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ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

Studies in Recolonization of Stream Substrates by Aquatic Organisms

Project WS 4.1
July 1979

Sponsored jointly by

Alberta ENVIRONMENT

Environment Canada Environnement Canada

15th Floor, Oxbridge Place
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Edmonton, Alberta, Canada
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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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Studies in Recolonization of Stream Substrates
By Aquatic Organisms

Project WS 4.1

This report may be cited as:

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

and

The Hon. John Fraser
Minister of the Environment
Environment Canada
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Sirs:

Enclosed is the report "Studies in Recolonization of Stream Substrates by Aquatic Organisms".

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

Respectfully,

W. Solodzuk, P.Eng.
Chairman, Steering Committee, AOSERP
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STUDIES IN RECOLONIZATION OF STREAM SUBSTRATES BY AQUATIC ORGANISMS

DESCRIPTIVE SUMMARY

BACKGROUND

Initial AOSERP aquatic research activities were almost entirely aimed at delineating baseline states in the Athabasca Oil Sands region. When the baseline picture approached adequate description, emphasis in the research program began to shift to applied areas, such as testing the resiliency of the environmment to stress and developing methodology for restoration of over-stressed areas.

The present project stems from the likelihood of numerous stream diversions caused by oil sands development projects. An AOSERP literature review had been conducted on the subject: "Review and Annotated Bibliography of Stream Diversion and Stream Restoration Techniques and Associated Effects on Aquatic Biota". The present project addressed the following objectives:

1. To experimentally evaluate the ability of bacteria, algae, and aquatic invertebrates to recolonize various types of stream substrates under a variety of environmental conditions in the AOSERP study area; and
2. To evaluate methods of stream substrate restoration that may be employed through stream diversion and reclamation activities relative to oil sands development.

ASSESSMENT

A draft of the report has been reviewed by university scientists in Alberta and British Columbia and the authors had opportunity to consider their input. Even though the information is of a preliminary nature, it is our recommendation that the report be distributed to selected Canadian libraries. The Alberta Oil Sands

Environmental Research Program accepts this report "Studies in Recolonization of Stream Substrates by Aquatic Organisms" and thanks the authors for their efforts.

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STUDIES IN RECOLONIZATION OF STREAM SUBSTRATES
BY AQUATIC ORGANISMS

by

M. A. LOCK and R. R. WALLACE
Environment Canada
Freshwater Institute

FOR

ALBERTA OIL SANDS

ENVIRONMENTAL RESEARCH PROGRAM

Project WS 4.1

July 1979

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ABSTRACT

The colonization of limestone gravel, limestone gravel + organic matter, and limestone gravel from a river bed was followed over time in order to compare two possible stream reclamation substrates with a control (river gravel). After nine weeks of colonization by benthic micro- and macro-organisms there were few significant differences between the river gravel control and limestone gravel and limestone gravel + organic matter, the two gravels under test. Specific differences were noted in algal composition of the epilithon, with the numbers of Cyanophyta and Chlorophyta being 50% below those on river gravel while the numbers of Bacillariophyta were considerably higher (300 to 1000%), yet the chlorophyll *a* concentration was approximately the same on all three gravels at 0.4 $\mu g \cdot cm^{-2}$. However, the similar numbers and biomass of micro-invertebrates on the three gravels suggested that the amount of energy available for higher trophic levels was equivalent. A major difference between the river gravel and the two test gravels was in the very much larger macro-invertebrate population found in the latter.

It was concluded that, although limestone rubble would be a suitable substrate for river reclamation, the time for recolonization would be considerably longer than indicated in the study because of the very high levels of propagules available from the river in which the experiments were carried out.

ACKNOWLEDGEMENTS

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Sincere thanks are also due to our pilots who transported us efficiently, safely, and cheerfully in the field, especially Fred Wiskar, Rick Churcott, Mike Jeffery, and Dave Percintile, also their engineer Jack La Roux for small services and much entertainment.

Thanks also go to Dirk Hadler and Carl Kloss for field operations and to Nargis Champsi for office services.

This research project WS 4.1 was funded by the Alberta Oil Sands Environmental Research Program, a joint Alberta-Canada research program established to fund, direct, and co-ordinate environmental research in the Athabasca Oil Sands area of northeastern Alberta.

1. INTRODUCTION

Sikstrom and Martin (1978), in their review of stream diversion and restoration techniques, state that "relatively little is known about the ability of aquatic ecosystems in the Alberta Oil Sands Environmental Research Program (AOSERP) study area to withstand or recover from the types of environmental change that can result from stream diversion." Barton and Wallace (in prep.) carried out the first experimental study of this problem in the AOSERP study area by examining the capability of river macro-invertebrates to colonize a variety of substrate types varying from tailings sand to limestone rubble. They concluded that limestone gravel would provide a riffle habitat closest to the natural situation but also suggested that an addition of organic debris to the gravel might enhance the establishment of a benthic community.

The intention of this study was to investigate the suitability of limestone gravel as a substrate for microbial colonization as well as by invertebrates and to test the hypothesis that the addition of organic matter to the gravel would enhance the colonization process.

2. MATERIALS AND METHODS

The study site was located in a riffle on the Muskeg River (Figure 1), 10 km above its confluence with the Athabasca River in northeastern Alberta (57°08'N, 111°35'W). Discharge over the study period was monitored by Water Survey of Canada and levels of conductivity, ammonium-nitrogen (NH_4 - N), nitrate + nitrite-nitrogen (NO_3 + NO_2 -N), phosphate-phosphorus (PO_4 - P), and dissolved organic carbon (DOC) were determined by Chemex Laboratories Ltd. according to the methods of Traversey (1977), being data collected for AOSERP Water Sector projects WS 1.1 and WS 1.2 respectively.

The experiment was conducted in three plywood channels (35 cm wide and 240 cm long) constructed side by side on a plywood base which was staked to the river bed. Into one channel was placed gravel from the riffle (primarily limestone pebbles 1 to 5 cm) and this was designated "river gravel". Into the other two channels was placed limestone gravel (1 to 5 cm) taken from a gravel pit close to the river, and in addition, one of these channels received ~0.1 m^3 of organic debris (decomposed leaves and other vegetation). The latter channel was designated "gravel + organic matter" and the former "gravel".

The experiment was started on 21 May 1978 and colonization of each of the substrates was to be examined at four, nine, and 16 weeks after commencement. The epilithic communities were examined by taking five 4 cm^2 scrapes from the individual limestone pebbles (Lock and Wallace in prep.a) and determining bacterial numbers by direct counting (Geesey and Costerton 1979), chlorophyll *a* by the method of Moss (1967a, 1967b), and carbohydrate by the phenol/sulphuric acid method (Strickland and Parson 1972). Scrapes for micro-invertebrates were fixed in cacodylate buffered 0.5% glutaraldehyde and later sorted under x12 magnification and transferred to 70% alcohol. After identification, the wet weights of the invertebrate groups were obtained using a Cahn electrobalance. The macro-invertebrate colonization was determined by placing a net into the channel that fitted the inside dimensions

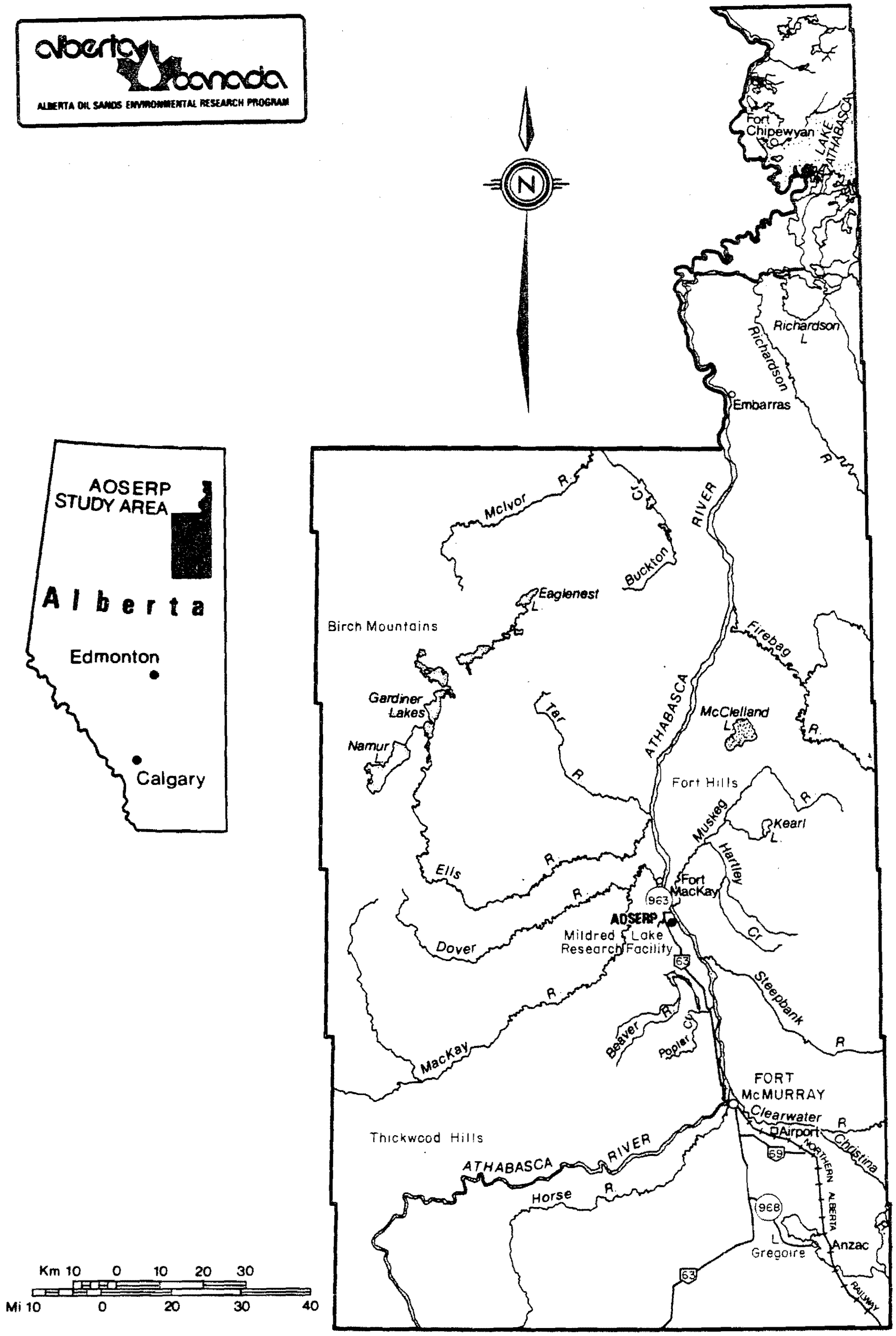

Figure 1. Map of the AOSERP study area.

exactly and then removing a 0.05 m^2 area of gravel into a dish for subsequent scrubbing. Then contents of the net and the scrubbings from the rocks were combined to give the final sample, which was preserved with 10% formalin. The samples were done in duplicate.

3. RESULTS

The physical and chemical characteristics of the Muskeg River over the study period are presented in Table 1. Throughout the latter half of August through to the middle of October, extreme precipitation increased the river discharge to very high levels, with a peak occurring in October which was three times the maximum discharge in the previous spring. It had been the intention to obtain three data points with the last one being obtained in September, but we were unable to reach the channels because of extremely high water until 8 November 1978, by which time all the substrates had been washed out. Thus, the analysis was confined to four and nine weeks of colonization.

After four weeks of colonization, the number of bacteria cm^{-2} (Table 2) on gravel was 40% of river gravel, while the number on gravel + organic matter was 60% of river gravel, differences which were both significant ($p < 0.05$). After nine weeks, the number of bacteria cm^{-2} on gravel was 72% higher than river gravel ($p < 0.05$), while the number of bacteria cm^{-2} on gravel + organic matter was not significantly different from river gravel (Table 3). The concentration of chlorophyll *a* on all three gravels was approximately 0.4 $\mu g \cdot cm^{-2}$; there were no significant differences from the river gravel (Table 2 and Figure 2). Direct algal counts (Table 4) revealed that at four weeks the numbers of Cyanophyta on the gravel and gravel + organic matter were approximately 60% of the control river gravel. However, this proportion dropped by week 9 to 28% and 6%, respectively. The same comparison for Bacillariophyta showed them to be 66% and 33% of the river gravel at four weeks increasing to 300% and 1000% by week 9. The Chlorophyta on the gravel and gravel + organic matter were approximately 25 and 40%, respectively, of the numbers on river gravel. Carbohydrate concentrations on the river gravel remained at about the same mean level of 13 $\mu g \cdot cm^{-2}$ after four and nine weeks of colonization (Table 2 and Figure 2). At four weeks, the mean concentration on gravel was 3.8 $\mu g \cdot cm^{-2}$ and on gravel + organic matter only 2.2 $\mu g \cdot cm^{-2}$; both were significantly different (Table 3) from the river gravel, at 13.1 $\mu g \cdot cm^{-2}$ ($p < 0.05$). At

Table 1. Physical and chemical parameters of the Muskeg River over the study period in 1978.

	April	May	June	July
Mean daily discharge ($m^3 \cdot s^{-1}$)	113	324	174	43
Temperature (°C)	0	6.5	16.0	16.0
Conductivity (S·m)	430	120	170	340
NH_4 - N ($\mu g \cdot L^{-1}$)	580	50	40	20
$NO_3 + NO_2$ - N ($\mu g \cdot L^{-1}$)	82	5	8	3
PO_4 - P ($\mu g \cdot L^{-1}$)	8	13	< 3	10
DOC ($mg \cdot L^{-1}$)	18	22	53	24
pH	7.5	7.8	7.8	7.8

Table 2. Epilithic biomass determinations on three substrates over time.

Sampling Time	River Gravel			Gravel			Gravel and Organic Matter		
	Sessile Bacteria	Chlorophyll *a*	Carbohydrate	Sessile Bacteria	Chlorophyll *a*	Carbohydrate	Sessile Bacteria	Chlorophyll *a*	Carbohydrate
Week 4	$2.5 \pm 0.5 \times 10^7$	0.50 ± 0.07	13.09 ± 2.92	$1.0 \pm 0.2 \times 10^7$	0.32 ± 0.07	3.76 ± 1.57	$1.4 \pm 0.4 \times 10^7$	0.47 ± 0.15	2.24 ± 0.37
Week 9	$1.8 \pm 0.4 \times 10^7$	0.36 ± 0.10	12.50 ± 2.44	$3.1 \pm 0.5 \times 10^7$	0.53 ± 0.10	7.24 ± 0.88	$2.0 \pm 0.4 \times 10^7$	0.34 ± 0.05	7.79 ± 1.00

Table 3. Comparison of the means, using a t test, of the epilithic biomass determinations on three substrates over time.

Sampling Time	Pair[a]	Sessile Bacteria		Chlorophyll *a*		Carbohydrate	
		t	df	t	df	t	df
Week 4	RG / G	5.90	8	2.26	8	2.60	7
	RG / GOM	3.42	8	0.49	8	3.69	8
	G / GOM	2.18	8	0.94	8	1.05	7
Week 9	RG / G	4.94	8	1.18	7	2.02	8
	RG / GOM	0.86	8	0.13	7	1.79	8
	G / GOM	3.41	8	1.70	6	0.41	8

[a]RG = River gravel; G = Gravel; GOM = Gravel + organic matter.

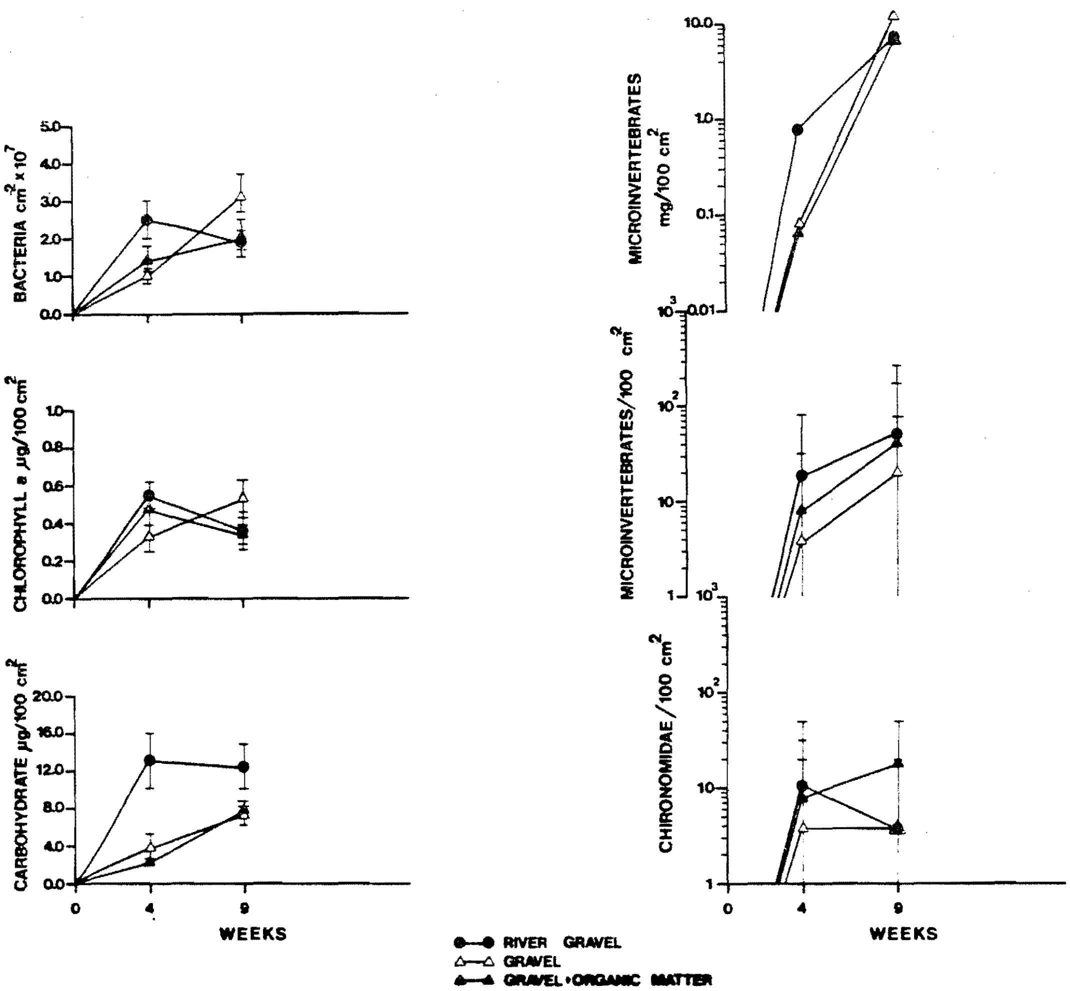

Figure 2. Epilithic biomass determinations on three substrates over time.

Table 4. The number of algal cells cm^{-2} on the three gravel substrates.

Substrate	Week	Cyanophyta	Bacillariophyta	Chlorophyta
River gravel	4	1.3×10^6	6.0×10^2	1.4×10^5
Gravel	4	7.3×10^5	4.0×10^2	3.0×10^4
Gravel + organics	4	8.8×10^5	2.0×10^2	5.5×10^4
River gravel	9	5.7×10^5	2.0×10^2	4.0×10^4
Gravel	9	1.6×10^5	6.0×10^2	1.1×10^4
Gravel + organics	9	3.9×10^4	2.0×10^3	1.8×10^4

nine weeks, the concentration had risen to around 7.5 $\mu g \cdot cm^{-2}$ and the difference between that and the concentration on river gravel of 12.5 $\mu g \cdot cm^{-2}$ was no longer significant.

No significant differences were found between the total numbers of micro-invertebrates and the number of Chironomidae per 100 cm^2 on each of the three gravels (Table 5 and Figure 2). However, attention must be drawn to the extremely large 95% confidence limits. There appears to be a trend of increasing numbers of micro-invertebrates over time which is also reflected in the weight of micro-invertebrates per 100 cm^2 (Table 5 and Figure 2). Inspection of the data on the macro-invertebrates reveals that at four and nine weeks of colonization there was either no significant difference ($p<0.05$) in the numbers of macro-invertebrates on the three gravel types or, more usually, a $<$ 100% increase occurred on the gravel and gravel + organic matter (Table 6). The responses of the macro-invertebrates colonizing the gravel and gravel + organic matter are summarized in Table 7. In only a very few instances were fewer invertebrates found on the gravel and gravel + organic matter compared with the river gravel and these were confined to the Simuliidae, Acarina, Ostracoda, and "other". Substantial increases in invertebrate numbers over those in river gravel ($>$ 100%) were found in the Ostracoda, Plecoptera, Trichoptera, and others on gravel, and Cladocera, Mollusca, Plecoptera, and Trichoptera on gravel + organic matter.

Table 5. Mean with 95% confidence limits of the numbers of micro-invertebrates per 100 cm^2 on three substrates over time.

Week	Parameter		River Gravel				
			Chironomidae	Simuliidae	Trichoptera	Others	Total
4	Number	Mean	10.8	8.0	-	-	16.0
		Upper	49.0	31.5			84.3
		Lower	0	0			0
	Weight	Mean	0.391	0.407	-	-	0.799
9	Number	Mean	3.8	36.5	10.8		54.8
		Upper	19.8	215.0	49.0		265.30
		Lower	0	0	0		0
	Weight	Mean	0.080	0.095	7.250	-	7.425

Table 6. Mean number of macro-invertebrates per 0.05 m^2 from three gravel substrates over time.

	Week 4			Week 9		
	River Gravel	Gravel	Gravel + Organic Matter	River Gravel	Gravel	Gravel + Organic Matter
Cladocera	22.5[b]	18[a]	44.0[b]	59.5	268[b]	1397.5[b]
Copepoda	24	24[a]	39.5[a]	84.5	114[b]	177.5[b]
Chironomidae	626.5	1440[b]	618[a]	47.5	37[a]	122.5[b]
Simuliidae	49	80[b]	32.5[a]	468.5	309[b]	1198.5[b]
Ephemeroptera	1073	2106[b]	1721.5	67.0	85[a]	158.0[b]
Acarina	87	146[b]	62.0[b]	45.0	75[b]	64.5[a]
Mollusca	9.5	14[a]	12.0[a]	6.0	7[a]	17.5[b]
Ostracoda	3.5	4[a]	15.5[b]	119.5	5[b]	12.5[b]
Plecoptera	4	8[a]	15.0[b]	20.5	41[b]	70.0[b]
Trichoptera	50	152[b]	87.0[b]	284.0	476[b]	1370.0[b]
Others	39	88[b]	123.5[b]	139.5	9[b]	16.5[b]

[a] No significant difference from river gravel (X^2 test).

[b] Significantly different from river gravel, $p \leq 0.05$ (X^2 test).

Table 7. A summary of the responses of macro-invertebrates colonizing gravel and gravel + organic matter in comparison with river gravel[a].

	Gravel		Gravel + Organic Matter	
	Week 4	Week 9	Week 4	Week 9
Cladocera	0	+	++++	++++
Copepoda	0	0	+	+
Chironomidae	+	0	0	+
Simuliidae	+	0	-	+
Ephemeroptera	+	+	0	+
Acarina	+	-	+	0
Mollusca	0	0	0	++
Ostracoda	0	+++	----	----
Plecoptera	0	+++	+	++
Trichoptera	++	+	+	+++
Others	+	++	----	----

[a]+ or -: < 100% increase (+) or decrease (-) over numbers in river gravel.
++ or --: 100-200% increase (+) or decrease (-) over numbers in river gravel.
+++ or ---: 200-300% increase (+) or decrease (-) over numbers in river gravel.
++++ or ----: > 300% increase (+) or decrease (-) over numbers in river gravel.
0: no significant difference from river gravel.

4. DISCUSSION

At the end of nine weeks of colonization, there were very few significant differences among the epilithon components of river gravel (the control) and limestone gravel on its own and with an organic supplement. Specific differences were observed in the algal communities on gravel and gravel + organic matter, where both Cyanophyta and Chlorophyta populations were around 50% below those on river gravel, while the Bacillariophyta populations were considerably higher (300 to 1000%). Such differences may indicate that the epilithic communities were still going through seral stages and had not reached equilibrium. However, the total algal biomass indicated by chlorophyll *a* was the same on all three gravels. Although microbial taxonomic uniformity had not occurred at nine weeks in the gravel and gravel + organic matter epilithon, the equal numbers and weights of micro-invertebrates living within it would suggest that the amount of energy and matter available for the subsequent trophic levels (i.e., protozoans and micro-invertebrates) was probably equivalent between the three gravels. A comparison of the present data with concurrent observations from the same river on an established community on granite discs (Lock and Wallace in prep.b) revealed that the numbers of bacteria and algae and concentrations of chlorophyll *a* were broadly similar. This is considered further supportive evidence that an equilibrium epilithic community was being approached.

In contrast, macro-invertebrate populations in the gravel and gravel + organic matter channels were equal or generally much higher than the river gravel. This at first seemed a rather surprising observation since it had already been suggested that the energy produced or trapped by the epilithon which was available to higher trophic levels was probably the same on each gravel. However, it has been recently shown that gravel size and porosity can be important determinants in the size of the macro-invertebrate populations they can support (Rabeni and Minshall 1977; Williams and Mundie 1978). These studies showed that certain gravel sizes were better able to trap organic matter and sediment. Rabeni and Minshall (1977) demonstrated that macro-invertebrates were attracted to this material. Therefore, it is possible that the two experimental gravels were sufficiently different in size from the river gravel and more efficient accumulators of sediment and organic matter and, subsequently, were able to support higher macro-invertebrate populations. Unfortunately, the loss of the gravels during the autumn flood precluded the testing of this hypothesis. In general, the gravel + organic matter supported the higher macro-invertebrate population (Table 7) and the addition of organic matter at the outset of the experiment may have supplemented the organic matter and sediment that was later to become naturally trapped.

It seems reasonable to conclude that limestone gravel would be a very suitable substrate for reclamation of riffle sections of rivers in the AOSERP study area. However, it might be appropriate to consider further the size of the gravel used and, although it is acknowledged that economic and engineering constraints may have to dictate this aspect of reclamation, it may be feasible, by using specific gravel sizes, to increase the productivity of some of the reclaimed rivers above the "normal" level for the area. This hypothesis would be amenable to simple field testing.

Lastly, this study has shown that fresh gravels (i.e., unexposed to river water) are able to support communities very similar to the naturally occurring benthic communities within two months. Yet it is important to stress that these gravels were exposed to an optimum situation for colonization, i.e., they were in direct continuity with the water and substrates of a normal river. If a river channel is produced which has no continuity with any existing natural water bodies then it is reasonable to expect that the colonization period of even a suitable substrate such as limestone will be much longer than two months. Colonization in this instance would be by propagules, from adjacent water bodies or soil, transported through the air or over the land. An indication of the time involved could be obtained by feeding filtered lake water (i.e., water least like river water) into channels located on the land filled with substrates and following the rate and type of colonization. However, if at all feasible, the quickest return to "normal" conditions would be obtained in reclaimed rivers by ensuring at least one connection to a natural river with this input occurring as high up the reclaimed section as possible.

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6. 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 whithin 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
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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
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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.		Alberta Oil Sands Environmental Research Program Interim Report to 1978 covering the period April 1975 to November 1978
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 1.5.2	Air System Winter Field Study in the AOSERP Study Area, February 1977.
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. WS 3.3 Mixing Characteristics of the Athabasca River below Fort McMurray - Winter Conditions

41. AF 3.5.1 Acute and Chronic Toxicity of Vanadium to Fish

42. TF 1.1.4 Analysis of Fur 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 Effects on Vegetation and Soils, 1975 to 1978.

47. TF 1.1.1 A Visibility Bias Model for Aerial Surveys for Moose on the AOSERP Study Area

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52. ME 2.3.2 Plume Dispersion Measurements from an Oil Sands Extraction Plan, June 1977

53.	HY 3.1.2	Baseline States of Organic Constituents in the Athabasca River System Upstream of Fort McMurray
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58.	AF 2.0.2	Interim Report on Ecological Studies on the Lower Trophic Levels of Muskeg Rivers Within the Alberta Oil Sands Environmental Research Program Study Area
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60.	WS 1.1.1	Synthesis of Surface Water Hydrology
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63.		Calculate Sigma Data for the Alberta Oil Sands Environmental Research Program Study Area.
64.	LS 21.6.1	A Review of the Baseline Data Relevant to the Impacts of Oil Sands Development on Large Mammals in the AOSERP Study Area
65.	LS 21.6.2	A Review of the Baseline Data Relevant to the Impacts of Oil Sands Development on Black Bears in the AOSERP Study Area
66.	AS 4.3.2	An Assessment of the Models LIRAQ and ADPIC for Application to the Athabasca Oil Sands Area
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73.	LS 23.2	Distribution, Abundance and Habitat Associations of Beavers, Muskrats, Mink and River Otters in the AOSERP Study Area, Northeastern Alberta
-	--	Interim Report to 1978
74.	AS 4.5	Air Quality Modelling and User Needs
75.	LS 2.1	Interim Report on the Soils Inventory of the AOSERP Study Area

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

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