) that the IRD events coincided with cooler Holocene phases (BOND et al. 1997), wetter climate at mid-European latitudes and dry phases in the North and South of Europe (LANGDON et al. 2003), with special emphasis on the potential variations in the strength of the Westerly jet. It is worth noting that the Westerlies and precipitation effects at Saint-Omer might be overestimated due to some orographic process. Since a large part of the Aa river catchment is located between the “Boulonnais” and “Artois” reliefs, the precipitations and flooding may have been concentrated in the lowest part of the river (The “Audomarois marsh”).

To conclude, whatever the forcing mechanisms responsible for the fluctuations observed (e. g. BIANCHI & MCCAVE 1999, MORENO 2004, VAN GEEL et al. 1999), the use of chironomids as a descriptive index to alluvial habitats combined with a palaeoecological approach has shown in the present study that the chironomids are promising tools for use in palaeoecological studies on fluvial environments. Due to the limitations of the method (many chironomids have not yet been classified), it is not possible to state categorically that the Saint-Omer data provide an accurate reconstruction of past precipitation in the region. However, our study made it possible to put forward some interesting working hypotheses based on previously published scientific data. These initial results show that further multidisciplinary studies are required on the Saint-Omer basin. In parallel, we feel it is necessary to develop the chironomid tool by carrying out further studies on the taxonomy and the ecology of this insect family, especially on the ecological status of modern chironomids along gradients across the floodplains of large rivers.

Acknowledgements

This study was part of a multidisciplinary palaeoecological program supported by the ANDRA (the French National Radioactive Waste Management Agency). The BRGM (The Mining and Geological Research Agency) provided logistic support for the coring operations. The radiocarbon dating was carried out by Dr. DARDEN HOOD at the Laboratory of Physics and Atmospheric Sciences (University of Arizona) and by Dr. M. FRECHEN at the GAA-institut (University of Hannover). We are grateful to Dr. STEPHEN J. BROOKS for his welcome at the Natural History Museum of London, in November 2000, during a training course on chironomid larva determination. We thank

Dr. PETER LANGDON and all the members of the Chironomid Workshop which took place in Exeter in November 2002 for valuable discussions about taxonomic problems. We are particularly grateful to Dr. MARIA RIERADEVALL, who confirmed the identification of several Tanypodinae larvae. We also thank Professor DAVID KEEN, Dr. VALÉRIE ANDRIEU-PONEL and Dr. PHILIPPE PONEL for their helpful comments and Dr. JESSICA BLANC for translating the manuscript into English. Lastly, we thank Professor ERIC PATTEE and an anonymous referee for their corrections and valuable comments on this paper.

References

- AMOROS, C. & PETTS, G. E. (1993): Hydrosystèmes fluviaux. – Masson, Paris, 300 p.
- AMOROS, C. & VAN URK, G. (1989): Palaeoecological analysis of large rivers: some principles and methods. – In: PETTS, G. E., MOLLER, H. & ROUX, A. L.: Historical change of large alluvial rivers. – Wiley, Chichester, pp. 143–166.
- ANTOINE, P., LAUTRIDOU, J. P. & LAURENT, M. (2000): Long-term fluvial archives in NW France: response of the Seine and Somme rivers to tectonic movements, climatic variations and sea-level changes. – *Geomorphology* **33**: 183–207.
- BENZECRI, J. P. (1973): L'analyse des données: II l'analyse des correspondances. – Bordas, Paris, 620 p.
- BIANCHI, G. G. & McCAVE, I. N. (1999): Holocene periodicity in North Atlantic climate and deep-ocean flow south of Iceland. – *Nature* **397**: 515–517.
- BIRKS, H. J. B. & GORDON, A. D. (1985): Numerical Methods in Quaternary Pollen Analysis. – Academic Press, London, 317 pp.
- BOND, G., KROMER, B., BEER, J., MUSCHELER, R., EVANS, M. N., SHOWERS, W., HOFFMANN, S., LOTTI-BOND, R., HADJAS, I. & BONANI, G. (2001): Persistent solar influence on North Atlantic climate during the Holocene. – *Science* **294**: 2130–2136.
- BOND, G., SHOWERS, W., CHESEBY, M., LOTTI, R., ALMASI, P., DEMENOCAL, P., PRIORE, P., CULLEN, H., HADJAS, I. & BONANI, G. (1997): A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. – *Science* **278**: 1257–1266.
- BROOKS, S. J. & BIRKS, H. J. B. (2000): Chironomid-inferred late-glacial and early-Holocene mean July air temperatures for Krakenes Lake, Western Norway. – *J. Paleolim.* **23**: 77–89.
- (2001): Chironomid-inferred air temperatures from Lateglacial and Holocene sites in north-west Europe: progress and problems. – *Quatern. Sci. Rev.* **20**: 1723–1741.
- BROWN, A. G. (2002): Learning from the past: palaeohydrology and palaeoecology. – *Freshwat. Biol.* **47**: 817–829.
- BRYCE, D. (1960): Studies of the larvae of the British Chironomidae (Diptera), with keys to the Chironominae and the Tanypodinae. – *Trans. Soc. Brit. Ent.* **14**: 19–62.
- BRYCE, D. & HOBART, A. (1972): The biology and identification of the larvae of the Chironomidae (Diptera). – *Entomol. Gaz.* **23**: 175–217.
- COOPE, G. R. (1986): Coleoptera analysis. – In: BERGLUNG, B. E.: Handbook of Holocene Palaeoecology and Palaeohydrology. – Wiley & Sons Ltd., Chichester, pp. 703–713.

- CRANSTON, P. S. (1982): A key to the larvae of the British Orthocladiinae (Chironomidae). – *Sci. Publ. Freshwat. Biol. Assoc.* n° 45, London, 152 p.
- FERRARESE, U. & ROSSARO, B. (1981): Chironomidi, 1 (Diptera, Chironomidae: Generalità, Diamesinae, Prodiamesinae). – Consiglio nazionale delle Ricerche, Verona, 97 pp.
- FRANCIS, D. R. (2001): A record of hypolimnetic oxygen conditions in a temperate multi-depression lake from chemical evidence and chironomid remains. – *J. Paleolim.* **25**: 351–365.
- FRANQUET, E. (1996): Occupation d'un espace fluvial par les Diptères chironomidés à l'aval du Rhône: répartition des espèces selon la nature du substrat et les conditions de débit. – Thesis Univ. Lyon 1, 147 p.
- GANDOUIN, E. (2003): Enregistrement paléoclimatique interdisciplinaire de la transgression holocène: signature paléoenvironnementale des Chironomidae (Diptères) du Bassin de Saint-Omer (France). – Thesis Univ. Lille 1, 246 p.
- GANDOUIN, E. & FRANQUET, E. (2002): Late glacial and Holocene chironomid assemblages in Lac Long Inférieur, south of France, 2090 m. Palaeoenvironmental and palaeoclimatical implications. – *J. Paleolim.* **28**: 317–328.
- GARCIA, X.-F. & LAVILLE, H. (2001): Importance of floodplain waters for the conservation of chironomid (Diptera) biodiversity in a 6th order section of the Garonne river (France). – *Annls Limnol.* **37**: 35–47.
- GOEURY, C. (1997): Gestion, traitement et représentation des données de la paléécologie. – XVème Symposium de l'Association des Palynologues de Langue Française, Abstracts, 31 pp.
- GROSSMAN, M. A., BROWN, G. & KADOMOURA, H. (2001): Large floods and climatic change during Holocene on the Ara River, Central Japan. Contributions to temperate and humid tropical palaeohydrology. – *Geomorphology* **39**: 21–37.
- HEIRI, O., LOTTER, A. F., HAUSMANN, S. & KIENAST, F. (2003): A chironomid-based Holocene summer air temperature reconstruction from the Swiss Alps. – *The Holocene* **13**: 477–484.
- HOFMANN, W. (1986): Chironomid analysis. – In: BERGLUNG, B. E.: *Handbook of Holocene Palaeoecology and Palaeohydrology*. – Wiley & Sons Ltd., Chichester, pp. 715–727.
- HUISINK, M. (2000): Changing river styles in response to Weichselian climate changes in the Vecht valley, eastern Netherlands. – *Sediment. Geol.* **133**: 115–134.
- JELGERSMA, S. (1961): Holocene Sea Level Changes in the Netherlands. – Leiden, 100 pp.
- JUNK, W. J., BAYLEY, P. B. & SPARKS, R. E. (1989): The flood pulse concept in river-floodplain systems. – In: DODGE, D. P.: *The Proceedings of the international large river Symposium*. – *Can. J. Fish. Aquat. Sci., Spec. Publ.*, pp. 110–127.
- KIELY, G. (1999): Climate change in Ireland from precipitation and streamflow observations. – *Adv. Water Resour.* **23**: 141–151.
- KLINK, A. (1989): The lower Rhine: palaeoecological analysis. – In: PETTS, G. E., MOLLER, H. & ROUX, A. L.: *Historical change of large alluvial rivers: Western Europe*. – Wiley, J. Sons, Ltd, pp. 183–201.
- LANGDON, P. G., BARBER, K. E. & HUGHES, P. D. M. (2003): A 7500-year peat-based palaeoclimatic reconstruction and evidence for an 1100-year cyclicity in bog surface wetness from Temple Hill Moss, Pentland Hills, southeast Scotland. – *Quatern. Sci. Rev.* **22**: 259–274.

- LOTTER, A. F., BIRKS, H. J. B., HOFMANN, W. & MARCHETTO, A. (1997): Modern diatom, Cladocera, chironomid, and chrysophyte cyst assemblages as quantitative indicators for the reconstruction of past environmental conditions in the Alps. I. Climate. – *J. Paleolim.* **18**: 395–420.
- – – (1998): Modern diatom, Cladocera, chironomid, and chrysophyte cyst assemblages as quantitative indicators for the reconstruction of past environmental conditions in the Alps. II. Nutrients. – *J. Paleolim.* **19**: 443–463.
- MAGNY, M. (2004): Holocene climate variability as reflected by mid-European lake-level fluctuations and its probable impact on prehistoric human settlements. – *Quat. Int.* **113**: 65–79.
- MAGNY, M., BÉGEOT, C., GUIOT, J. & PEYRON, O. (2003): Contrasting patterns of hydrological changes in Europe in response to Holocene climate cooling phases. – *Quatern. Sci. Rev.* **22**: 1589–1596.
- MANGERUD, J., ANDERSEN, S. T., BERGLUND, B. E. & DONNER, J. J. (1974): Quaternary stratigraphy of Norden, a proposal for terminology and classification. – *Boreas* **3**: 109–127.
- MANSY, J. L., MANBY, G. M., AVERBUCH, O., EVEREARTS, M., BERGERAT, F., VAN VLIET-LANOË, B., LAMARCHE, J. & VANDYCKE, S. (2003): Dynamics and inversion of the Mesozoic Basin of the Weald-Boulonnais area: role of basement reactivation. – *Tectonophysics* **373**: 161–179.
- MOL, J., VANDENBERGHE, J. & KASSE, C. (2000): River response to variations of periglacial climate in mid-latitude Europe. – *Geomorphology* **33**: 131–148.
- MORENO, P. I. (2004): Millennial-scale climate variability in northwest Patagonia over the last 15000 yrs – *J. Quatern. Sci.* **19**: 35–47.
- NESJE, A., LIE, O. & DAHL, S. O. (2000): Is the North Atlantic Oscillation reflected in Scandinavian glacier mass balance records? – *J. Quatern. Sci.* **15**: 587–601.
- QUINLAN, R. & SMOL, J. P. (2001): Setting minimum head capsule abundance and taxa deletion criteria in chironomid-based inference models. – *J. Paleolim.* **26**: 327–342.
- RIERADEVALL, M. & BROOKS, S. J. (2001): An identification guide to subfossil Tanyptodinae larvae (Insecta: Diptera: Chironomidae) based on cephalic setation. – *J. Paleolim.* **25**: 81–99.
- RÎMBU, N., BORONEANT, C., BUTA, C. & DIMA, M. (2002): Decadal variability of the Danube river flow in the lower basin and its relation with the North Atlantic Oscillation. – *Int. J. Climatol.* **22**: 1169–1179.
- ROSSARO, B. (1982): Chironomidi, 2 (Diptera Chironomidae: Orthocladiinae). – Consiglio nazionale delle Ricerche, Verona, 80p.
- SCHMID, P. E. (1993): A key to the larval chironomidae and their instars from Austrian Danube region streams and rivers. – Federal Institute for Water Quality **93**, Vienna, 514 pp.
- SOMMÉ, J., MUNAUT, A. V., EMONTSPOHL, A. F., LIMONDIN, N., LEFÈVRE, D., CUNATBOGÉ, N., MOUTHON, J. & GILOT, E. (1994): The Watten boring-an Early Weichselian and Holocene climatic and palaeoecological record from the French North Sea coastal plain. – *Boreas* **23**: 231–243.
- STUIVER, M., REIMER, P. J., BARD, E., BECK, J. W., BURR, G. S., HUGHEN, K. A., KROMER, B., MCCORMAC, G., VAN DER PLICHT, J. & SPURK, M. (1998): INTCAL98 Radiocarbon Age Calibration, 24,000 to 0 cal BP. – *Radiocarbon* **40**: 1041–1083.

- THIOULOUSE, J., CHESSEL, D., DOLÉDEC, S. & OLIVIER, J. M. (1997): ADE-4: a multivariate analysis and graphical display software. – *Stat. Comp.* **7**: 75–83.
- VAN DER WOUDE, J. D. & ROELEVELD, W. (1985): Paleocological evolution of an interior coastal zone: the case of the northern France coastal plain. – *Bulletin de l'Association française pour l'Etude du Quaternaire* **1**: 31–39.
- VAN GEEL, B., RASPOPOV, O. M., RENNSSEN, H., VAN DER PLICHT, J., DERGAVECH, V. A. & MEIJER, H. A. J. (1999): The role of solar forcing upon climate change. – *Quatern. Sci. Rev.* **18**: 331–338.
- VAN VLIET-LANOË, B., VANDERBERGHE, N., LAURENT, M., LAIGNEL, B., LAURIAT-RAGE, A., LOUWJE, S., MANSY, J.-L., MERCIER, D., HALLÉGOUËT, B., LAGA, P., LAQUEMENT, F., MEILLIEZ, F., MICHEL, Y., MOGUEDET, G. & VIDIER, J.-P. (2002): Palaeogeographic evolution of northwestern Europe during the Upper Cenozoic. – *Geodiversitas* **24**: 511–541.
- VANDENBERGHE, J. (1995): Timescales, climate and river development. – *Quatern. Sci. Rev.* **14**: 631–638.
- WALKER, I. R. & BRODERSEN, K. (1997): Key to genera in the tribe Chionomini. Part I. – In: WALKER, I. R.: *The WWW Field Guide to Subfossil Midges*. – <http://www.sci.ouc.bc.ca/fwsc/iwalker/chironomid/chironomini/chir2key.htm>.
- WALLER, M. P. (1994): Flandrian vegetational history of south-eastern England. Stratigraphy of the Brede valley and pollen data from Brede Bridge. – *New Phytol.* **126**: 369–392.
- WARD, J. V. & STANFORD, J. A. (1995): Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. – *Regul. Rivers: Res. Managem.* **11**: 105–119.
- WATERLOT, M. G. (1957): *Saint-Omer. Carte géologique au 1/ 80 000*. – Paris.
- WIEDERHOLM, T. (1983): Chironomidae of the Holarctic region. Keys and diagnoses. part 1: Larvae. – *Entomol. Scand. Suppl.* **19**: 457p.
- WILSON, R. S. (1980): Classifying rivers using Chironomid pupal exuviae. – In: MURRAY, D. A.: *Chironomidae Ecology, Systematics, Cytology and Physiology*. – Pergamon Press, Oxford, pp. 209–216.