INTERM REPORT ON ECOLOGICAL STUDIES ON THE BENTHIC INVERTEBRATES OF VARIOUS RIVERS IN THE ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM STUDY AREA, NORTHEASTERN ALBERTA

prepared by

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for

ALBERTA OIL SANDS ENVIRONMENTAL
RESEARCH PROGRAM

Project AF 2.0

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ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

RESEARCH REPORTS

These research reports describe the results of investigations funded under the Alberta Oil Sands Environmental Research Program, which was established by agreement between the Governments of Alberta and Canada in February 1975 (amended September 1977). This 10-year program is designed to direct and co-ordinate research projects concerned with the environmental effects of development of the Athabasca Oil Sands in Alberta.

A list of research reports published to date is included at the end of this report.

Enquiries pertaining to the Canada-Alberta Agreement or other reports in the series should be directed to:

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Interim Report on Ecological Studies
on the Benthic Invertebrates Of Various
Rivers in the Alberta Oil Sands Environmental
Research Program Study Area, Northeastern Alberta
Project AF 2.0

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The Hon. John W. (Jack) Cookson
Minister of the Environment
222 Legislative Building
Edmonton, Alberta

and

The Hon. L. Marchand
Minister of the Environment
Environment Canada
Ottawa, Ontario

Sirs:

Enclosed is the report "Interim Report on Ecological Studies on the Benthic Invertebrates of Various Rivers in the Alberta Oil Sands Environmental Research Program Study Area, Northeastern Alberta".

This report was prepared for the Alberta Oil Sands Environmental Research Program, through its Hydrology Technical Research Committee (now Water System), under the Canada-Alberta Agreement of February 1975 (amended September 1977).

Respectfully,

W. Solodzuk, P.Eng.
Chairman, Steering Committee, AOSERP
Deputy Minister, Alberta Environment

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Member, Steering Committee, AOSERP
Regional Director-General
Environment Canada
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INTERIM REPORT ON ECOLOGICAL STUDIES ON THE BENTHIC INVERTEBRATES OF VARIOUS RIVERS IN THE ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM STUDY AREA, NORTHEASTERN ALBERTA

DESCRIPTIVE SUMMARY

ABSTRACT

This report details preliminary experimental and survey research on benthic communities affected by selected hydrocarbons and tailings sludge produced by existing oil sands mining and up-grading operations.

Taxonomic surveys of macrobenthic communities are carried out in the Muskeg and Steepbank river drainages concurrent with experimental manipulations.

BACKGROUND

AOSERP project AF 2.0 entitled "Aquatic Invertebrate Sub-Project Administration and Support" was authorized early in 1976 via the Aquatic Fauna Technical Research Committee. The intention of this sub-project was to "better assess the qualitative and quantitative aspects of aquatic invertebrates and support the total research effort on watersheds in the AOSERP study area". This project undertook field investigations in the Muskeg, Steepbank and Athabasca rivers which are reported herein. Invertebrate investigations subsequent to AF 2.0 were carried on in 1977-78 under AOSERP project AF 2.0.1 and related field investigations on invertebrates were undertaken at the same time in the Hartley Creek sub-basin, by other scientists under AOSERP project AF 2.5.1.

The approach adopted by the authors stemmed from the feeling that it was necessary first to establish a sound taxonomic understanding of macrobenthic communities in the Muskeg River basin as part of intensive studies of brown-water tributary streams of the Athabasca Oil Sands area. This taxonomic base was to allow progress on experimental studies while establishing a reference list of macrobenthos for this and future studies at the same time.

ASSESSMENT

This report has been reviewed by scientists in the University of Calgary, the private consulting industry, the oil sands industry and in the AOSERP Program. Independent referees commented on the lack of methodology descriptions (rearing methods, literature citations for identifications and some sampling methods). Some small differences in the taxonomic listing occurred in the review. Also, some reviewers felt that the authors took too much latitude in generalizing preliminary work. In response the authors have stated they are fully prepared to accept scientific responsibility for their work.

It is the overall impression of the AOSERP Management that the work is a preliminary contribution to be released for distribution at selected Canadian libraries with the understanding that later work containing more extensive taxomonic listings and more complete understanding will become available shortly. The content of the report does not necessarily reflect the views of Alberta Environment, Fisheries and Environment Canada, or representatives of the oil sands industry. The mention of trade names for commercial products does not consititute an endorsement or recommendation for use. The Alberta Oil Sands Environmental Research Program accepts the report "Interim Report on Ecological Studies on the Benthic Invertebrates of Various Rivers in the Alberta Oil Sands Environmental Research Program Study Area, Northeastern Alberta" and thanks the researchers for their contributions.

S.B. Smith, Ph.D.
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Research Manager
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ABSTRACT

This report details preliminary experimental and survey research on benthic communities affected by selected hydrocarbons and tailings sludge produced by existing oil sands mining and upgrading operations.

Taxonomic surveys of macrobenthic communities were carried out in the Muskeg and Steepbank river drainages concurrent with experimental manipulations.

ACKNOWLEDGEMENTS

For the taxonomic survey report, Hemiptera were examined by M. Lamont. We wish to thank Drs. N. Hynes, H. Clifford, R. Hartland-Rowe and Mr. R. Crowther for assistance in identifications of other groups.

In the study of the sludge addition, the authors would like to thank Mr. W. Cary of Great Canadian Oil Sands Limited for advice and cooperation in providing the tailings sludge. J. Buchanan, B. Brown and M. Lamont toiled over the many benthic samples that were picked. Mr. M. Korchinski of the Inland Waters Directorate of Fisheries and Environment Canada, generously arranged for the chemical analyses of the sludge.

For the oil basket experiments, the authors acknowledge the assistance in the field of Mr. B. Anholt, Mr. D. Berry, Mr. R. Crowther, Ms. D. Loucks, and Ms. L. Manchester. Ms. B. Brown, Mr. A. Furnell, and Mr. D. Bespalko picked over many of the samples.

Mr. W. Cary generously supplied the synthetic crude oil and the oil fractions. The oil analyses were performed by Chemical and Geological Laboratories Limited, Edmonton.

Dr. M.A. Lock provided many useful comments and M. Hirst typed the manuscript. We acknowledge the service and space provided at the Northern Forest Research Centre, Edmonton.

1. TAXONOMIC SURVEYS ON THE MUSKEG AND STEEPBANK RIVER DRAINAGES

1.1 INTRODUCTION

The literature dealing with benthic invertebrates of the Athabasca Oil Sands area is extremely limited. Clifford's (1969) study of the Bigoray River, a typical northern brown-water stream similar to the muskeg streams in the Alberta Oil Sands Environmental Research Program (AOSERP) study area (Figure 1), is an invaluable introduction to the benthic biology of this type of region. He found that community structure changed very little from September to April, but considerably from month to month in summer. The fauna was composed of summer and winter, as well as plains and cordilleran species. Clifford concluded that the long period of ice cover and low temperatures resulted in a compression of emergence periods and the fauna as a whole grew more rapidly in autun as temperatures were falling.

The study of Beaver River, prior to its diversion (Syncrude 1971), suggests that the methods used (but not described) were not suitable to the objective of defining the benthic communities of Beaver River. The Poplar Creek study (Syncrude 1975) gives a rough idea of the conditions prevailing during summer before the Beaver River diversion. Unfortunately, a 0.6 mm sieve was used to concentrate the samples so that the reported estimates of both density and community composition must be interpreted with great care.

The only detailed taxonomic list of aquatic organims from northern rivers is that of Wiens et al. (1975) who listed taxa collected from the Mackenzie and Porcupine watersheds which might be expected to occur also in the Athabasca Oil Sands area. This report does not include any information other than collecting sites, times, and the list of taxa which provided a taxonomic

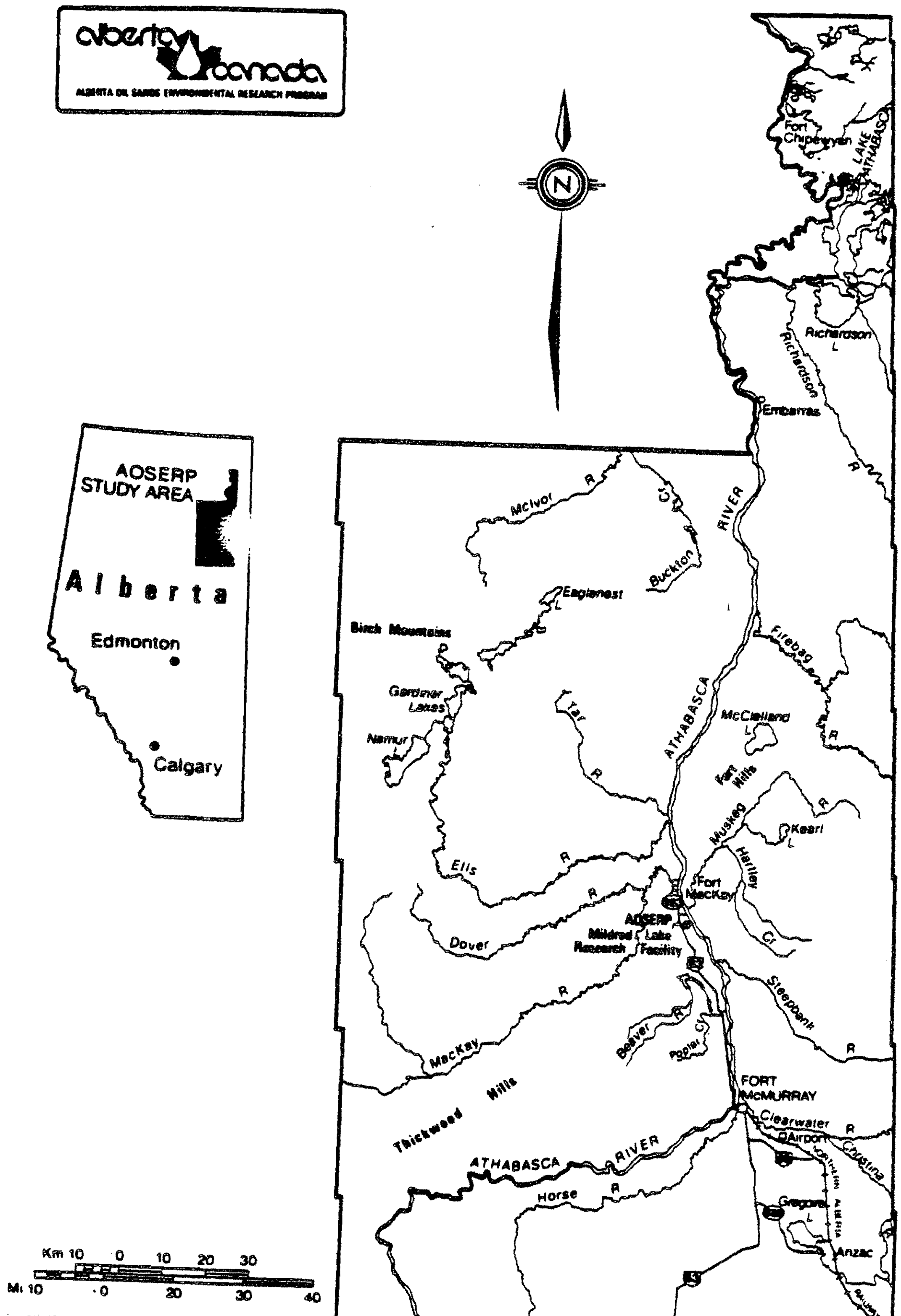


Figure 1. The AOSERP study area.

base for other studies conducted in relation to pipeline development. Rosenberg and Snow (1975) described the responses of aquatic macrobenthos, especially chironomids, to sedimentation and recommended that man-induced sediment additions to streams should not exceed 80 mg/ℓ. Chang (1975) noted that the benthic fauna of two Arctic lakes consisted primarily of Chironomidae and that the period of adult emergence was even more restricted than that found by Clifford (1969). The need for detailed knowledge of life histories in interpreting responses to environmental changes was shown by Rosenberg et al. (1977a, b) who found that crude oil contamination of rock substrates not only led to an increase in the abundance of certain chironomid species, but also that the growth patterns of two important species were altered on the oiled rocks.

Large rivers, such as the Athabasca, have not been extensively studied anywhere in the world. The reports by Flannagan (1975, 1977) contain preliminary data about life cycles of some species, drift patterns and several useful techniques for studying the fauna of the Athabasca River. Elsewhere, Russian rivers appear to have attracted the most attention, but their faunas have been described only in very general terms (Greze 1953; Lastochin 1943; Shadin 1956, 1964). Ertl and Tomajka (1973), Ertl et al. (1975) and Jankovic (1975a, b) described algal and invertebrate communities in the littoral of the Danube River which were strongly affected by fluctuations in water level and dominated by a very small number of chironomid species.

The paucity of published information dealing with the benthos of the AOSERP study area suggest that the first step in describing the basic ecology of the rivers of the area should be to inventory the species present and identify taxonomic problems, elucidate life histories of common species and attempt to gain sufficient insight into the nature of the aquatic habitats in the area to allow planning of future, more detailed studies. The need for such basic groundwork is illustrated by reports suggesting that previously published life histories may not be directly applicable to northern areas where local populations have adapted to the long winters (Clifford 1969; Rosenberg et al. 1977a).

1.2 METHODS

From 23 June through late October 1976, random collections of benthic invertebrates were made at approximately weekly reaches at two sites: one about 0.5 km above the mouth of the Steepbank River (site S-8), and another 1 km above the mouth of the Muskeg River (site M-1, Figures 1 and 2). Organisms were collected using the "kick" technique (Hynes 1961) and by hand-picking while wading or snorkeling. Additional material was collected from the lower reaches of the Beaver and MacKay rivers at irregular intervals, and incidental collections were made at remote sites by various members of crews working on fishery projects. On 22 July and 11 October, six sites on the Muskeg River and eight on the Steepbank River were kick-sampled (Figure 2). Six of these were revisited in late January. All samples were preserved in 10% formalin and sorted in the laboratory (under 10X magnification).

Cultures of organisms from the Muskeg and Steepbank rivers were maintained in aerated aquaria in the laboratory at the AOSERP Mildred Lake Research Facility throughout the summer and emerging insects collected from them. Fresh specimens from the field were added at frequent intervals.

1.3 RESULTS AND DISCUSSION

Over 200 discrete taxa have been recognized from the material examined to date (Table 1). Many of

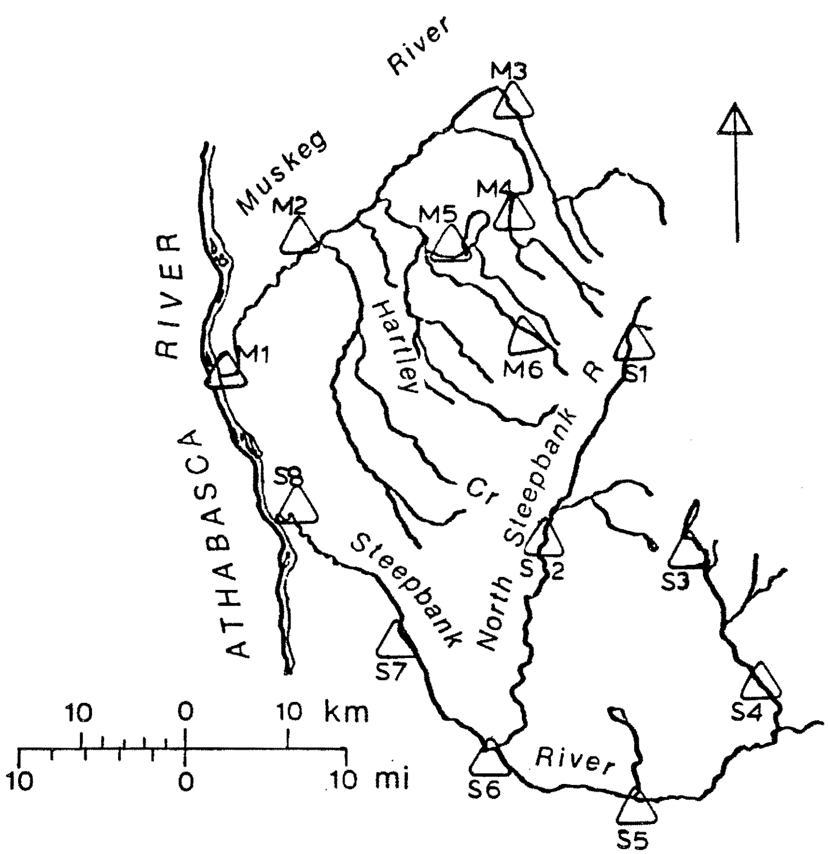


Figure 2. Collection sites, Muskeg (M) and Steepbank (S) rivers.

Table 1. A preliminary list of benthic taxa collected from the AOSERP study area, 1976-77.

Porifera
- *Spongilla* Lamarck

Coelenterata
- *Hydra*

Nematoda

Hirudinoidea
- *Dina*
- *Glossiphonia complanata* (Linnaeus)
- *Haemopis grandis* (Verrill)
- *Helobdella stagnalis* (Linnaeus)

Oligochaeta

Aoelosomatidae

Enchytraeidae

Lumbriculidae
- *Lumbriculus variegatus* (Müller)

Tubificidae
- *Limnodrilus claparedianus* Ratzel
- *L. hoffmeisteri* Claparede
- *Peloscolex ferox* (Eisen)
- *P. ?superiorensis* Brinkhurst & Cook

Naididae
- *Chaetogaster diaphanus* (Gruithuisen)
- *C. diastrophus* (Gruithuisen)
- *C. langi* Bretscher
- *Dero digitata* (Müller)
- *Nais* sp. Müller — possibily undescribed
- *N. communis/variabilis*
- *N. pseudobtusa* Piquet
- *N. simplex* Piquet
- *Pristina breviseta* Bourne
- *P. ?foreli* (Piquet)
- *P. longiseta* Ehrenberg
- *Slavina appendiculata* d'Udekem
- *Specaria josinae* (Vejdovsky)
- *Stylaria lacustris* (Linnaeus)
- *Uncinais uncinata* (Örsted)

Mollusca

Pelycepoda

Sphaeriidae
- *Musculium* Link
- *Pisidium* spp. Pfeiffer
- *Sphaerium* spp. Scopoli

Continued ...

Table 1. Continued.

Unionidae	
Lampsilis sp. Rafinesque	
Gastropoda	
Amnicola ?limosa (Say)	
Ferrissia Walker	
Gyraulus parvus (Say)	
Lymnaea spp. Lamarck	
Physa Draparnaud	
Valvata ?lewisii Currier	
Insecta	
Ephemeroptera	
Ephemeridae	
Ephemera sp. Linnaeus	
Caenidae	
Caenis Stephens	
Brachycercus Curtis	
Tricorythodes Ulmer	
Baetiscidae	
Baetisca ?columbiana	
B. obesa Say	
Ametropidae	
Ametropus sp. Albarad	Athabasca R.
Siphlonuridae	
Ameletus Eaton	
Siphlonurus Eaton	
Baetidae	
Baetis spp. Leach	
Callibaetis Eaton	
?Heterocloeon McDunnough	
Isonychia Eaton	
Ephemerellidae	
Ephemerella aurivillii (Bengtsson)	
E. grandis ingens McDunnough	
E. margarita Needham	
E. simplex McDunnough	
E. spinifera Needham	
E. tibialis McDunnough	
Leptophlebiidae	
Leptophlebia Westwood	
Paraleptophlebia Lestage	
Heptageniidae	
Heptagenia spp. Walsh	
Rhithrogena Eaton	
Stenacron interpunctatum (Say)	
Stenonema vicarium (Walker)	

Continued ...

Table 1. Continued.

Odonata

Anisoptera
Aeshna Fabricius
Cordulia shurtleffi Scudder
Leucorrhina Brittinger
Ophiogomphus Selys
?Perithemis Hagan

Zygoptera
Agrion Fabricius

Plecoptera

Nemouridae
Amphinemoura ?linda Ricker
Nemoura Pictet
Zapada Ricker

Leuctridae
Leuctra ?sara (Claassen)

Taeniopterygidae
Brachyptera glacialis (Newport) Athbasca R.
Taeniopteryx nivalis (Fitch)
T. parvula Banks

Capniidae
Capnia limata Frison

Pteronarcidae
Pteronarcella Banks
Pteronarcys dorsata (Say)

Perlodidae
Arcynopteryx Klapalek
Isogenus Newman
Isogenoides ?frontalis (Hagen)
Isoperla Banks

Chloroperlidae
Hastaperla brevis (Banks)

Perlidae
Acroneuria ?lycorias (Newman)
Claassenia sabulosa Banks

Megaloptera
Sialis Latreille

Trichoptera

Rhyacophilidae
Rhyacophila Pictet

Glossosomatidae
Glossosoma Curtis

Philopotamidae
Dolophilodes McLachlan

Continued ...

Table 1. Continued.

Psychomyidae
Polycentropus Curtis
?Psychomyia Pictet

Hydropsychidae
Arctopsyche McLachlan
Cheumatopsyche Wallengrean
Hydropsyche spp. Pictet

Hydroptilidae
Agraylea Curtis
Hydroptila Dalman
Mayatrichia Mosely
Ochrotrichia Mosely
Orthotrichia Eaton
Oxyethira Eaton

Phryganaeidae
Ptilostomis Kolenati

Limnephilidae
?Astenophylax Ulmer
Dicosmoecus McLachlan
Glyphopsyche Banks
Goera spp. Curtis
Grammotaulius Kolenati
Limnephilus Leach
?Onocosmoecus Banks
Pycnopsyche Banks

Leptoceridae
Athripsodes Billberg
Ceraclea Stephens
Oecetis avara-grp. (Banks)

Lepidostomatidae
Lepidostoma Rambur

Brachycentridae
Brachycentrus spp. Curtis
Micrasema McLachlan

Helicopsychidae
Helicopsyche borealis (Hagen)

Lepidoptera
Nymphula Schrank

Hemiptera

Corixidae
Callicorixa audeni Hungerford
C. alaskensis (Hung.)
Hesperocorixa atopodonta (Hungerford)
H. michiganensis (Hungerford)
H. minorella (Hungerford)

Continued ...

Table 1. Continued.

Sigara cf. *alternata* (Say)	
S. conocephala (Hungerford)	
S. decoratella (Hungerford)	
S. grossolineata Hungerford)	
S. solensis (Hungerford)	
S. trilineata (Provancher)	Lake Athabasca
Trichocorixa borealis Sailer	Lake Athabasca
S. bicoloripennis (Wally)	
S. penniensis (Hung.)	
Gerridae	
Notonectidae	
Notonecta ?kirbyi Hungerford	
Coleoptera	
Haliplidae	
Brychius Thomson	
Dytiscidae	
Agabetes Crotch	
Deronectes Sharp	
Dytiscus Linnaeus	
Hydaticus Leach	
Hydroporus Clairville	
Ilybius Erichson	
Gyrinidae	
Gyrinus pleuralis Fall	
Hydrophilidae	
Paracymus Thomson	
Elmidae	
Optioservus fastiditus (leConte)	
Diptera	
Tipulidae	
Antocha Osten Sacken	
Dicranota Zetterstedt	
Eriocera Macquart	
Holorusia Loew	
Prionocera Loew	
Tipula Linnaeus	
Psychodidae	
?Telmatoscopus Eaton	
Simuliidae	
Ceratopogonidae	
Stratiomyidae	
Stratiomyia Geoffrey	
Tabanidae	

Continued ...

Table 1. Continued.

Empididae

Ephydridae
?Psilopa Fallen

Rhagionidae
Atherix prob. *pachypus* Bigot

Chironomidae

Tanypodinae
Ablabesmyia Johannsen
Conchapelopia Fittkau
Labrundinia Fittkau
Nilotanypus Kieffer
Paramerina Fittkau
Procladius Skuse
Thienemannimyia Fittkau

Chironominae - Chironomini
Chironomus annularis-grp. (Meigen)
C. tentans (Fabricius)
C. thummi-grp. (Kieffer)
Cryptochironomus Kieffer
Cryptocladopelma Lenz
Cryptotendipes Lenz
Endochironomus Kieffer
Glyptotendipes Kieffer
?Kiefferulus Goetghebuer
Microtendipes Kieffer
Parachironomus Lenz
Paraclodopelma Harnisch
Paralauterbourniella Lenz
Paratendipes Kieffer
Phaenopsectra Kieffer
Polypedilum spp. Kieffer
Robackia claviger (Townes)
Stictochironomus Kieffer

Tanytarsini
Cladotanytarsus Kieffer
Micropsectra Kieffer
Paratanytarsus Kieffer
Rheotanytarsus (Bause)
Stempellina Bause
Tanytarsus van der Wulp
Zavrelia Kieffer

Diamesinae
Diamesa (Meigen)
Monodiamesa Kieffer
Potthastia (Kieffer)
Syndiamesa Kieffer

Continued ...

Table 1. Concluded.

Orthocladiinae
Acricotopus Kieffer
Brillia Kieffer
?Cardiocladius Kieffer
Corynoneura Winnertz
Cricotopus spp. van der Wulp
C. (Isocladius) spp. van der Wulp
Diplocladius Kieffer
Eukiefferiella spp. Thienemann
Heterotrissocladius Sparck
Krenosmittia Thienemann
Limnophyes (Eaton)
?Metriocnemus van der Wulp
Nanocladius (Thienemann & Harnisch)
Orthocladius (van der Wulp)
Parakiefferiella (Thienemann)
Paraphanocladius Thienemann
Psectrocladius (Kieffer)
Rheocricotopus (Thienemann & Harnisch)
Synorthocladius Thienemann
Thienemanniella Kieffer
genus nr. *Pseudorthocladius*

these, especially certain genera of Chironomidae, appear to include several species which will be separated as more material, both immature and adult, is examined.

The nature of benthic communities which are found in the running waters of our study area is strongly influenced by local topographic and geologic features. There appear to be at least seven distinct stream types or zones within the area; five of which, have been examined: (1) high-gradient brooks with sand and gravel substrates which drain directly into deeper river valleys or off high areas such as Muskeg Mountain; (2) small seeps which drain areas of wet muskeg; (3) larger, low-gradient streams which drain extensive muskegs; (4) large, high-gradient streams which cut through glacial till and thus have substrates consisting of boulders and gravel; (5) large, high-gradient streams which cut through limestone and have substrates consisting primarily of limestone rubble and gravels; (6) streams cutting through oil sands deposits; and (7) the very large, Athabasca River whose substrate appears to be a complex mosaic of sand, gravel, mud, boulders, and bedrock. The small muskeg seeps and the mainstem Athabasca have not been considered in any detail in the present report.

The fauna of small, steep-gradient streams is not very diverse, probably due to the intermittent flow regime which prevails. These streams appear often to go dry in the summer and freeze solidly into the substrate during the winter. The summer fauna is characterized by the dominance of *Amphinemoura linda*, *Glossosoma* and *Stempellina*. It will be of great interest to discover whether any of these populations survive the winter.

Major portions of all of the tributary streams in the AOSERP study area flow through wet muskeg. These low-gradient reaches have steep banks of mud held together by the roots of plants. Rooted macrophytes develop in summer along the margins and in shallow sections. The substrate in midstream is gravel which becomes covered with silt during summer and winter low flows. Spring runoff clears the substrate of this annual accumulation of organic and inorganic detritus and the larvae of blackflies develop on stones and sticks which have entered the stream largely as a result of beaver activity. The fauna is characterized by oligochaetes (Naididae in summer, Tubificidae in winter), Ostracoda, Amphipoda and Chironomidae (especially *Chironomus* spp., *Tanytarsus*, and a variety of Orthocladiinae).

Most of the benthic biomass of boulder streams, such as Hartley Creek (Figure 1) and much of the Steepbank and MacKay rivers, consists of larvae of caddisflies (Trichoptera). Especially abundant are species of Glossosomatidae, Hydropsychidae, Lepidostomatidae, and Brachycentridae. Mayflies, such as *Baetis* spp. and *Ephemerella ?spinifera*, are common and the diverse stonefly fauna is dominated by *Nemoura* spp., *Pteronarcys dorsata*, *Hastaperla brevis* and *Claassenia sabulosa*. Chironomini are rare and such other chironomids as *Micropsectra*, *Rheotanytarsus* and *Eukiefferiella* spp. are as numerically abundant as the Trichoptera but contribute less biomass. Samples analyzed to date suggest that the seasonal changes in species composition of boulder streams may be smaller than in other types of streams.

Mayflies (e.g. *Baetis spp.*, *Ephemerella aurivillii*, *Leptophlebia*, *Heptagenia*) and stoneflies e.g. *C. sabulosa*, *P. dorsata*, *H. brevis*, *Nemoura*, *Taeniopteryz*, *Isoperla*) characterize the fauna of streams whose substrate consists of limestone rubble. The trichopteran fauna, while diverse in the number of species present, is dominated by larvae of *Hydropsyche* and *Cheumatopsyche.* The larvae and adults of *Optioservus fastiditus* are common and the larvae of *Eriocera* and *Atherix* probably *pachypus* (D. Webb, pers. comm.) are important predators. The abundance of individuals of several winter and summer species makes the seasonal changes in the fauna more noticeable than in boulder streams. Summer forms include the mayflies *Caenis*, *Brachycercus*, *Tricorythodes*, *Paraleptophlebia*, and some species of *Heptagenia*. Organisms which are actively present only from autumn to early spring include the mayfly *Leptophlebia* and the stonefly *Taeniopteryx nivalis*, *Nemoura* and *Isoperla*. Larvae and pupae of Simuliidae are abundant only during the spring.

The density of the fauna on exposed oil sand is several orders of magnitude lower than on other substrates, but this appears to be due to the thin layer of the inhabitable substrate rather than to any toxic effects (in preparation). This fauna is dominated by smaller organisms such as Enchytraeidae, Naididae, *Baetis* spp., *Simulium tuberosum*-complex, Tanytarsini, and Orthocladiinae. Sampling in January suggested that the density of the fauna in winter may be greatly reduced, probably as a result of ice abrasion and freezing of this substrate which offers no deep refuges.

The range of the standing stocks in these various types of streams appears to be very great. In part of a quantitative study of the fauna of the exposed area of the lower Steepbank (in progress), it was found that the summer standing stock of organisms averaged about $4000/m^2$. Where a thin layer of gravel and rubble covered the oil sand surface, the density of the fauna averaged about $5800/m^2$. In contrast, the top 10 cm of fine rubble and gravel in the lower Muskeg River in October supported about 10,000 organisms/m^2.

As in the only previous comprehensive study of the benthos of a muskeg stream (Clifford 1969), the fauna of the streams studied so far in the AOSERP study area includes many plains (i.e. eastern) and cordilleran (i.e. western) species. Since many of these species have not been previously recorded from the study area and their biology is poorly known, several of the insect groups merit individual consideration.

1.3.1 Ephemeroptera

1.3.1.1 Baetiscidae. The genus *Baetisca* is primarily eastern in its distribution although the ranges of *B. obesa* and *B. lacustris* have recently been extended westward to the South Saskatchewan River near Prince Albert (Lehmkuhl 1972). The only truly western species, *B. columbiana*, was described from one nymph collected from the Columbia River in Washington (Edmunds 1960) and does not appear to have been recorded since. Thus our records of *B. obesa* represent a further range extension and first record of this species from the Mackenzie drainage. Since our collections of *B. columbiana* are from near the mouths of the Muskeg and Steepbank rivers, and the nymphs of this genus are generally found in sandy habitats, it seems likely that further work will show this very rare species to be primarily an inhabitant of the mainstem Athabasca River.

1.3.1.2 Ephemerellidae. Among the species of *Ephemerella* recorded so far, the occurrence of *E. aurivillii* and *E. tibialis* is not surprising while *E. margarita* has been previously reported from southern Alberta and *E. spinifera* from British Columbia (Allen and Edmunds 1961, 1962a, 1965). The record of *E. simplex* represents a western extension of its previously reported range which was only as far west as Manitoba (Allen and Edmunds 1962b).

1.3.1.3 Heptageniidae. Nymphs of *Stenonema* and *Stenacron* are among the most common mayflies in many streams of eastern North America. In a recent review of the taxonomy and biology of this group, Lewis (1974) listed only *Stenonema tripunctatum* as occurring as far west as Manitoba. Clifford (1969) found *Stenonema canadense* (=*Stenacron interpunctatum*) in the Bigoray River, a tributary of the Athabasca. Both *S. interpunctatum* and *Stenonema vicarium* occur in the AOSERP study area and the latter is very common but not numerically abundant.

1.3.2 Plecoptera

Our list of stonefly species is far from complete since the nymphs of many species are active only in the winter. Further collecting, especially during early spring, should yield several more species as well as mature specimens which will allow the specific determination of several others.

As with the Ephemeroptera, the plecopteran species recognized so far include both eastern and western forms: *Leuctra sara* and *Hastaperla brevis* are widespread throughout the Nearctic region; *Amphinemoura, linda, Zapada, Pteronarcella regularis* and *Claassenia sabulosa* are cordilleran species; *Taeniopteryx parvula, T. nivalis* and *Pteronarcys dorsata* are predominantly eastern in their distribution.

Pteronarcys dorsata is common in the mainstem Athabasca River (Flannagan 1977) and it and *C. sabulosa* were the most common stoneflies in the lower Muskeg River in summer of 1976. The life cycle of both species has not been reported in the literature. While the paucity of specimens in present collections from certain strategic periods of the year preclude any definitive statements at this time, it appears that both species require three years to reach maturity in the Muskeg

River (Figures 3 and 4). Emergence probably occurs in May for *P. dorsata* and adults of *C. sabulosa* were found in July and early August.

Among the stoneflies which develop in winter in the Muskeg and Steepbank rivers, one of the most abundant is *Taeniopteryx nivalis*. Adults emerge in mid-April as the ice is breaking up (Figure 5). Young larvae of eastern populations have been found to burrow deeply into the substrate where they undergo a summer diapause (Harper and Hynes 1970). Active larvae, 2-3 mm in length, appear in the Muskeg River in mid-Septmber as water temperatures fall. Growth is rapid through October and some larvae reach full size by the end of January.

1.3.3 Hemiptera

1.3.3.1 Corixidae. The distributions of 11 species of Corixidae in the Muskeg and Steepbank rivers are given in Figures 6-11. All of the species found so far are already known from this geographical region (Brooks and Kelton 1967) with the possible exception of the taxon listed as "*Sigara* cf. *alternata*" (Table 1) which do not appear to correspond to any of the known Alberta species. *Hesperocorixa atopondonta* (Figure 9) and *H. michiganensis* (Figure 10) were found throughout the Muskeg and Steepbank watersheds. *Callicorixa audeni* appears to be restricted to the lower reaches of these streams and also occurs, with *C. alaskensis*, in the mainstem Athabasca River (Figure 11). The other, rarer species will probably occur in future collections throughout the study area wherever their specific microhabitat requirements are met (Macan 1976).

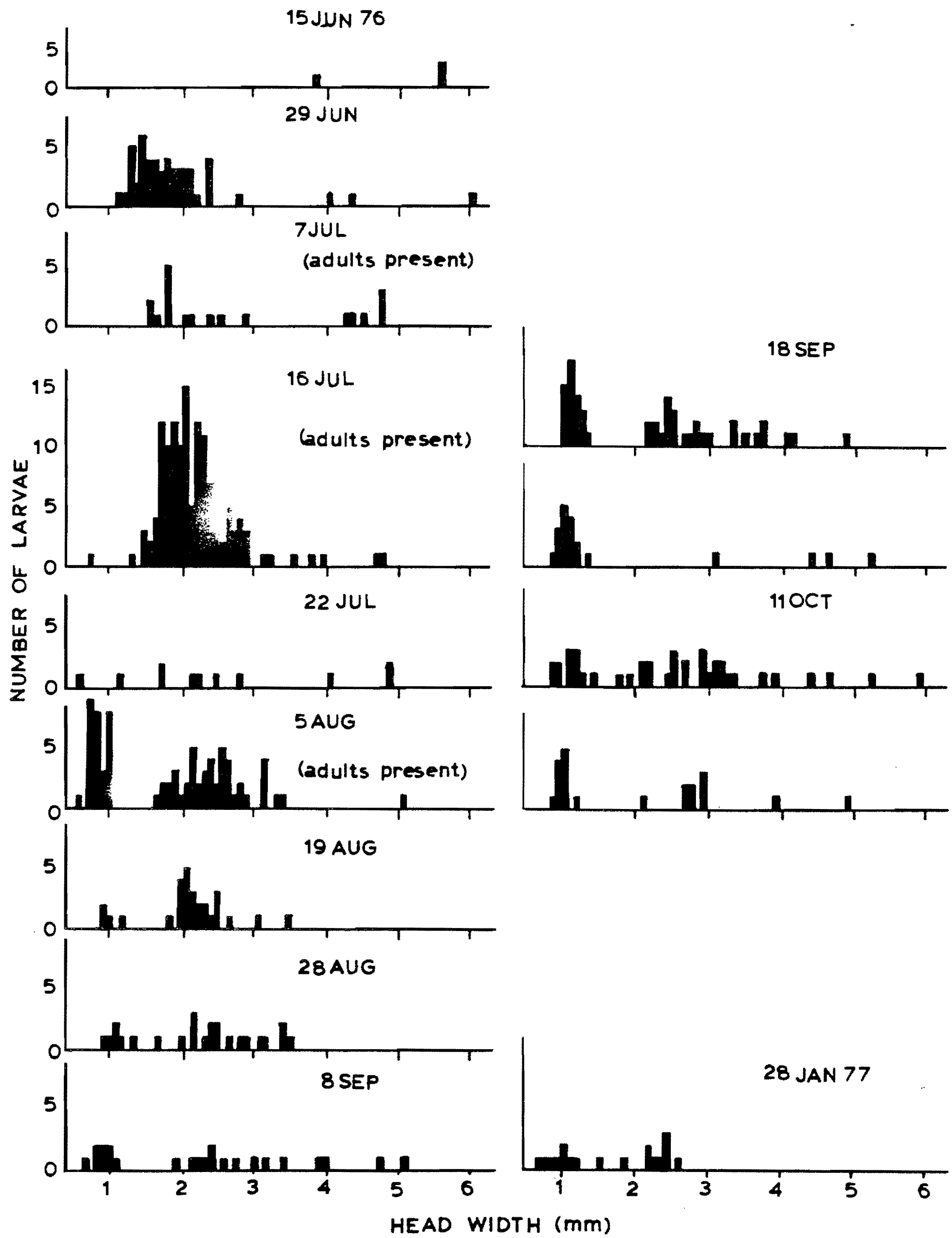


Figure 3. Growth of *Claassenia sabulosa*.

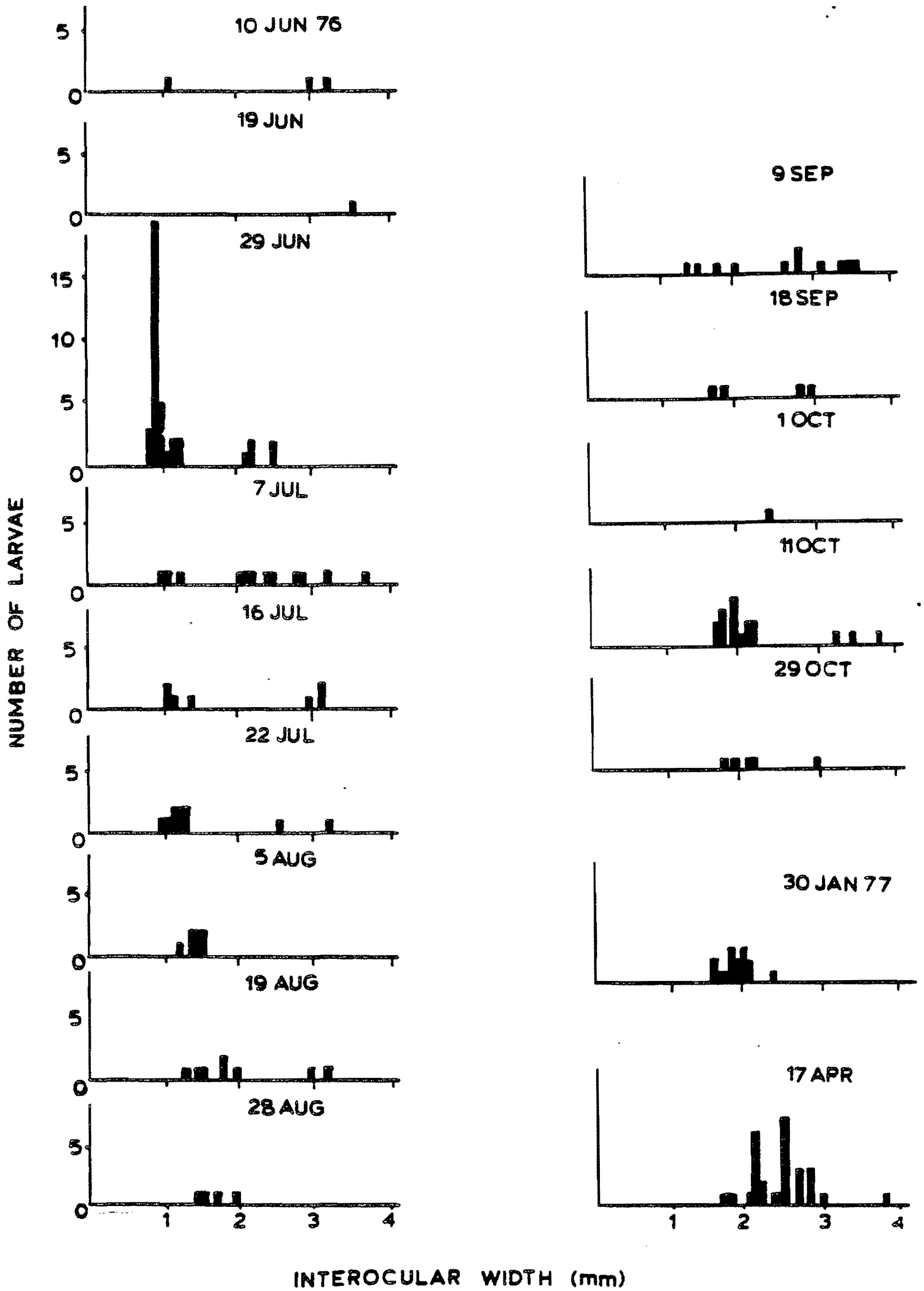


Figure 4. Growth of *Pteronarcys dorsata*.

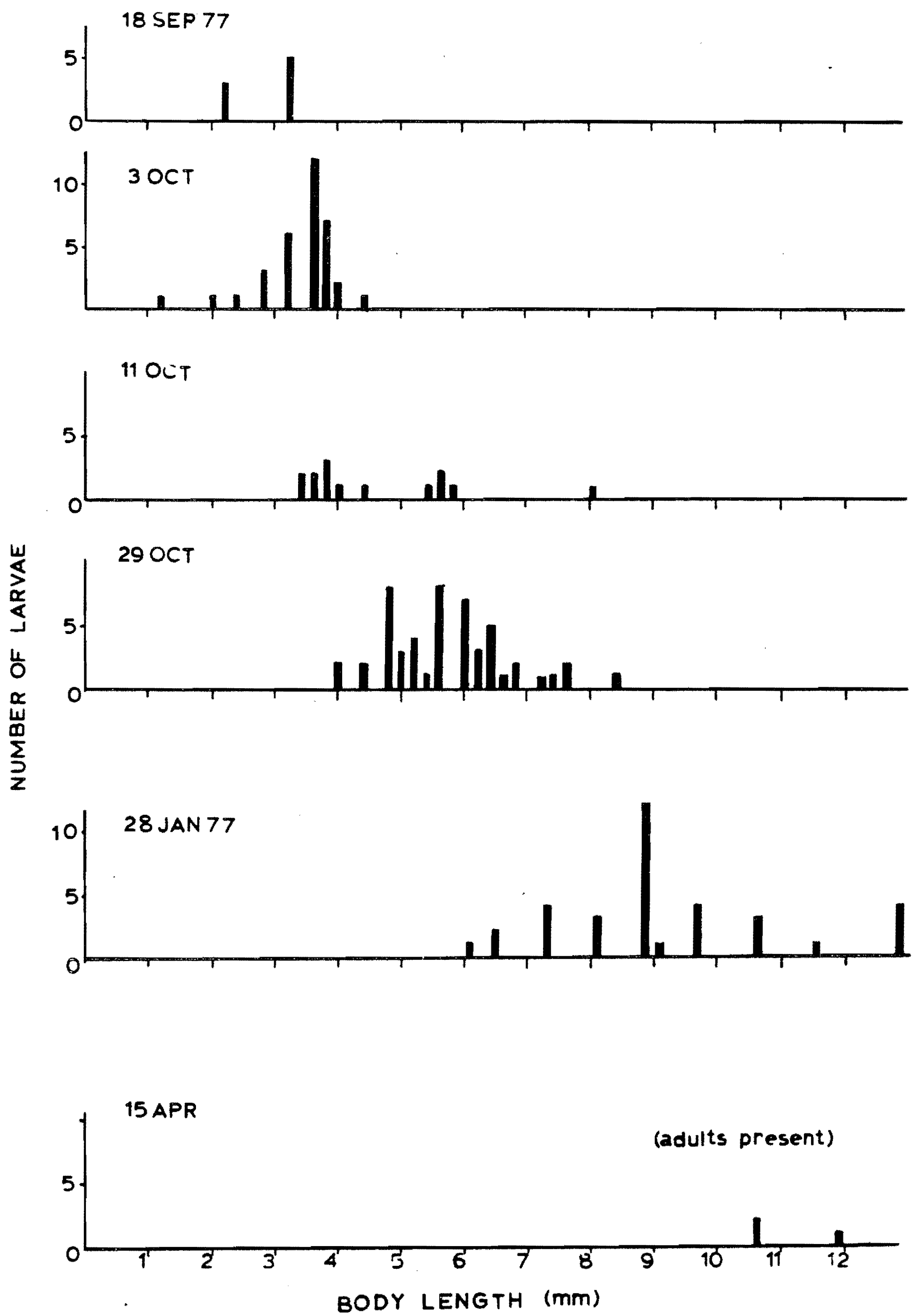


Figure 5. Growth of *Taeniopteryx nivalis*.

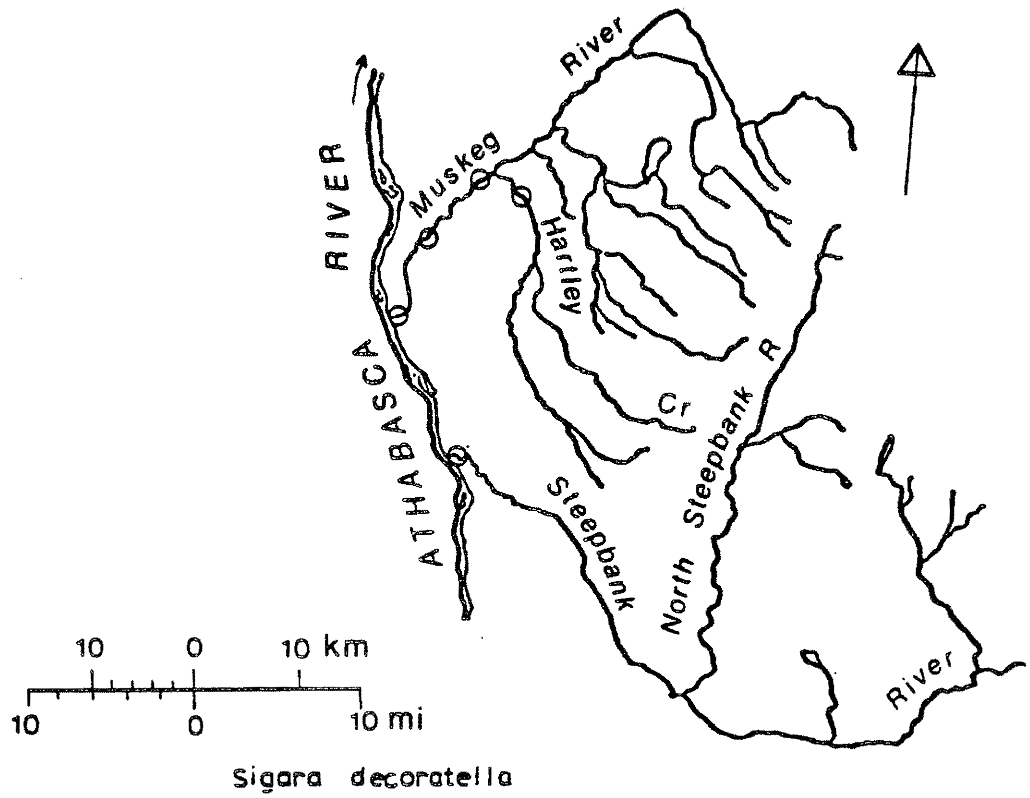
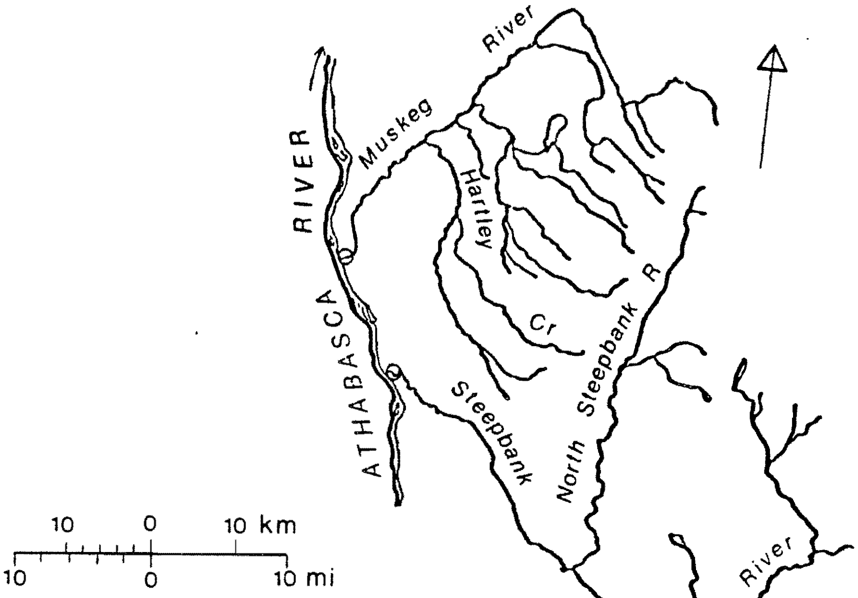
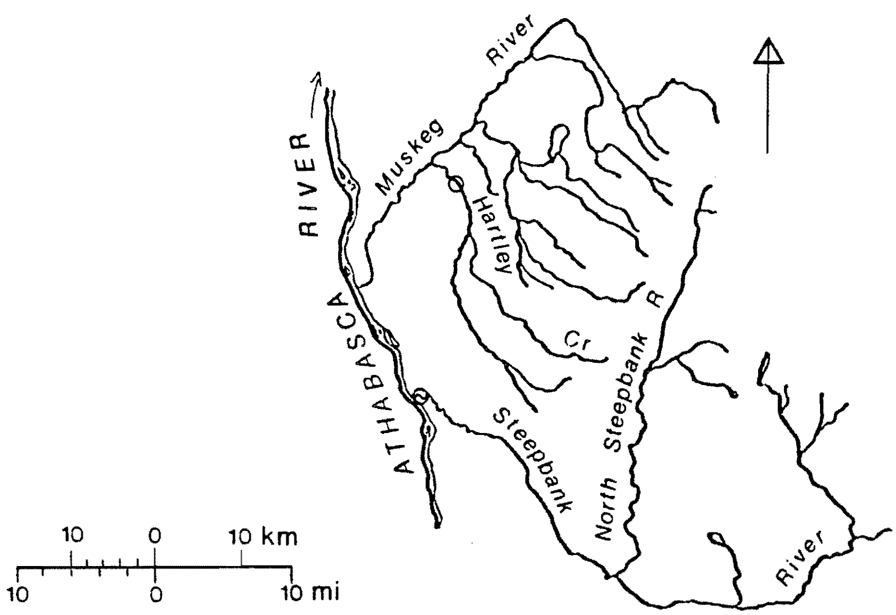


Figure 6. Collection records for *Sigara decoratella*.



(b) Sigara solensis



(b) Sigara conocephala

Figure 7. Collection records for *Sigara solensis* (a) and *S. conocephala* (b).

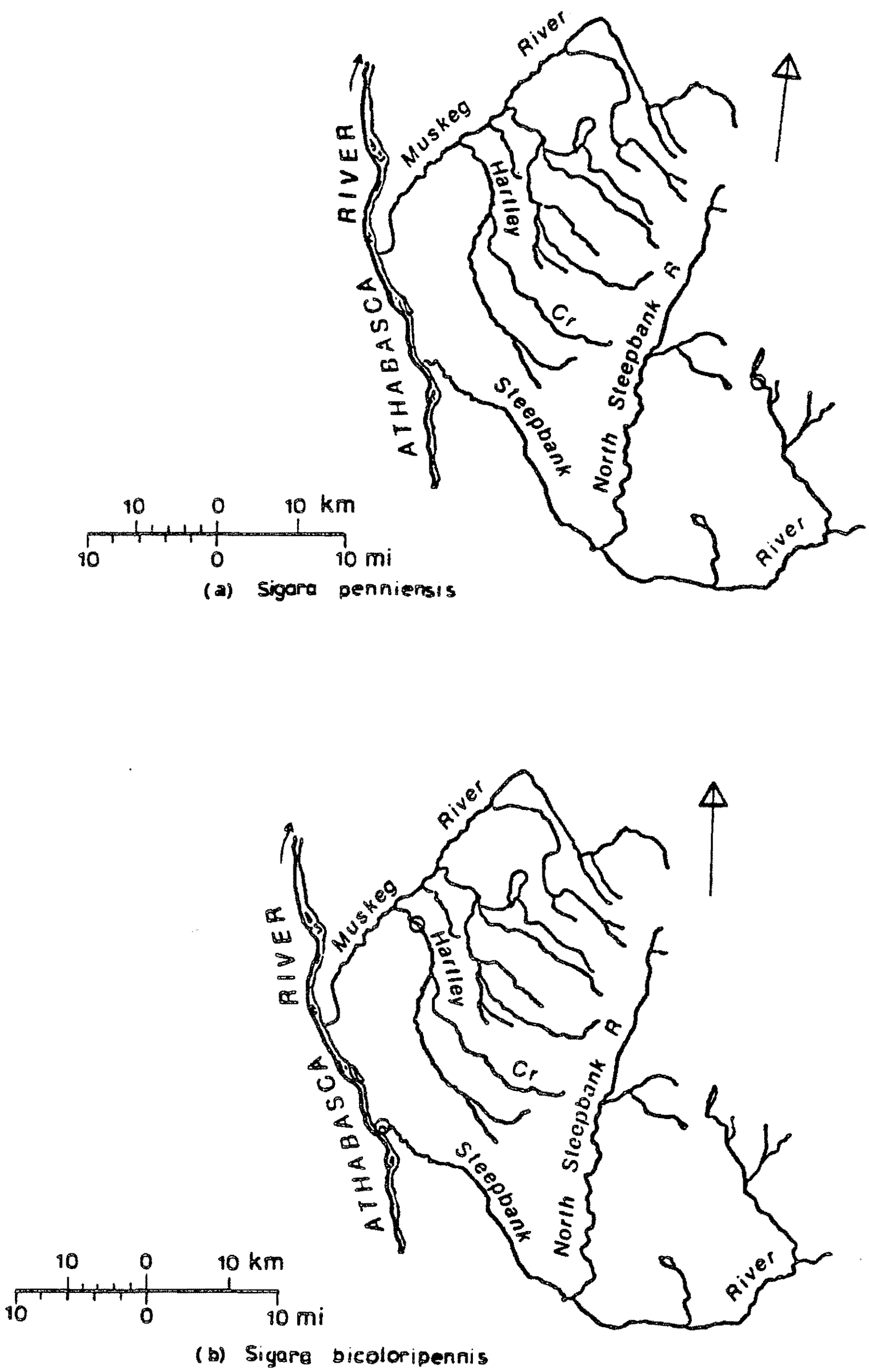
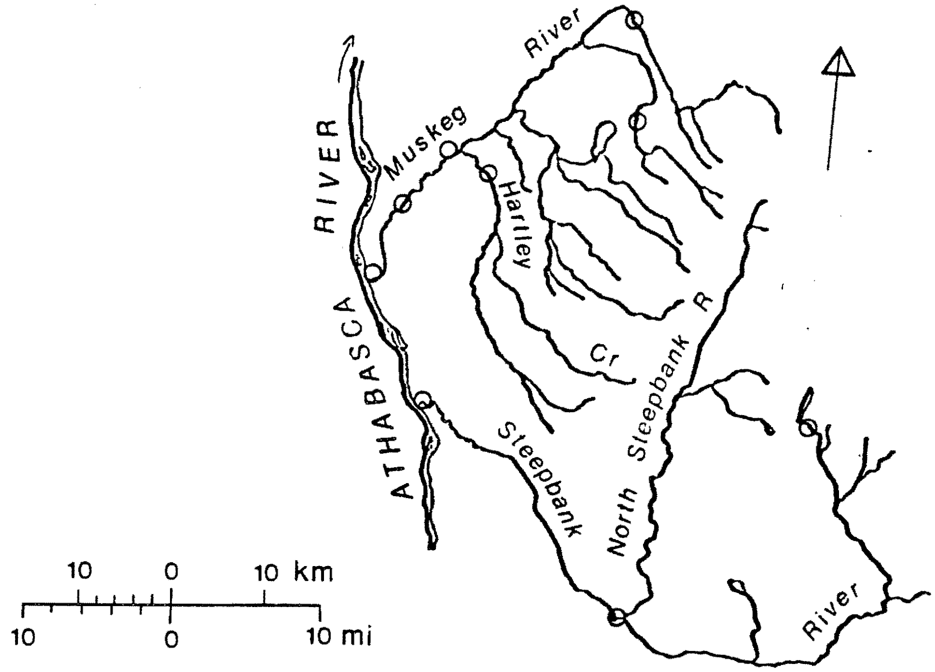
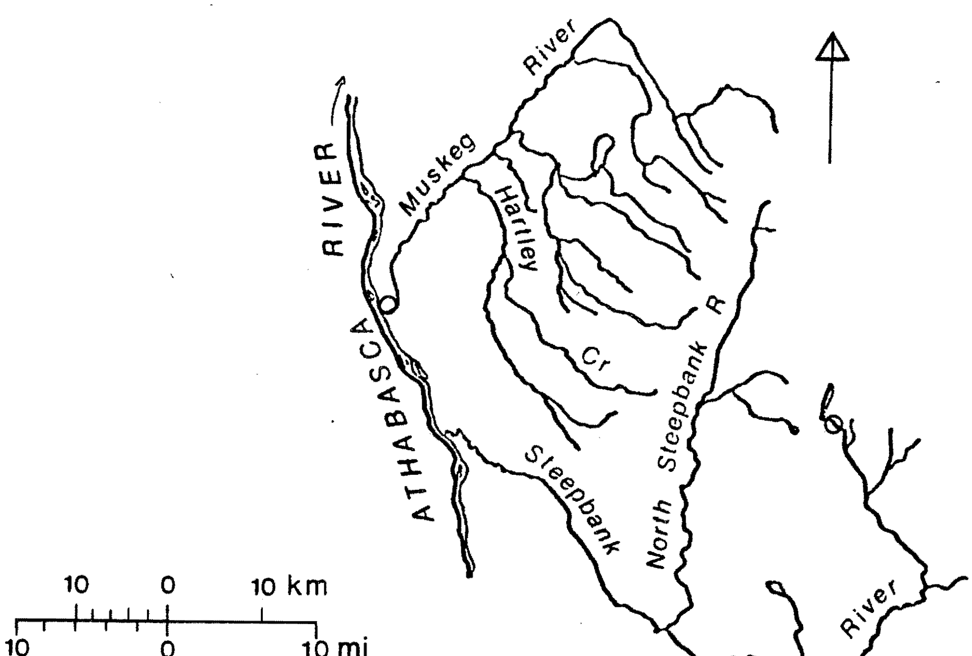


Figure 8. Collection records for *Sigara penniensis* (a) and *S. bicoloripennis* (b).

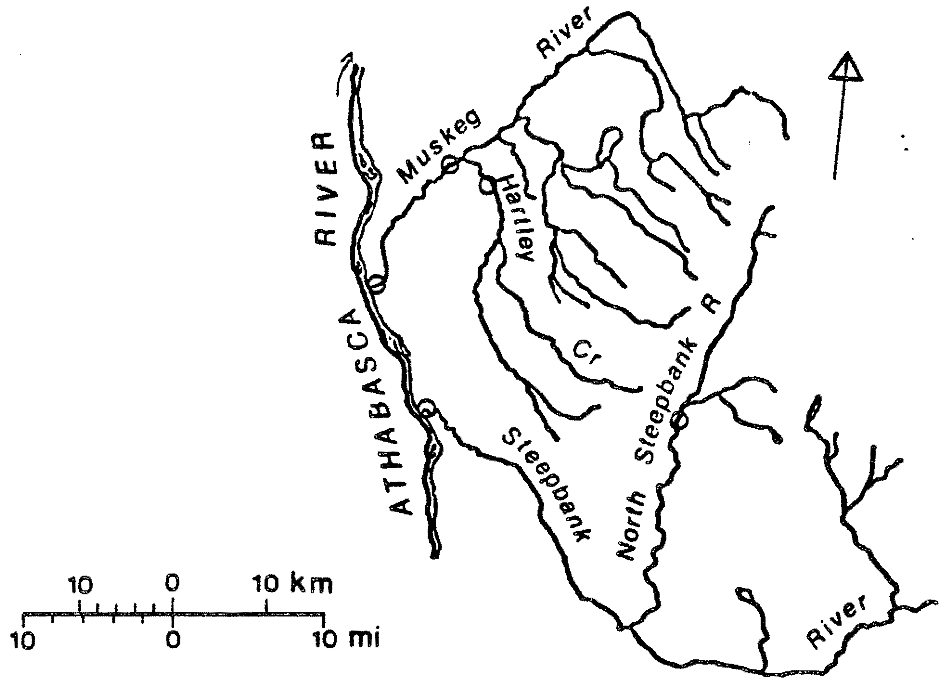


(a) Hesperocorixa atopodonta

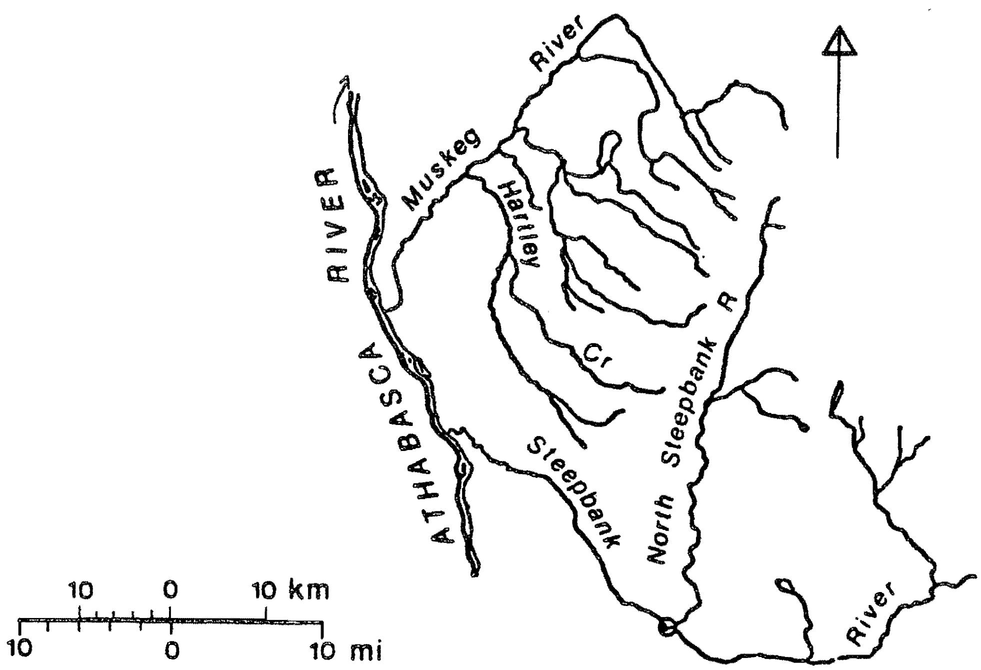


(b) Sigara grossolineata

Figure 9. Collection records for *Hesperocorixa atopodonta* (a) and *Sigara grossolineata* (b).



(a) Hesperocorixa michiganensis



(b) Hesperocorixa minorella

Figure 10. Collection records for *Hesperocorixa michiganensis* (a) and *H. minorella* (b).

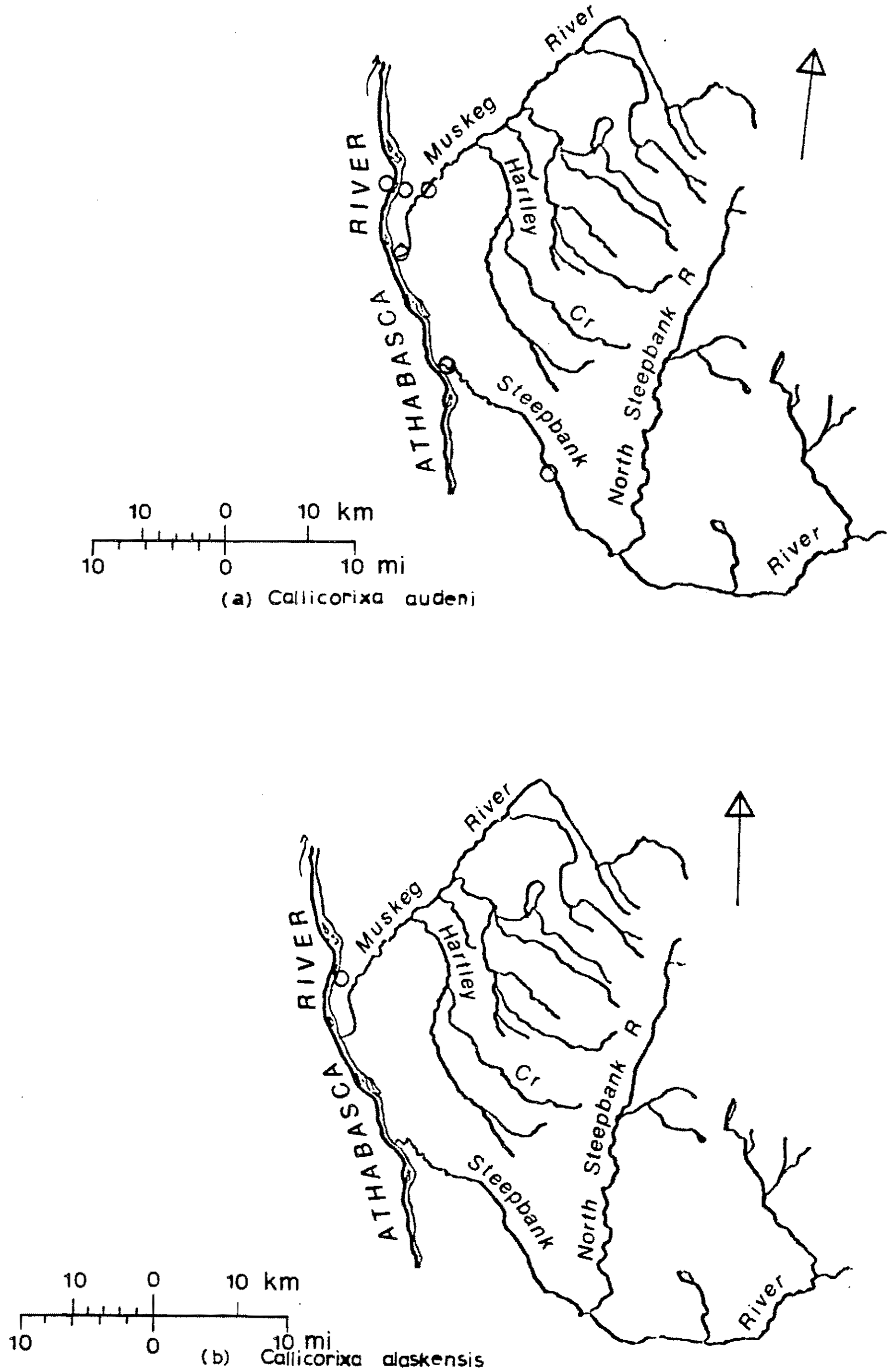


Figure 11. Collection records for *Callicorixa audeni* (a) and *C. alaskensis* (b).

1.3.4 Diptera

1.3.4.1 Simuliidae. While blackflies are common, and seasonally or locally abundant in the study area, they have not been treated taxonomically due to the confused status of most of the species and species-complexes present. Co-operative studies with B.V. Peterson (Biosystematics Research Institute, Ottawa) planned for the coming year should clarify many of these problems.

1.3.4.2 Rhagionidae. One of the most common large organisms inhabiting riffles in the study area is the larvae of the snipe fly, *Atherix* prob. *pachypus*. Little is known of the biology of *Atherix* in North America, but in Japan both larvae and adults are primarily predaceous (Nagatomi 1962). The larvae feed on immature chironomids, mayflies, and craneflies as well as diatoms and associated microfauna while the adults have been reported to feed on frogs, cattle, horses and rarely, man.

The eggs are layed on objects overhanging the water, 0.3 to 2.0 m above the surface of the stream, usually in large clusters (Johannsen 1935, Nagatomi 1962). Hatching occurs within 5-12 days among the Japanese species, at which point the larvae crawl from the egg and drop into the water.

In the Muskeg and Steepbank rivers, emergence of the adults takes place prior to mid-June when empty pupal exuviae were found under stones on dry gravel bars. Young larvae, 2-3 mm in length, appeared in mid-July and grew to a length of 10-12 mm by January (Figure 12). There appears to be little growth beyond this size between January and June, though smaller larvae probably catch up during this time. Growth is rapid during the second summer with most larvae reaching 15 mm by mid-July and a final length of 18-20 mm by early October.

The literature indicates that oil sands

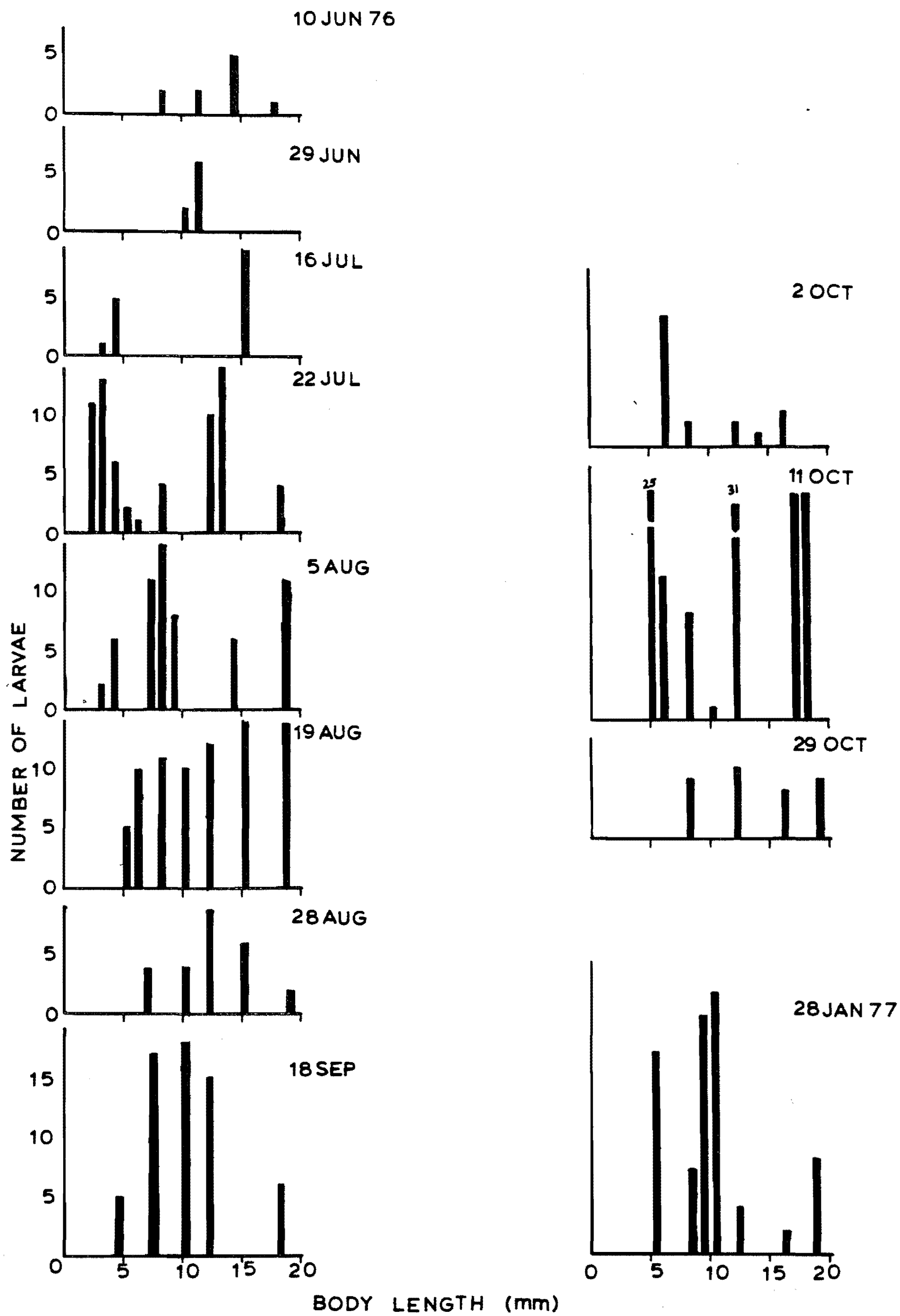


Figure 12. Growth of *Atherix ?pachypus* larvae.

developments would probably be detrimental to this species where such development causes the removal of overhanging vegetation from stream banks eliminating most of its potential oviposition sites. Otherwise, the larvae of this genus appear to be very tolerant of stresses such as lampricides (Rye and King 1976) as well as siltation and saline groundwaters since it is still common in the lower Beaver River.

1.3.4.2 Chironomidae. To date, there has not been time for detailed study of the chironomid fauna, so we will not comment here as to the species present. Over 100 mature larvae were reared through to the adult stage in the laboratory and more intensive rearing efforts are planned for the coming year. The incomplete knowledge of this group in North America in general, and in the north in particular, makes it virtually certain that a number of previously unknown species will be discovered. So far, at least one larval type, designated "genus near *Pseudorthocladius*" (Table 1), has been found which may represent a new species.

To summarize, the tributary streams which have been studied support a benthic fauna which is rich in number of species. These occur in distinct communities in each of the principle types of streams present and both diversity and productivity of these communities appear to be related to the complexity of the environment (i.e. substrate heterogeneity) and possibly natural stresses such as high summer temperatures, flow regime, ice development, and scouring.

Taxonomically, many of the groups and species present are poorly known. The AOSERP study area appears to be representative of a unique region of overlap of eastern and western species groups. The presence of such eastern species as *Baetisca obesa*, *Stenacron interpunctatua* and *Stenonema vicarium* which have poor powers of dispersal in the aerial adult stage poses some interesting zoogeographical questions including the possibility of a link between the Mackenzie and Hudson's Bay drainages during one or more periods of glaciation.

Trophic relationships among the species inhabiting the tributaries of the Athabasca River remain largely unknown. Many predatory species, e.g. *Atherix pachypus*, *Classenia sabulosa*, *Arcynopteryx* sp. (which feeds on simuliid larvae in spring), *Ophiogomphus* sp., *Aeshna* spp., are present but their prey species remain to be defined. Studies on the other organisms not included in this discussion, but which appear in the list of species, were not completed at this time.

2. EXPERIMENTAL MANIPULATIONS

2.1 EFFECTS OF AN EXPERIMENTAL SPILLAGE OF OIL SANDS TAILINGS SLUDGE ON AQUATIC INVERTEBRATES

2.1.1 Introduction

The disposal or storage of residual aqueous tailings which result from the processing of oil sand derived from surface mining constitutes one of the major problems of environmental management associated with the development of the Athabasca Oil Sands in northeastern Alberta.

The residual tailings, commonly termed "tailings sludge" or "sludge" are produced in quantity by the presently operating oil sands mine, Great Canadian Oil Sands Limited (GCOS). Future open-pit mines, such as Syncrude Canada Ltd. will also produce this waste. GCOS mines 90,720 t of oil sand per day and produces tailings sludge at a rate of 0.131 m^3 t^{-1} (Camp 1976). These tailings are presently stored in large tailings ponds.

The objective of the present study was to determine the impact of an instantaneous experimental spill of tailings sludge on the benthic fauna of a small brown-water stream tributary to the Athabasca River.

2.1.2 Materials and Methods

The study was in a 30 m reach of the Muskeg River about 1 km above its confluence with the Athabasca River in northeastern Alberta (57° 08' N, 111° 35' W) (Figure 13). The site was chosen for its uniformity of depth, current velocity and substrate. At the beginning of the experiment, the mean width of the river at the study site was 15.5 m, the mean depth was 27 cm, and the discharge was 3.38 m^2 S^{-1}. The substrate consisted of angular limestone pebbles up to 5 cm in greatest diameter lying on an apparently uniform matrix of finer gravels, sand and clay. The upper surfaces of most of the larger pebbles were covered with a sparse growth of filamentous algae.

Samples of sludge from the GCOS tailings pond were collected for use by GCOS staff by means of a suction pump mounted on a floating platform. Chemical analyses were done on samples of the sludge, the methods and results of which are detailed in Appendix 1.

At 1445 M.D.T. on 2 October 1976, 0.11 m^3 (25 imp. gal.) of sludge from the GCOS tailings pond were quickly spilled into one side of the upper portion of the study site. Some of the sludge adhered to the substrate at the point of addition, but most passed through the 30 m reach in a distinct oily plume about 3 m in width. The water column in the treated area cleared within 15 minutes. Oil was observed emanating from the upstream area for several days.

Benthic samples were taken with a cylindrical scoop sampler which collected approximately 1ℓ of sediment from the surface down to a depth of 6 to 8 cm. Each scoop was emptied into a bucket and benthic organ-

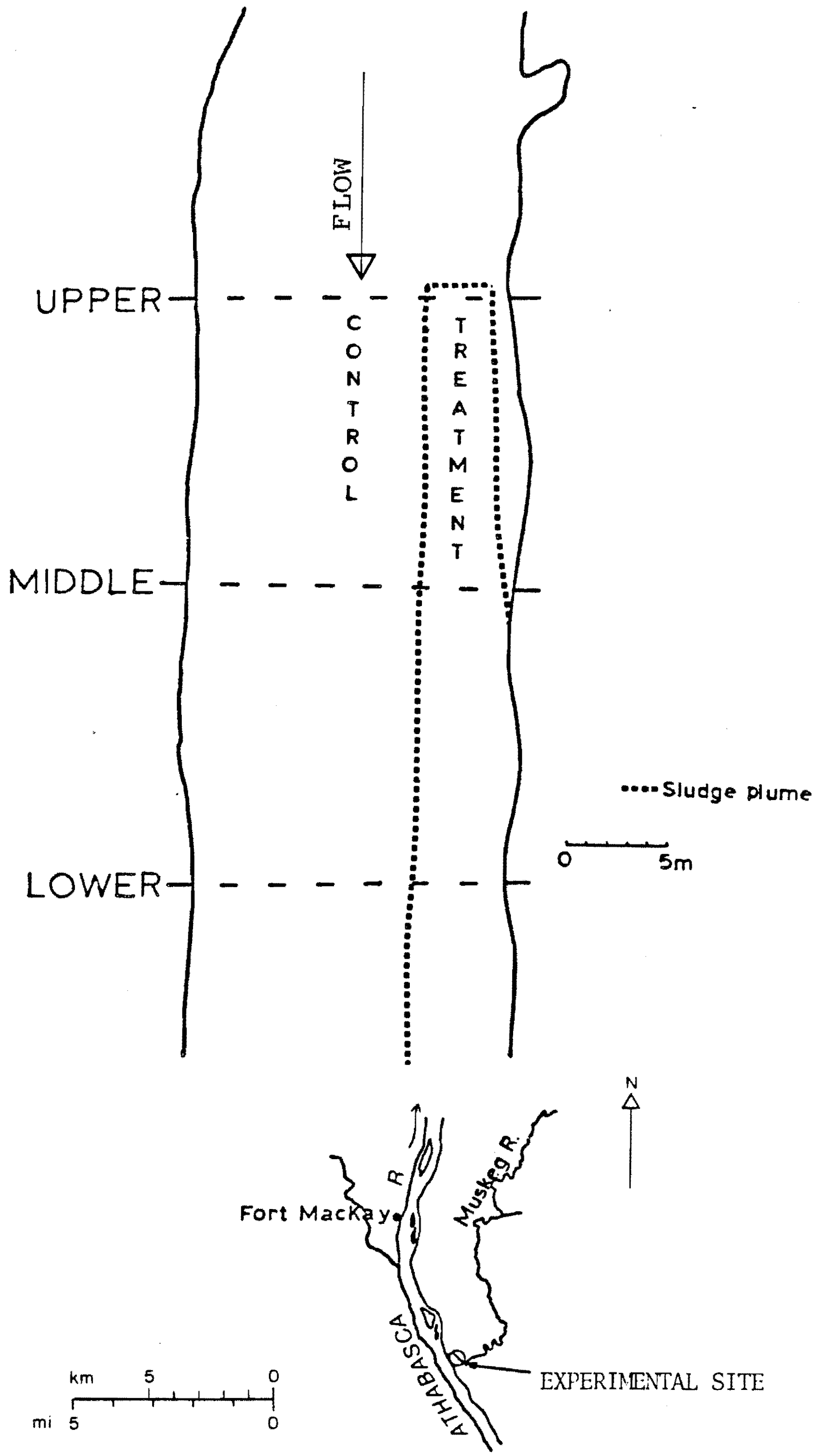


Figure 13. Experimental plan and view of the Muskeg River.

isms were eluted from it by adding river water, agitating thoroughly, and decanting through a 180 μm sieve. The agitating and decanting procedure was repeated until no new organisms occurred on the sieve following three successive decants. The remaining sediments in the bucket were examined for heavy-cased caddis larvae which were added to the material in the sieve. The samples were preserved in 10% formalin and the organisms were removed from the associated debris in the laboratory under 10X magnification.

Nine scoop samples were collected immediately prior to the addition of tailings sludge, 3 each from the upper, middle and lower sections of the study area (Figure 13). Of these, one was taken from the control side, one from the treatment side, and one between the two. Two hours after the sludge addition, two samples were taken from each of the upper, middle and lower areas of the untreated (control) side, and from the area covered by the tailings plume (treated side). Twelve samples were collected in the same pattern, 1, 3, 7, 14 and 28 days after the sludge was added. For each series, the order of sampling was from downstream (lower) to upstream (upper) to avoid disturbances of each area prior to sampling.

All organsisms except the Nematoda, Crustacea and Chironomidae were identified and enumerated at the generic or specific level. With the exception of several easily recognizable genera, the chironomids were separated only to subfamily or tribe since most of those from the treated samples were more or less covered with tar and therefore unidentifiable.

The standing stocks of various taxonomic groups, as well as total benthos from the treated and control sides of the study site, were compared over the entire sampling period using a t-test for paired samples.

2.1.3 Results

The sludge can be divided into three principle components: silt and sand, organic residues (including tars and asphaltenes), and heavy metals (Appendix 5.1).

The largest part (71%) of the silt-sand was made up of very fine clays. The "oil and grease" figure of 1.07 mg/kg was arrived at by the extraction being carried out with petroleum ether. Asphaltenes are largely insoluble in this solvent, and we therefore consider the Total Organic Carbon (TOC) figure (17.7%) to be a more accurate reflection of the amount of hydrocarbon residue present.

The amounts of cadmium, nickel, zinc, lead, and vanadium were all well above levels which are known to elicit a toxic response in aquatic organisms (Anon. 1971).

While the total number of animals in the pre-treatment samples did not differ significantly ($p > 0.05$) among the upper, middle and lower reaches, the large variances within individual taxa or groups indicated that most of these were distributed in a non-random, or clumped, pattern on the stream bed (Table 2). There was no significant difference between the prospective control and treatment sides of the study reach.

The total standing stock of benthic invertebrates on the treated side was significantly ($p < 0.05$) reduced within the 28 days of observation in the upper portion of the study area (Table 3). Samples from the treated side contained significantly lower ($p < 0.05$) numbers of all groups except the Oligochaeta, Trichoptera, Elmidae and Chironomini.

At the middle and lower sites, the total density of the fauna did not appear to be affected by the sludge, but significant ($p \leq 0.05$) reductions in the numbers of mayflies, stoneflies and the chironomid, *Corynoneura*, were observed (Tables 4 and 5). The

Table 2. Means and standard deviations for numbers of organisms in major groups taken in 1ℓ scoop samples prior to the sludge addition. Each value is based on three samples.

Taxa	Upper	Middle	Lower
Oligochaeta	95±25.2	103±52.4	139±55.0
Crustacea	38±12.7	32±13.6	43±32.7
Ephemeroptera	11±3.5	24±10.1	35±5.5
Plecoptera	16±4.2	9±1.7	8±3.5
Trichoptera	11±10.4	23±16.5	9±5.8
Coleoptera	20±11.8	34±30.1	20±11.9
Chironomidae			
Tanypodinae	104±21.2	81±41.1	120±34.2
Chironomini	80±28.7	119±78.7	84±1.2
Tanytarsini	143±14.4	201±124.8	188±38.0
Corynoneura	102±50.2	60±47.6	144±68.0
?Genus A	393±91.3	418±360.0	146±166.3
Other Orthocladiinae	84±27.2	102±42.4	96±15.7
Total Benthos	1185±131.9	1275±719.1	1082±116.7

Table 3. Means and standard deviations for numbers of organisms in major groups taken in 1ℓ scoop samples from the upper study site. Each value is based on 12 samples. Asterisk indicates significance ($p \leq 0.05$).

Taxa	Control	Treated	t
Oligochaeta	98±78	64±42	1.52
Crustacea	33±41	8±6	2.10*
Ephemeroptera	7±5	1±2	4.79*
Plecoptera	18±12	3±4	5.03*
Trichoptera	8±12	2±2	1.76
Coleoptera	10±8	10±5	0.14
Tanypodinae	84±64	22±18	3.24*
Chironomin	47±24	64±59	0.84
Tanytarsini	132±60	47±18	4.77*
Corynoneura	86±88	20±19	2.46*
Genus A	302±112	77±88	5.07*
Other Orthocladiinae	34±18	16±7	3.10*
Total Benthos	894±372	362±191	4.13*

Table 4. Means and standard deviations for numbers of organisms in major groups taken in 1ℓ scoop samples from the middle study site. Each value is based on 12 samples. Asterisks indicate significance ($p \leq 0.05$).

Taxa	Control	Treated	t
Oligochaeta	94±49	79±44	0.93
Crustacea	26±13	24±19	0.68
Ephemeroptera	20±9	9±10	3.85*
Plecoptera	8±4	5±3	3.24*
Trichoptera	8±5	7±5	1.66
Coleoptera	27±11	30±14	0.44
Tanypodinae	86±31	74±36	1.00
Chironomini	93±41	136±80	1.87*
Tanytarsini	100±48	75±51	1.40
Corynoneura	60±30	38±24	2.08*
Genus A	416±199	441±142	0.38
Other Orthocladiinae	70±46	53±22	1.30
Total Benthos	1042±349	1008±322	0.26

Table 5. Means and standard deviations for numbers of organisms in major groups taken in 1ℓ scoop samples from the lower study site. Each value is based on 12 samples. Asterisks indicate significance ($p \leq 0.05$).

Taxa	Control	Treated	t
Oligochaeta	41±32	47±21	1.01
Crustacea	21±11	19±19	0.38
Ephemeroptera	19±14	11±7	1.93*
Plecoptera	8±3	6±4	3.02*
Trichoptera	12±8	10±6	0.52
Coleoptera	26±18	24±18	0.23
Tanypodinae	112±46	77±39	2.22*
Chironomini	48±25	51±20	0.49
Tanytarsini	142±84	124±74	0.53
Corynoneura	97±63	55±43	4.38*
Genus A	89±91	158±112	1.71
Other Orthocladiinae	86±48	67±37	1.72
Total Benthos	737±238	675±283	0.78

Chironomini were significantly more abundant on the treated side at the middle site, while Tanypodinae were significantly less abundant in the lower treated samples. The groups affected at the lower and middle sites appeared to respond to the sludge between 24 and 72 hours following the sludge addition, and no recovery was detected by day 28.

A visible amount of sludge remained on the bottom of the stream in the upper portion of the treated area throughout the 28 days of observation. The contaminated area decreased in size toward the end of the time period, but also appeared to erode and shift slightly downstream as a discrete body. Excepting the Oligochaea , many organisms in all groups from samples taken in the treated area were more or less covered with tar. This was especially the case in the upstream treated area, but it could not be ascertained whether the organisms were actually caught in the tar before being collected or during the sampling process.

2.1.4 Discussion

Since the volume of tailing sludge used in this experiment amounted to only about 16% of the flow through the treated portion of the study site at the instant it was dumped, the experiment simulated what must be considered a very minor spill. Even so, a 60% reduction in the standing stock of benthic invertebrates was observed within a four week period in the immediate area of the spill. The abundance of several sensitive forms, including *Ephemerella* spp., *Hastaperla brevis*, *Taeniopteryx nivalis* and *Corynoneura* sp., was depressed for at least 30 m downstream.

The sludge from the GCOS tailings pond can be briefly characterized as a thick slurry of inorganic particles in the clay to fine sand range, mixed with globules of tar-like hydrocarbon material suspended in an aqueous solution of a variety of organic and inorganic compounds. Such material can affect benthic invertebrates and other aquatic life in two basic ways: by covering breathing, feeding or living surfaces with fine particulates, and through toxic effects due to the organic and inorganic components of the sludge.

Since most lotic macrobenthos require solid surfaces to maintain position on the stream bed, an increase in the proportion of fine sediments decreases the habitable surface area of the substratum (Nuttall and Bielby 1973). Deposition of sand on stony stream beds has been shown to cause a decrease in the abundance of organisms requiring firm attachment surfaces such as the stoneflies, caddisflies, amphipods, blackflies and most mayflies (Nuttall 1972; Chutter 1969). The reduction of the standing stock of benthic invertebrates which we observed in the upper treated portion of the study site was probably due largely to the stream bed being covered with fine sediment. It is not surprising, therefore, that organisms which are typically abundant in fine sediments, especially the Oligochaeta and Chironomini, did not suffer significant reductions.

The non-significance of the reduction of the abundance of Trichoptera in the treated side of the study area is not consistent with the results of other sedimentation studies. The amount of sediment which reached the substratum was perhaps small enough that these relatively large, firmly attached animals could clear their nets and retreats with no ill effects. It is more likely, however, that the effect of the tailings sludge on the dominant genera *Hydropsyche*, *Cheumatopsyche* and *Glossosoma*, was masked by the extremely clumped distribution of these organisms which is evidenced by the large standard deviations in their numbers per sample throughout the study area.

Luedtke and Brusven (1976) found that only certain Chironomidae and Tipulidae settled on newly deposited sand in a Montana stream, while other organisms merely drifted past the disturbed area. Rosenberg and Snow (1975) reported reductions in both the density and diversity of the macrobenthic fauna of Yukon streams following deposition of silt and clay, but found that recovery occurred within one month as the fine particles were eroded away. The present study suggests, however, that recovery following a single spill of tailings sludge can be expected to be very slow, since the fine sediment adhering to the stream bed would be relatively resistant to resuspension (Nielson 1950). We observed no recovery within four weeks in the area of greatest substrate alteration.

Unlike the "biologically inert" sediment cited above, tailings sludge from oil sands processing contains a variety of toxic compounds, the concentrations of which are shown in Appendix 5.1. The effects of these compounds were detected well downstream from the immediate area of heavy siltation resulting from the sludge addition in the Muskeg River and probably synergized the deleterious effects of the sedimentation in the upper area as well.

While the smothering of the stream bed by fine sediment affected most of the benthic fauna, the tailings sludge appeared to affect only certain sensitive species. Most notable among these were the mayflies, *Ephemerella inermis* and *Baetis* spp., the stoneflies, *Hastaperla brevis*, *Taeniopteryx nivalis* and *Claassenia sabulosa*, and the chironomid *Corynoneura*. All of these are active organisms which live on or just below the surface of the substratum.

2.2 PRELIMINARY STUDIES ON THE EFFECTS OF UPGRADED HYDROCARBONS, ASSOCIATED WITH THE PROCESSING OF OIL SANDS, ON BENTHIC INVERTEBRATES

2.2.1 Introduction

This study is a preliminary examination of the effects of synthetic crude oil and its component oils on colonization of rocky substrates by benthic invertebrates. The study was intended to provide a basis for monitoring and predicting the gross responses of macrobenthic communities to substrate contamination by oils for the design of further, more detailed, studies.

Great Canadian Oil Sands Limited provided an opportunity to study hydrocarbon effects on benthos by making available the component fractions for its product, synthetic crude oil (naphtha, kerosene and gas-oil). Research on the effects of hydrocarbons on benthic communities has been done principally on marine littoral communities and has concentrated on the effects of heavy unrefined oils [Parker et al.(1976); Moore and Dwyer (1974)]. There is considerably less information available on the impacts of light refined oils on freshwater communities (NTIS 1977).

2.2.2 Materials and Methods

The Muskeg River is a brown-water tributary stream of the Athabasca River, about 40 km north of Fort McMurray, Alberta (57° 08' N, 111° 35' W) (Figure 2). The experimental work centered on an area within 2 km of its confluence with the Athabasca River. Here the Muskeg River cuts deeply down through Devonian limestone and flows through a series of pools and riffles which have sandy-clay and limestone rubble (particles up to 30 cm in diameter) substrates, respectively. In the summer of 1976, the river was about 15 m wide and had a mean discharge of about 2.86 m^{-3}/s^{-1}.

The artificial substrates used were steel barbeque baskets (Anderson and Mason 1968) filled with stones, chiefly granite and sandstone, quarried from alluvial deposits above the Athabasca River. Seven sets of baskets were installed: four in a riffle and three in a pool. Each set consisted of a control basket, initially dry baskets treated with each of the various grade of oil (synthetic crude oil, kerosene, naptha and gas-oil) and an initially wet basket treated with synthetic crude oil (hereafter referred to as "wet synthetic crude"). Treatment of the stones in the baskets consisted of dipping them into the oil for one minute and allowing the excess oil to drain off before placing them on the stream bed. The wet synthetic crude baskets were held in river water before dipping them in the oil. Each set of baskets was arranged laterally across the stream bed to avoid contamination, and the individual baskets were secured to metal stakes driven into the stream bed.

The experiment was begun on 17 July 1976, and one set of baskets was removed on 24 July, 7 August, 21 August, and 11 September for the riffle series, and on the same dates, except 21 August, for the pool series.

The baskets were lifted from the river after approaching each from downstream. They were carefully freed from their restraining lines and placed directly into a submerged 200 µ mesh Nitex net held just downstream. The basket was then carried, in the net, to shore where it was placed in an enamel pan. Any algae or detritus which was lodged in or growing upon the wire basket frame was carefully separated and preserved in 10% formalin. One rock from each basket was randomly selected and removed for oil analysis.

The remaining rocks from the basket were carefully scrubbed and the benthos preserved in formalin after being concentrated using a 180 µ sieve. Each rock was weighed and its three greatest diameters measured for later computation of the surface area. The sizes of the rocks used in the baskets were consistent as were the resultant surface areas (Table 6).

The rocks taken for oil analyses were placed in plastic bags, frozen and shipped to Edmonton. Each rock was immersed in n-pentane for 24 hours, the residue filtered through Whatman #42 filter paper and the residue weighed. A number of samples were selected for infrared spectrophotometry. Detailed chemical analyses of the oil fractions used are shown in Appendix 5.2. In order to test the initial levels of the different oils on the rocks, rocks similar to those used in the baskets were dipped in the several oils in the laboratory, the excess was allowed to run off and then an extraction with n-pentane was carried out.

Generic, and in some cases specific, identifications were made for the more abundant invertebrates. All Chironomidae were counted, but subsamples were taken for identification. Rare genera were missed in some subsamples as shown when some samples were fully identified.

The surface area of the rocks in each basket was calculated by the formula for an ellipsoid:

$$S = 2\pi c^2 + \frac{2\,b}{\sqrt{(a^2-c^2)}}\left[c^2 F(\kappa,\phi) + (a^2-c^2)\,E\,(\kappa,\phi)\right]$$

where $$K = \frac{a}{b}\sqrt{\frac{b^2-c^2}{a^2-c^2}}, \quad \phi = \text{arc cos}\ \frac{c}{a}$$

[F (κ,ϕ), E (κ,ϕ) are elliptic integrals of the first and second kinds.]

The numerical data for benthos were analysed with an F statistic in a one way analysis of variance

2.2.3 Results

The amount of oil on the rocks tended to decrease the longer the rocks were in the water. There was a marked difference between the various grades of oil which

Table 6. Rock surface areas in baskets, upper site Muskeg River.

LOCATION	NUMBER OF BASKETS	MEAN AREA (cm^{-2})	STANDARD DEVIATION	DEVIATION AS %
Riffle	24	1970	237	12%
Pool	18	2059	95	4.6%

remained on the rock immediately after immersion. The gas-oil fraction was initially strongly absorbed, with synthetic crude oil, kerosene and naphtha being progressively less strongly absorbed (Table 7). This trend closely corresponded with oil viscosity (Table 8). Rocks wetted before oil immersion retained considerably less synthetic crude oil than did the dry rocks. However, the analyses of oil residues on the rocks were rather erratic. The infrared spectrophotometry will not measure weathered or oxidized hydrocarbons and, therefore, the results were always less than for the n-pentane extractions. The latter could also have included organic residue contaminants, such as chlorophylls, in the final weighings. Gas chromotographic determinations would have been more desirable, but were unavailable.

The total numbers of benthos generally tended to be less in the baskets in the pool than those in the riffle (Tables 9 and 10). The data suggest that in riffles, the rate of colonization was initially suppressed by the heavier oils (gas-oil, synthetic crude oil), but became similar to the controls (Figure 14) by day 21. The lighter oil fractions (kerosene, naphtha and "wetted" synthetic crude oil) initially appeared to enhance the rates of colonization (Figure 14). In the pool, similar trends are suggested with the exception that colonization of the control baskets initially lagged behind but then rapidly outstripped the oiled baskets (Figure 15). In both series, the baskets with the heavier oils (gas-oil, synthetic crude oil) ended with fewer total numbers than did the lighter oils or the control (Figure 15).

The numerically dominant genera on the baskets were *Rheotanytarsus* sp., *C. bicinctus*, *Baetis* spp., *Hydropsyche* spp., and *Cheumatopsyche* spp. (Table 1). The number of genera of Ephemeroptera, Plecoptera,

Table 7. Oil residues (mg/cm^{-2}) on rocks from baskets - Muskeg River. The n-pentane extractions are shown with the I.R. spectrophotometry results in parentheses.

OIL	RIFFLE			
	Time 0	24 July	7 Aug.	21 Aug.
Gas-Oil	10.89	2.35 (0.81)	0.8	0.48 (0.21)
Synthetic Crude	4.0	0.76 (0.13)	1.02	0.14 (0.05)
Wet Synthetic Crude	1.85	0.20 (0.04)	0.42	0.07 (0.004)
Kerosene	1.95	0.26 (0.04)	0.41	0.07 (0.006)
Naphtha	0.12	0.02 (0.02)	0.09	0.31 (0.08)
Control	-	0.04 (0.03	0.12	0.02 (0.003)
	POOL			
Gas-Oil	-	2.09 (0.68)	1.28	N/A
Synthetic Crude	-	1.32 (0.34)	0.02	N/A
Wet Synthetic Crude	-	N/D[a]	0.135	N/A
Kerosene	-	0.26 (0)	0.29 (0.06)	N/A
Naphtha	-	0.297 (0.04)	0.67	N/A
Control	-	0.18 (0.016)	0.126 (0.06)	N/A

[a] Lost in shipment

Table 8. Oil viscosity of fractions.

OIL TYPE	TEMPERATURE (°F)	ABSOLUTE CENTIPOISES
Gas-Oil	35	202.5
Synthetic Crude	30	6.54
Kerosene	30	3.53
Naphtha	30	0.65

Table 9. Total number of benthic invertebrates from baskets from the pool.

Date/Oils	Ephem-eroptera	Plecop-tera	Trichop-tera	Oligo-chaeta	Gastra-poda	Acari	Simulii-dae	Chirono-midae
24 July 1976								
W. Syncr [a]	10	4	4	0	4	0	1	174
Kerosene	13	3	1	0	1	1	0	153
Naptha	3	2	1	0	2	0	1	84
Gas-Oil	3	1	1	0	5	0	2	85
Syncrude [b]	3	0	0	0	2	0	0	54
Control	20	22	12	0	1	1	6	254
7 Aug. 1976								
W. Syncr	32	2	4	76	80	19	0	307
Kerosene	28	1	4	104	11	2	0	364
Naptha	27	3	2	21	22	3	0	702
Gas-Oil	35	2	4	12	33	3	0	356
Syncrude	19	1	2	48	16	2	0	356
Control	40	11	5	6	64	17	0	480
11 Sept. 1976								
W. Syncr	38	15	30	17	391	88	0	496
Kerosene	40	16	32	43	506	8	0	427
Naptha	66	22	56	30	459	91	0	619
Gas-Oil	19	8	7	72	71	8	0	282
Syncrude	19	3	20	22	314	15	0	149
Control	46	22	61	40	864	75	0	432

[a] Wetted Synthetic Crude Oil [b] Synthetic Crude Oil

TABLE 10. Total number of benthic invertebrates from baskets from the riffle.

Date/Oils	Ephem-eroptera	Plecop-tera	Trichop-tera	Oligo-chaeta	Gastra-poda	Acari	Simulii-dae	Chirono-midae
24 July 1976								
W. Syncr[a]	27	18	18	0	1	1	24	432
Kerosene	8	5	3	1	1	0	12	119
Naptha	13	1	16	0	0	0	11	120
Gas-Oil	4	1	6	0	0	2	15	29
Syncr[b]	6	7	12	0	0	0	43	59
Control	24	34	99	0	0	6	69	206
7 Aug. 1976								
W. Syncr	30	49	54	112	45	75	0	1659
Kerosene	42	28	36	90	47	36	6	1241
Naptha	69	35	71	28	65	38	39	1638
Gas-Oil	34	15	23	98	34	3	1	518
Syncrude	19	13	10	100	60	2	2	397
Control	58	31	90	11	23	26	15	95
21 Aug. 1976								
W. Syncr	80	24	83	118	3	62	1	1574
Kerosene	81	27	79	85	18	65	2	1430
Naptha	167	47	240	91	11	185	2	2872
Gas-Oil	36	22	90	134	26	35	3	1314
Syncrude	92	19	101	104	25	31	4	756
Control	90	28	124	22	70	70	2	902
11 Sept. 1976								
W. Syncr	199	66	263	89	155	311	0	1434
Kerosene	154	48	190	343	380	116	0	1125
Naptha	217	42	128	64	346	136	0	1078
Gas-Oil	101	39	57	339	417	30	0	570
Syncrude	36	22	20	342	249	23	0	269
Control	87	46	160	113	264	5	0	1046

[a]Wetted Synthetic Crude Oil

[b]Synthetic Crude Oil

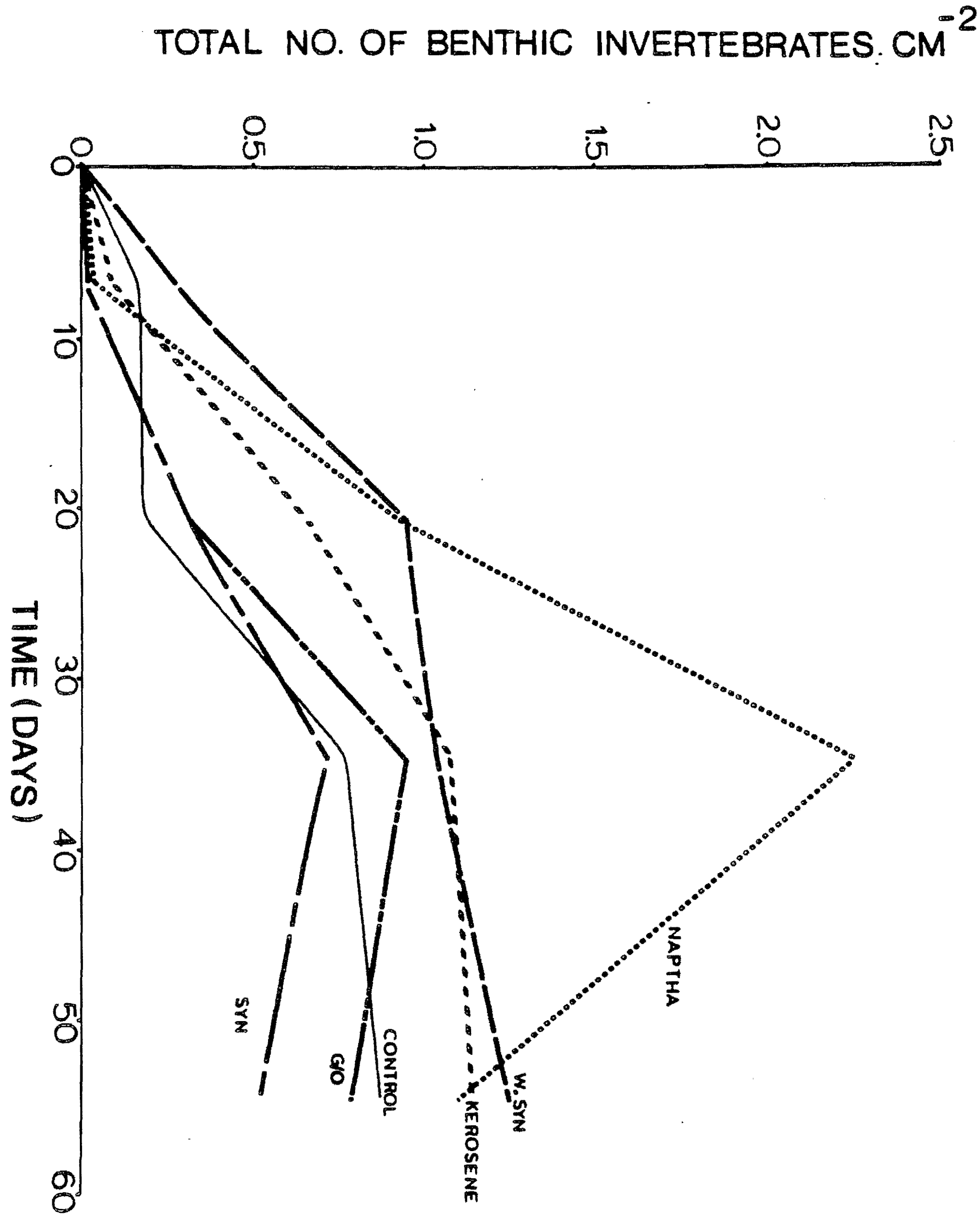


Figure 14. Total numbers of benthic invertebrates cm^{-2} on baskets from the riffle site, Muskeg River (refer to Table 10 for total numbers).

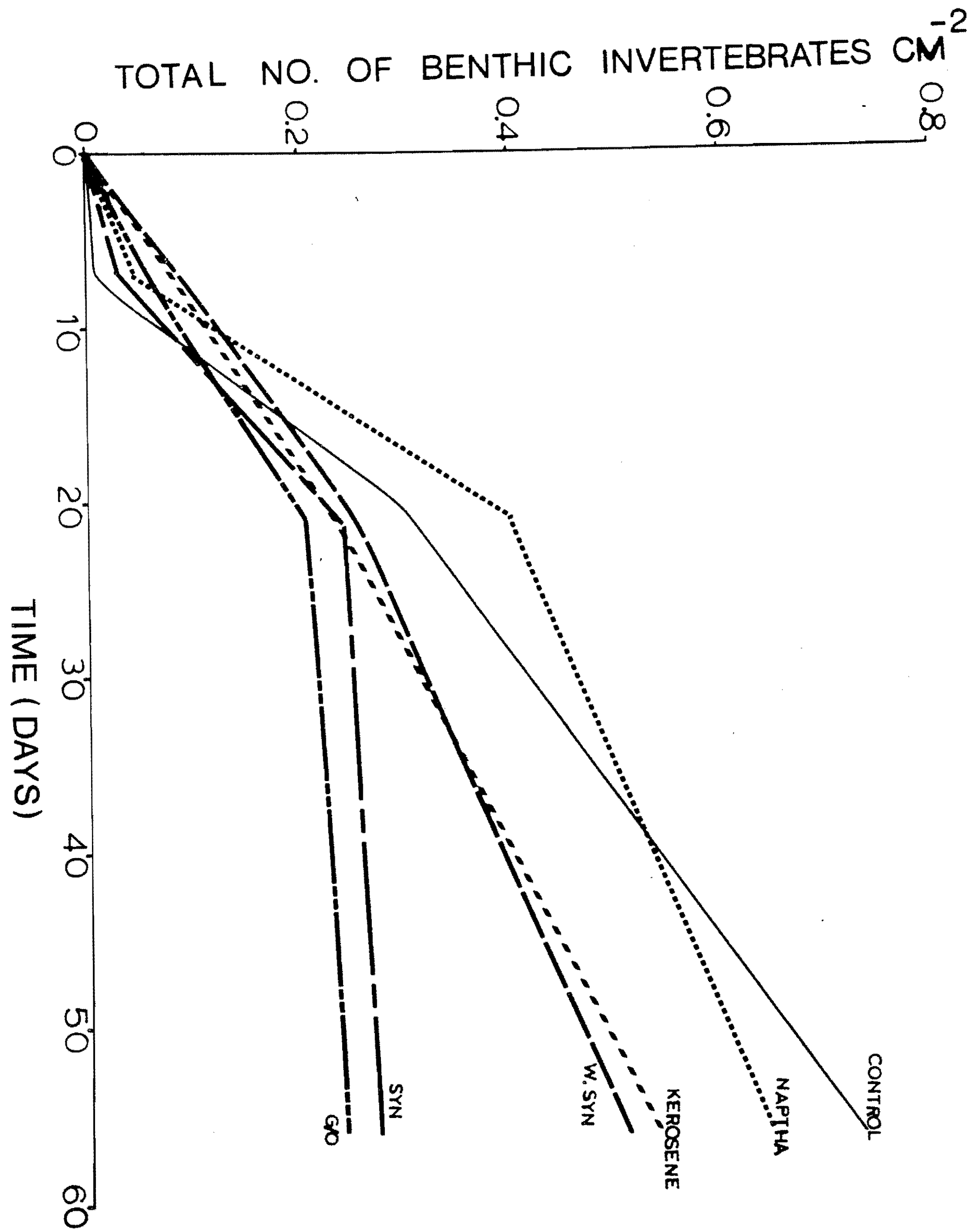


Figure 15. Total numbers of benthic invertebrates cm^{-2} on baskets from the pool site, Muskeg River (refer to Table 9 for total numbers).

and Trichoptera increased consistently throughout the sampling period (Figures 16 and 17) in both the riffle and the pool. Although broad generic comparisons for the Chrionomidae are not strictly possible, since some of the rarer genera were missed in the subsamples, the total numbers rapidly reached a plateau value and then declined. The Chironomidae were the most numerous component of the benthos in the baskets (Table 9 and 10).

2.2.4 Discussion

It is clear that the retention of the oil fractions on the rocks is correlated with oil viscosity. More of the higher viscosity oil, such as gas-oil or synthetic crude, is initially adsorbed on dry rocks than are the lighter oils. If the substrate surface is initially wetted before oiling, less of the oil is retained on the wet surface than on a dry surface, probably due to oil emulsification. The barrier of a wetted surface (interfering with oil adsorption) probably indicates that in a "true" oil spill into running waters, the amounts retained on the substrate would be less than in our experimental procedures (using initially dry, uncolonized substrates). Our study would therefore more closely simulate an oil spill onto any substrates in a river at a period of low flow. Barbeque baskets appear to us to be generally unsatisfactory for this type of study for several reasons. The baskets, lying on the substratum of the stream, project into the water and catch large quantities of organic debris which is being transported downstream. The debris is then colonized by invertebrates, but these do not necessarily reflect the experimental conditions being tested (in this case, the presence or absence of oil). The wire of the basket itself provides a substrate for sessile, filamentous algae supporting huge populations of various invertebrates which also are not subjected to the exper-

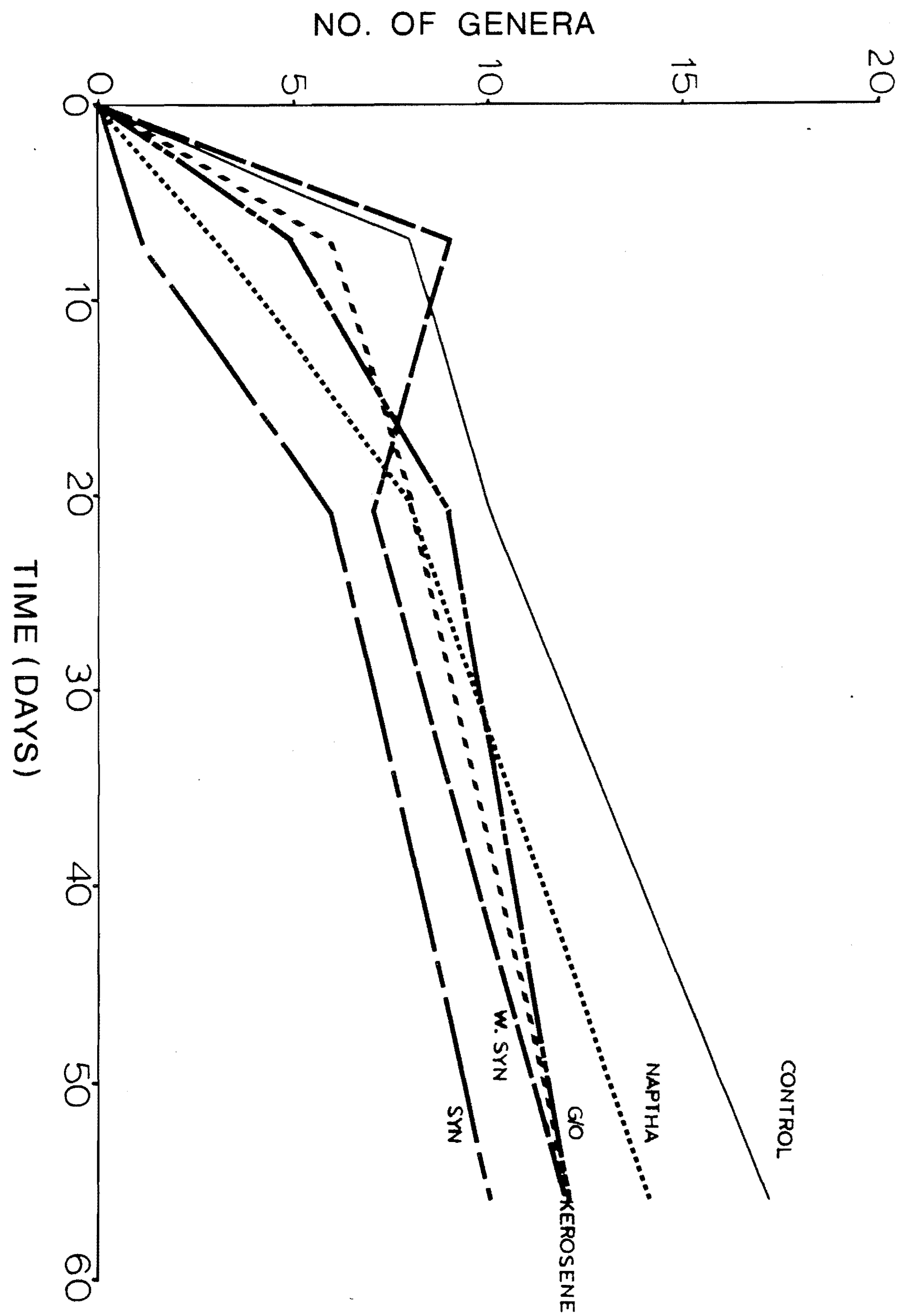


Figure 16. Number of Genera (Ephemeroptera, Plecoptera, and Trichoptera) on baskets in the riffle, Muskeg River.

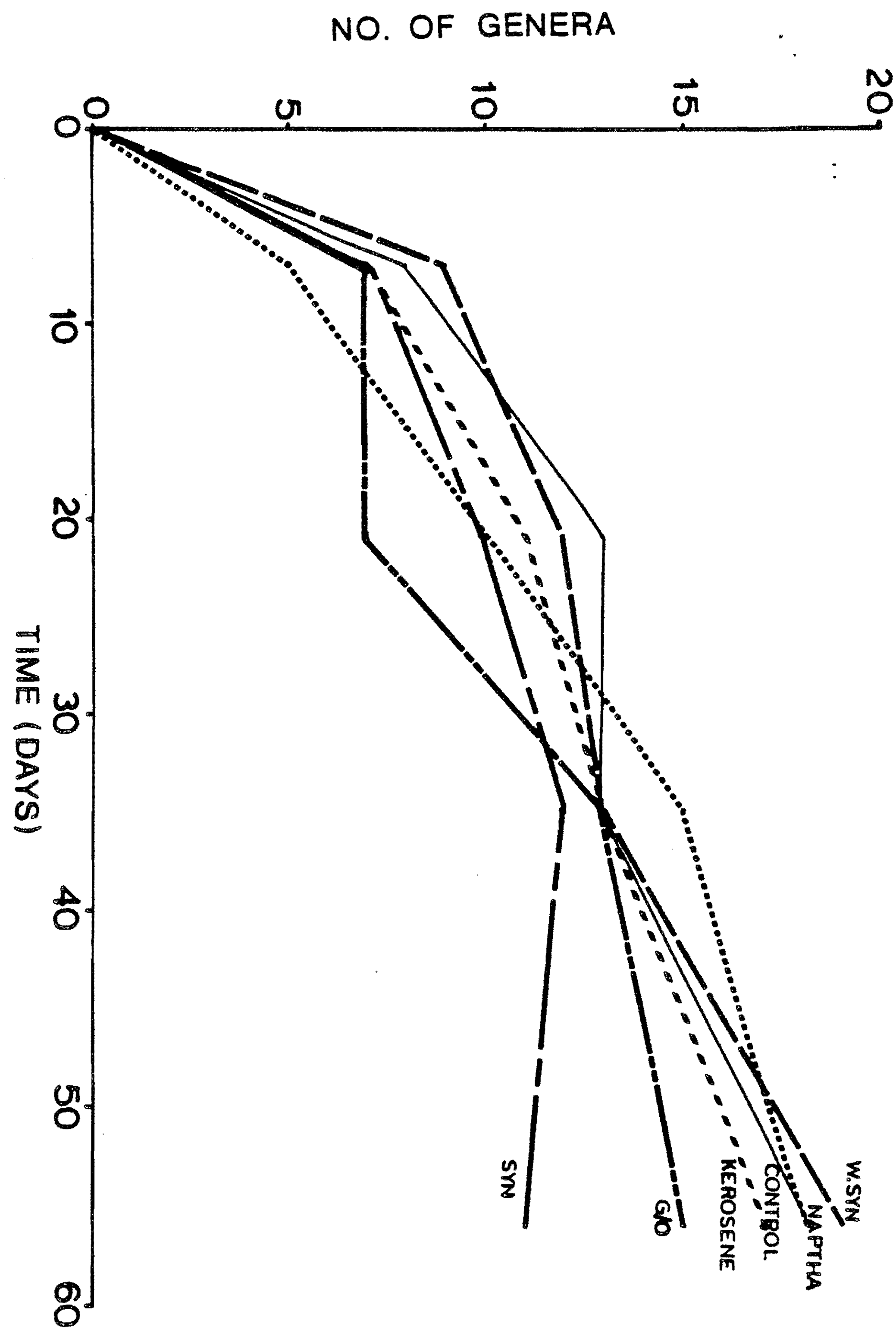


Figure 17. Number of Genera (Ephemeroptera, Plecoptera and Trichoptera) on baskets in the pool, Muskeg River.

imental conditions. Satisfactory separation of the attached debris and algae and the associated animals from the treated stones is impossible which leads to somewhat erratic results. Finally, the sheer volume of the samples collected using baskets prohibits extensive replication of samples. Each basket used in this study required at least ten man-days to process in the laboratory.

Despite these problems, this preliminary study did indicate several significant trends and individual responses to oil contamination of stream substrates.

In general, the baskets in the pools tended to support fewer organisms per unit area than those in the riffle. In the riffle, colonization was initially retarded by the presence of oil, whereas the opposite occurred in the pool. At the end of 56 days, there were fewer total organisms on baskets with the heavier oils, gas-oil and synthetic crude, than for the lighter oils. This trend was also more pronounced in the pool than in the riffle, probably due to increased retention of the heavier oils on the rocks.

Rosenberg and Weins (1976) and others have reported a stimulation of algal growth on oil contaminated substrates. It has been suggested that nutrients so supplied stimulate algal productivity and this, in turn, leads to an increase in the standing crop of grazing organisms. Measurements of algal growth was not attempted in this preliminary study. It is possible that the positive and negative responses of some of our species were, in part, due to the influence of hydrocarbons and resultant biological growths. Federle et al. (1977) indicated that Prudhoe Bay crude oil caused a reduction in primary productivity and a loss of zooplankton in tundra pools. The selective effects of oil caused changes in algal species composition, caused in turn by the loss of zooplankton grazing pressure. Walker et al. (1975) found that crude oil supported bacterial growth but fuel oil limited it in an estuary. In reference to control cultures both crude and fuel oil were found to be toxic to bacteria, the crude oil showing a greater toxicity.

There is some evidence suggesting that aquatic microbial interactions with hydrocarbons can substantially alter the amount of organic matter transferred into solution. Lysyj and Russel (1974) found that substantial quantities of organic matter can be introduced into solution as a result of contact between water and refined petroleum products. The acceleration of organics transferred to the aqueous phase over 44 days was inferred to be due to chemical modification of the water-insoluble petroleum fraction possibly caused by chemical oxidation or bacterial action.

Parker et al. (1976) reviewed the literature on oil contamination in fresh waters and concluded that toxicity correlates inversely with the molecular weight of the oil and the degree to which oils are emulsified. Low molecular weight oils are generally more toxic than those of higher molecular weight. Also, water temperature will affect the solubility of oil fractions. While this may be true for acute toxic effects of oils on aquatic life, our work indicates that, in the longer term (up to 56 days), the lighter, refined oils may actually enhance the habitat for benthic colonization, whereas the heavier oils may discourage or slow it. Caution is, therefore, warranted in the application of laboratory toxicity tests to longer-term responses by benthic communities. Indeed, as Berry and Brammer (1977) point out, comparisons of petroleum toxicant data derived from different laboratory methods provide little information of any real comparative value. For instance, Hoehn et al. (1974) concluded that the effects of an accidental spillage of Number 2 fuel oil on benthic stream invertebrates was a toxic one based on water-soluble fractions, but not one which rendered sediments unsuitable for colonization.

In addition to these chemical variables, intraspecific, as well as interspecific, effects may arise. Berry and Brammer (1977) found that water soluble fractions of gasoline are more toxic to younger instars of *A. aegypti* and that the larvae appeared to be exceptionally susceptible during moulting indicating that the cuticle may serve as a barrier against water-soluble aromatics.

The listing of benthos responding to hydrocarbons was expanded to include species of the Ephemeroptera, Plecoptera, Trichoptera and Oligochaeta. Organisms such as *Baetis*, *Claassenia*, *C. bicinctus*, *Nanocladius* sp., *Rheotanytarsus* sp. and *Cheumatopsyche* may be useful as indicators of hydrocarbon pollution, although the colonization of the animals on the substrates may have been influenced by secondary effects such as algal or bacterial growths. The strongly positive initial response by the Oligochaeta (*Nais* sp.) to all the oils (except naphtha, the lightest fraction used) is possibly indicative of a response to an initial microbial "bloom", or it could be a tolerant response to a hydrocarbon-contaminated and largely uncontested niche.

It is possible that a critical level of hydrocarbon residue must be reached before enhanced microbial/algal growth begins which, in turn, may influence colonization by macrobenthos. Such a mechanism would be dependent on the degree of oil emulsification and could explain the difference in community responses to "wetted" synthetic crude oil over oil placed onto dry substrates. The heavier, more viscous oils of high molecular weight would be retained on the substrate relatively longer than lighter oils, and would be more resistant to emulsification than the lighter oils.

It is important to stress that this study examined the effects of hydrocarbon contamination on the colonization of macrobenthos on dry, denuded substrates immersed first in oil and then in the stream. The more rapid erosion and decreased initial retention of synthetic crude oil placed on an initially wetted substrate, suggests that our study produced effects rather more pronounced than would result from an oil spillage into a river. However, the present study suggests that the long-term effects on stream benthos of the relatively light refined oil fractions which make up synthetic crude oil, are variable and more pronounced for the heavier fractions, but in general, are rather less than that reported for unrefined crude oils or residue oils.

3. CONCLUSIONS AND RECOMMENDATIONS

Over 200 discrete taxa have been recognized from the material examined to date. Many of these, especially certain genera of Chrionomidae, appear to include several species which will be separated as more material, both immature and adult, is examined.

The nature of benthic communities which are found in the running waters of the AOSERP study area is strongly influenced by local topographic and geologic features. There appear to be at least seven distinct stream types or zones within the area; five, of which, have been examined: (1) high-gradient brooks with sand and gravel substrates; (2) small seeps which drain areas of wet muskeg; (3) larger, low-gradient streams; (4) large, high-gradient streams which cut through glacial till; (5) large, high-gradient streams which cut through limestone; (6) streams cutting through oil sands deposits; and (7) the very large, Athabasca River. The small muskeg seeps and the mainstem Athabasca have not been considered in any detail in the present report.

The experimental spillage of tailings sludge simulated what must be considered to be a very minor, instantaneous spillage to a river. Even so, a 60% reduction in the standing stock of benthic invertebrates occurred within a four-week period in the immediate area of the spillage.

Sensitive indicator organisms decreased in abundance over an area of at least 30 m downstream of the spillage.

Tailings sludge contained fine silt, heavy, sticky oils, and heavy metals; all, of which, would have a deleterious effect on stream benthos. Fine silt mixed with the sticky oils of the sludge probably constitute the principle hazards to aquatic communities.

It is recommended that appropriate measures be established to prevent the addition of oil sands tailings sludge, by either accident or design, to lakes or rivers.

The contamination of artificial substrates with synthetic crude oil and its constituent fractions did not markedly alter the taxonomic composition of benthic invertebrate communities in riffles or pools after a period of 56 days. At least seven individual taxa, genera or species did show responses to the presence of oil, especially the heavier fractions (gas-oil and synthetic crude oil).

Colonization baskets from a riffle generally tended to support larger populations of invertebrates than did those in a pool. In the riffles, the rate of colonization was initially suppressed by the heavier oils and enhanced by the lighter oils. The rate of colonization tended to plateau after 21 days for the light oils and after 35 days for the heavier oils and the control.

In a pool, the rate of colonization on all the oiled baskets initially exceeded, but subsequently fell behind, that of the controls. After 56 days, the baskets with the heavier oils (gas-oil, synthetic crude) generally had fewer total numbers of macrobenthic organisms than the lighter oils (naphtha, kerosenë and "wetted" synthetic crude oil).

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5. APPENDICES

5.1 METHODOLOGIES AND ANALYTICAL RESULTS FOR SLUDGE SAMPLES FROM THE GCOS TAILINGS POND

Methods used for analysis

Parameter	References
Grain Size Distribution	American Society for Testing and Materials, Designation D 422-63
Loss on Ignition	APHA, 1971, Standard Methods for the Examination of Water and Wastewater 13th Ed. N.Y. p539-540
Total Carbon	Leco Corp., USA, 1959, Instruction Manual for Total Carbon
Total Sulfur	I.B.D. Instruction Manual for Total Sulfur
Oil and Grease	EPA Methods Manual (USA). Modified Soxhlet Extraction Method NOTE: Petroleum Ether was substituted for "Freon"
Trace Metals	Analytical Methods Manual, IWD, Ottawa, 1975 Addendum

ANALYTICAL RESULTS

Date Sampled	19/11/76
Location	Tar Island, GCOS Holding Pond
Sample Description	Sludge
Grain Size Description	
Sand (%)	22}
Silt (%)	7} % Total Solids (wt.)
Clay (%)	71}
Moisture, H_2O (%)	74.5
Loss on Ignition (%)	24.7
Total Inorganic Carbon (%)	0.25
Total Organic Carbon (%)	17.7
Total Sulphur (%)	1.32
Sulphates, Water Soluble (Mg/Kg)	NV
Chlorides, Water Soluble (Mg/Kg)	NV
Oil and Grease	1.07 mg/kg*

Trace Metals			Total	Aqua Regia Extractable	0.5m HCl Extractable
Cadmium	Cd	(mg/kg)	15	20	0.80
Cobalt	Co	(mg/kg)	55	120	15.0
Copper	Cu	(mg/kg)	24	24	2.1
Iron	Fe	(mg/kg)	26200	14800	12800
Lead	Pb	(mg/kg)	47	12	8
Manganese	Mn	(mg/kg)	480	440	440
Nickel	Ni	(mg/kg)	95	26	9
Zinc	Zn	(mg/kg)	63	40	32
Vanadium	V	(mg/kg)	240	36	21

*mg/kg denotes concentration of constituent in milligrams per kilogram of sample as received.

5.2 OIL FRACTION ANALYSES

5.2.1 Synthetic Crude

Gravity at 60/60°F.: Specific: 0.848
API: 35.4
Pour Point (°F.) : +5

VISCOSITY

Temperature (°F.)	Absolute Centipoises	Kinematic Centistokes	Saybolt Universal Seconds
30	6.54	7.61	50.6
50	4.30	5.05	4.24
70	3.09	3.66	38.0

SULFUR COMPOUNDS (PPM BY WEIGHT)

Hydrogen Sulfide	0
Mercaptan Sulfur	0
Elemental Sulfur	0
Aliphatic Sulfides	0
Aromatic Sulfide & Thiophenes	0
Water Soluble Sulfur Compounds	0
Total Sulfur	1550

HYDROCARBON TYPES (% BY VOLUME)

Saturates	74.8
Aromatics	24.2
Olefins	1.0

PHENOLIC COMPOUNDS (mg/litre) : 0.45

5.2.2 Naphtha

Gravity at 60/60° F.:	Specific:	0.729
	API:	62.6
Cloud Point (° F.)	:	-25
Pour Point (° F.)	:	Less than -65

VISCOSITY

Temperature (°F.)	Absolute Centipoises	Kinematic Centistokes	Saybolt Universal Seconds
0	0.83	1.10	Below 32
30	0.65	0.87	Below 32
50	0.56	0.76	Below 32
70	0.49	0.67	Below 32

SULFUR COMPOUNDS (PPM BY WEIGHT)

Hydrogen Sulfide	0
Mercaptan Sulfur	0
Elemental Sulfur	0
Aliphatic Sulfides	0
Aromatic Sulfide & Thiophenes	0
Water Soluble Sulfur Compounds	0
Total Sulfur	23

HYDROCARBON TYPES (% BY VOLUME)

Paraffins	54.37
Cycloparaffins	27.96
Dicycloparaffins	3.53
Alkylbenzenes	11.72
Indans & Tetralins	2.23
Naphthalenes	0.19

INDIVIDUAL HYDROCARBONS (% BY WEIGHT)

Component	Percent by Weight
ethane	0
propane	0
iso-butane	0.21
n-butane	2.25
iso-pentane	2.71
n-pentane	4.23
2, 2-dimethylbutane	0.06
cyclopentane	0.57
2-methylpentane	2.76
3-methylpentane	1.26
n-hexane	3.76
methylcyclopentane	1.68
2, 2-dimethylpentane	0.18

Naphtha (Concluded)

Component	Percent by Weight
benzene cyclohexane }	0.48
2-methylhexane	1.58
3-methylhexane	1.60
1-cis-3-dimethylcyclopentane	0.54
1-trans-3-dimethylcyclopentane	0.36
3-ethylpentane	0.79
n-heptane	3.49
methylcyclohexane	1.44
2, 2-dimethylhexane	0.17
2, 5-dimethylhexane	0.68
2, 4-dimethylhexane	0.09
2, 2, 3-trimethylpentane	0.16
1-trans-2-cis-4-trimethylcyclopentane	0.33
1-trans-2-cis-3-trimethylcyclopentane	0.19
3, 3-dimethylhexane	trace(<0.01)
toluene	0.23
2, 3, 4-trimethylpentane	0.23
2, 2, 3-trimethylpentane	0.40
2, 3-dimethylhexane 2-methyl-3-ethylpentane }	2.58
2-methylheptane 4-methylheptane }	0.65
3, 4-dimethylhexane 3-methyl-3-ethylpentane }	0.95
3-ethylhexane 3-methylheptane }	0.06
cycloheptane	0.38
1-trans-4-dimethylcyclohexane 1-cis-3-dimethylcyclohexane }	0.69
1-methyl-trans-2-ethylcyclopentane 1-methyl-1-ethylcyclopentane }	0.17
1-trans-2-dimethylcyclohexane	0.04
1-cis-2-cis-3-trimethylcyclopentane	0.27
1-cis-4-dimethylcyclohexane 1-trans-3-dimethylcyclohexane }	0.04
n-octane	2.59

5.2.3 Kerosene

Gravity at 60/60° F.:	Specific:	0.838
	API:	37.4
Cloud Point (° F.)	:	-20
Pour Point (° F.)	:	-65

VISCOSITY

Temperature (°F.)	Absolute Centipoises	Kinematic Centistokes	Saybolt Universal Seconds
-15	8.68	10.00	58.5
30	3.53	4.16	39.5
50	2.57	3.05	36.1
70	2.00	2.40	34.0

SULFUR COMPOUNDS (PPM BY WEIGHT)

Hydrogen Sulfide :	0
Mercaptan Sulfur :	0
Elemental Sulfur :	0
Aliphatic Sulfides :	0
Aromatic Sulfide & Thiophenes :	0
Water Soluble Sulfur Compounds:	0
Total Sulfur :	29

A hydrocarbon type analysis by ASTM D-1319 or analysis for individual hydrocarbons could not be made because of the heavy nature of the sample. A hydrocarbon distribution according to carbon number showed it consisted of hydrocarbons in the C_9 to C_{18} range. Hydrocarbon types were determined by a sulfonation and bromination method.

CARBON NUMBER DISTRIBUTION

Carbon Number	% by Weight
9	0.16
10	5.20
11	13.91
12	27.92
13	25.09
14	25.38
15	2.22
16	.11
17	.01
18	Trace

HYDROCARBON TYPES (% BY VOLUME)

Saturates:	79.5
Aromatics:	20.1
Olefins :	0.4

Kerosene (Concluded)

A distillation (ASTM-285) was made to determine the boiling point distribution.

Room Temperature : 75°F

Barometric Pressure: 27.45" Hg.

% DISTILLED	VAPOR TEMPERATURE (°F)
Initial Boiling Point	365
5	380
10	388
15	392
20	402
25	409
30	416
35	420
40	426
45	431
50	436
55	441
60	446
65	451
70	456
75	462
80	469
85	478
90	499
94 (Final Boiling Point)	530

5.2.4 Gas-Oil

Gravity at 60/60° F.: Specific: 0.917
API: 22.8

Pour Point (° F.) : +30

VISCOSITY

Temperature (°F)	Absolute Centipoises	Kinematic Centistokes	Saybolt Universal Seconds
35	187.5	202.5	935.5
50	73.4	79.7	368.
70	32.2	35.3	165.

SULFUR COMPOUNDS (PPM BY WEIGHT)

Hydrogen Sulfide	:	0
Mercaptan Sulfur	:	0
Elemental Sulfur	:	0
Aliphatic Sulfide	:	0
Aromatic Sulfide & Thiophenes	:	0
Water Soluble Sulfur Compounds	:	0
Total Sulfur	:	3480

HYDROCARBON TYPES (% BY VOLUME) (BY SULFONATION AND BROMINATION)

Saturates:	63.5
Aromatics:	34.2
Olefins :	2.3

Hydrocarbon distribution could not be determined for components heavier than C9/ Beyond C9, chromatographic peaks overlapped and separation could not be obtained.

CARBON NUMBER	% BY WEIGHT
1C4	0.01
NC4	0.03
1C5	0.06
NC5	0.06
C6	0.13
C7	0.23
C8	0.36
C9	0.17
C10 & Heavier	98.95
Phenolic Compounds (mg/litre)	0.27

AOSERP RESEARCH REPORTS

1.		AOSERP First Annual Report, 1975
2.	AF 4.1.1	Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta--1975
3.	HE 1.1.1	Structure of a Traditional Baseline Data System
4.	VE 2.2	A Preliminary Vegetation Survey of the Alberta Oil Sands Environmental Research Program Study Area
5.	HY 3.1	The Evaluation of Wastewaters from an Oil Sand Extraction Plant
6.		Housing for the North--The Stackwall System
7.	AF 3.1.1	A Synopsis of the Physical and Biological Limnology and Fisheries Programs within the Alberta Oil Sands Area
8.	AF 1.2.1	The Impact of Saline Waters upon Freshwater Biota (A Literature Review and Bibliography)
9.	ME 3.3	Preliminary Investigations into the Magnitude of Fog Occurrence and Associated Problems in the Oil Sands Area
10.	HE 2.1	Development of a Research Design Related to Archaeological Studies in the Athabasca Oil Sands Area
11.	AF 2.2.1	Life Cycles of Some Common Aquatic Insects of the Athabasca River, Alberta
12.	ME 1.7	Very High Resolution Meteorological Satellite Study of Oil Sands Weather: "a Feasibility Study"
13.	ME 2.3.1	Plume Dispersion Measurements from an Oil Sands Extraction Plant, March 1976
14.	HE 2.4	Athabasca Oil Sands Historical Research Project. Volume I: Design
15.	ME 3.4	A Climatology of Low Level Air Trajectories in the Alberta Oil Sands Area
16.	ME 1.6	The Feasibility of a Weather Radar near Fort McMurray, Alberta
17.	AF 2.1.1	A Survey of Baseline Levels of Contaminants in Aquatic Biota of the AOSERP Study Area
18.	HY 1.1	Interim Compilation of Stream Gauging Data to December 1976 for the Alberta Oil Sands Environmental Research Program
19.	ME 4.1	Calculations of Annual Averaged Sulphur Dioxide Concentrations at Ground Level in the AOSERP Study Area
20.	HY 3.1.1	Characterization of Organic Constituents in Waters and Wastewaters of the Athabasca Oil Sands Mining Area

21.		AOSERP Second Annual Report, 1976-77
22.	HE 2.3	Maximization of Technical Training and Involvement of Area Manpower
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 4.2.1	Review of Dispersion Models and Possible Applications in the Alberta Oil Sands Area
25.	ME 3.5.1	Review of Pollutant Transformation Processes Relevant to the Alberta Oil Sands Area
26.	AF 4.5.1	Interim Report on an Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
27.	ME 1.5.1	Meteorology and Air Quality Winter Field Study in the AOSERP Study Area, March 1976
28.	VE 2.1	Interim Report on a Soils Inventory in the Athabasca Oil Sands Area
29.	ME 2.2	An Inventory System for Atmospheric Emissions in the AOSERP Study Area
30.	ME 2.1	Ambient Air Quality in the AOSERP Study Area, 1977
31.	VE 2.3	Ecological Habitat Mapping of the AOSERP Study Area: Phase I
32.		AOSERP Third Annual Report, 1977-78
33.	TF 1.2	Relationships Between Habitats, Forages, and Carrying Capacity of Moose Range in northern Alberta. Part I: Moose Preferences for Habitat Strata and Forages.
34.	HY 2.4	Heavy Metals in Bottom Sediments of the Mainstem Athabasca River System in the AOSERP Study Area
35.	AF 4.9.1	The Effects of Sedimentation on the Aquatic Biota
36.	AF 4.8.1	Fall Fisheries Investigations in the Athabasca and Clearwater Rivers Upstream of Fort McMurray: Volume I
37.	HE 2.2.2	Community Studies: Fort McMurray, Anzac, Fort MacKay
38.	VE 7.1.1	Techniques for the Control of Small Mammals: A Review
39.	ME 1.0	The Climatology of the Alberta Oil Sands Environmental Research Program Study Area
40.	VE 7.1	Interim Report on Reclamation for Afforestation by Suitable Native and Introduced Tree and Shrub Species
41.	AF 3.5.1	Acute and Chronic Toxicity of Vanadium to Fish
42.	TF 1.1.4	Analysis of Fish Production Records for Registered Traplines in the AOSERP Study Area, 1970-75
43.	TF 6.1	A Socioeconomic Evaluation of the Recreational Fish and Wildlife Resources in Alberta, with Particular Reference to the AOSERP Study Area. Volume I: Summary and Conclusions
44.	VE 3.1	Interim Report on Symptomology and Threshold Levels of Air Pollutant Injury to Vegetation, 1975 to 1978
45.	VE 3.3	Interim Report on Physiology and Mechanisms of Air-Borne Pollutant Injury to Vegetation, 1975 to 1978

46.	VE 3.4	Interim Report on Ecological Benchmarking and Biomonitoring for Detection of Air-Borne Pollutant
47.	TF 1.1.1	A Visibility Bias Model for Aerial Surveys of Moose on the AOSERP Study Area
48.	HG 1.1	Interim Report on a Hydrogeological Investigation of the Muskeg River Basin, Alberta
49.	WS 1.3.3	The Ecology of Macrobenthic Invertebrate Communities in Hartley Creek, Northeastern Alberta
50.	ME 3.6	Literature Review on Pollution Deposition Processes
51.	HY 1.3	Interim Compilation of 1976 Suspended Sediment Data in the AOSERP Study Area
52.	ME 2.3.2	Plume Dispersion Measurements from an Oil Sands Extraction Plant, June 1977
53.	HY 3.1.2	Baseline States of Organic Constituents in the Athabasca River System Upstream of Fort McMurray
54.	WS 2.3	A Preliminary Study of Chemical and Microbial Characteristics of the Athabasca River in the Athabasca Oil Sands Area of Northeastern Alberta.
55.	HY 2.6	Microbial Populations in the Athabasca River

These reports are not available upon request. For further information about availability and location of depositories, please contact:

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