EFFECTS OF CRUDE OIL CONTAMINATION ON EPHEMEROPTERA IN THE TRAIL RIVER, NORTHWEST TERRITORIES, CANADA

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ABSTRACT

Artificial substrates were soaked in crude oil and placed in the Trail River, N.W.T. for periods up to almost 1 year. Ephemeroptera nymphs usually occurred in lower numbers, fewer taxa and lower diversity on oiled substrates than on unoiled substrates. Communities of nymphs were significantly different except for the substrates left in the river for the longest period (335 days). Numbers of *Heptagenia (flavescens* Walsh?), *Stenonema vicarium* (Walker), *Ameletus* sp. 1, and *Baetis* spp. decreased in response to the oil while numbers of *Pseudocloeon* sp. 1 and *Ephemerella aurivillii* Bengtsson increased. Numbers of *E. (bicolor* Clemens?) and *E. simplex* McDunnough were unaffected. *H. (flavescens?)* should be the best indicator (reduced numbers) of low level contamination of aquatic systems by oil and petroleum products although *S. vicarium* (reduced numbers) and *E. aurivillii* (increased numbers) may also be useful. Responses of these three species to oil contamination are related to the presence of food and to quality of the substrate.

INTRODUCTION

Development of petroleum reserves in Alaska and northern Canada will increase the contamination of northern freshwater habitats by oil and petroleum products. A large-diameter oil pipeline has already been built across Alaska; a large-diameter natural gas pipeline is planned for Alaska and the Yukon Territories; another is planned for the Canadian Arctic Islands; and mining of

the vast oil sands reserves in northern Alberta has begun. Little is known about the responses of freshwater invertebrates to such contamination, especially in northern areas where only a few studies have been done (Rosenberg and Wiens 1976; Mozley and Butler 1978; Barton and Wallace 1979). Our objectives in this paper are to describe the responses of Ephemeroptera experimentally exposed to crude oil and to identify species that might be used as indicators of low-level contamination by oil and petroleum products.

METHODS

Experiments were done in the Trail River, N.W.T., ≈1 km above its confluence with the Mackenzie River (62°06'N, 122°11'W). The river is in the boreal forest of the Upper Mackenzie Valley lowlands (150-300 m a.s.l.) and drains a watershed (mainly muskeg) of 660 km^2.

Artificial substrate samplers (Anderson and Mason 1968) were filled with approximately 30-35 dry stones (5-8 cm diameter) taken from the river bank. Some of the samplers were dipped in a pan of Norman Wells crude oil, allowed to drain, and installed on the river bottom (≈1 m depth). An equal number of untreated (control) samplers were placed upstream to avoid contamination. Sufficient samplers were installed to provide three replicates of oiled and control substrates (= 1 set) per sampling. Samplers usually were removed after ≈1 month colonization and/or for varying periods thereafter. Experiments were begun on three dates (Table 1). After removal of the samplers, invertebrates were brushed from the surface of the stones, preserved in 70% ethyl alcohol and returned to the laboratory for identification and enumeration.

Diversity of Ephemeroptera was characterized using Brillouin's H (Pielou 1966; Lloyd *et al.* 1968), an index based on information theory. Kendall's τ (Siegel 1956; Ghent 1963), a non-parametric measure of rank correlation, was used to determine similarity of communities on oiled and control substrates. Categories of responses of species of Ephemeroptera to the crude oil and evaluation of indicator potential are adapted from Rosenberg and Wiens (1976).

Further details of the study area and methods used can be found in Brunskill *et al.* (1973) and Rosenberg and Wiens (1976).

RESULTS

Numbers of individuals, numbers of taxa, and diversity (Brillouin's H) of Ephemeroptera on oil-treated artificial substrates were generally lower than on the untreated controls (Table 1). Communities of Ephemeroptera on the two types of

Table 1. Comparison of communities of Ephemeroptera on oil-treated (O) and untreated (U) artificial substrates.

Date Artificial Substrates Installed	No. of Days of Colonization	% Oil Remaining[a]	No. of Individuals[b] U	No. of Individuals[b] O	No. of Taxa[b] U	No. of Taxa[b] O	Diversity (Brillouin's H) U	Diversity (Brillouin's H) O	τ Corrected	Kendall's τ P-Value	Are Communities Similar?[c]
July 14, 1972	28	69.5	190	138	9	7	2.33	1.80	.354	.260	No
	56	33.2	179	88	10	6	2.43	2.24	.167	.600	No
	132	4.7	144	23	10	4	2.19	1.43	.196	.612	No
	335	28.3	680	392	7	7	1.38	1.38	.823	.009	Yes
Sept. 8, 1972 (Set A)	279	28.2	619	318	7	7	1.82	1.59	.704	.015	No
(Set B)	279	4.4	616	407	9	6	1.78	1.58	.530	.060	No
July 12, 1973	28	28.3	193	361	6	4	1.61	1.02	.500	.272	No
	57	15.8	146	250	7	7	1.66	1.87	.333	.472	No

[a] See Table 1 in Rosenberg and Wiens (1976)

[b] Total number on three artificial substrates

[c] Decision based on $P \leq .01$

substrate were significantly different (Kendall's τ) on seven of the eight sets. Discrepancies in these trends occurred in samplers with the longest colonization times (279 and 335 days) and in the sets from 1973. Residues of oil remaining on these substrates were <30% of the amount originally applied (Table 1; Rosenberg and Wiens 1976) probably due to longer exposure to river water and/or the higher annual discharge in 1973 ($\simeq 69.5 \times 10^6$ m^3) than in 1972 ($\simeq 26.6 \times 10^6$ m^3). A threshold quantity of oil may therefore be necessary to cause changes in characteristics of communities of Ephemeroptera.

Table 2. Taxa of Ephemeroptera occurring on artificial substrates

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Siphlonuridae
- *Ameletus* sp. 1
- *Siphlonurus* sp. 1

Baetidae
- *Baetis* spp.
- *Pseudocloeon* sp. 1

Heptageniidae
- *Epeorus (Iron)* sp. 1
- *Heptagenia (flavescens* Walsh?)
- *Rhithrogena* sp. 1
- *Stenacron (pallidum* (Traver)?)
- *Stenonema (fuscum* (Clemens)?)
- *Stenonema (ithaca* (Clemens & Leonard)?)
- *Stenonema pulchellum* (Walsh)
- *Stenonema vicarium* (Walker)

Leptophlebiidae
- *Leptophlebia cupida* (Say) or *L. nebulosa* (Walker)
- *Paraleptophlebia* sp. 1

Ephemerellidae
- *Ephemerella (Dannella) simplex* McDunnough
- *Ephemerella (Ephemerella) aurivillii* Bengtsson
- *Ephemerella (Eurylophella) (bicolor* Clemens?)

Seventeen taxa of Ephemeroptera, representing five families, colonized the artificial substrates (Table 2). Out of a possible of 16 occurrences (eight sets of oiled substrates, eight sets of controls), nine taxa occurred on four sets or less (0-<25% occurrence) and were not used in the following consideration of responses because of their erratic occurrence. Five taxa occurred in 12-16 sets (≥75-100% occurrence, Group I), one species occurred on 8-12 sets (≥50-<75% occurrence, Group II) and two species occurred on 4-8 sets (≥25-<50% occurrence, Group III). Two species showed a positive response to the oil (i.e. numbers higher on oiled substrates than on controls in more than half the occurrences), four species were negatively affected (i.e. numbers lower on oiled substrates than on controls in more than half the occurrences), and two species were unaffected (i.e. approximately equal numbers on oiled and control substrates) (Table 3). No species showed a strong positive response to the oil but three species showed a strong negative response. These results were verified, in a general way, when the total numbers of each species on oiled and control substrates were compared (Fig. 1).

DISCUSSION

Oil contamination can affect invertebrates in a number of ways (Moore and Dwyer 1974). Lighter fractions of the oil may be directly toxic. Substrate surfaces may be coated by oil and made unuseable. The oil may enhance microbial and algal growth (Rosenberg and Wiens 1976, Barton and Wallace 1978) thus increasing the food supply for invertebrates but also altering the microhabitat (e.g. by lowering dissolved oxygen concentrations, covering substrate surfaces and filling interstices).

Ephemeroptera appear to be sensitive to oil contamination, their numbers usually being reduced (Hynes 1965, U.S.E.P.A. 1973, Barton and Wallace 1979). Certainly, in this study, more species were reduced in number than increased by the oil treatment (Table 3, Fig. 1). This aversion to oil by Ephemeroptera is even more evident when the distribution of the species not considered in the above assessment (i.e. those occurring on 1-4 sets, the 0-<25% occurrence group) is examined (Table 4).

It would be useful to predict those species which may be potentially indicative of low-level, chronic oil contamination in lentic fresh waters. Species listed in the positive and negative response categories of Table 3 were assessed using three criteria: taxonomic soundness, zoogeographic distribution and abundance (for rationale, see Rosenberg and Wiens 1976). *Baetis* spp., *Pseudocloeon* sp. 1, and *Ameletus* sp. 1 were excluded because of their uncertain taxonomic status. No additional species were obtained for assessment from the literature because species identifications were rarely

Table 3. Responses of Ephemeroptera to oil.

Group[a]	Response Index[b]								
	Positive				Unaffected	Negative			
	Strong 1.0	Strong .875	Moderate .750	Weak .625	.500	Weak .375	Moderate .250	Strong .125	Strong 0
I			*Ephemerella aurivillii*	*Pseudocloeon* sp. 1	*Ephemerella (bicolor?)*		*Baetis* spp.		*Heptagenia (flavescens?)*
II								*Stenonema vicarium*	
III					*Ephemerella simplex*				*Ameletus* sp. 1

[a] Based on frequency of occurrence on all sets of artificial substrates (See text for explanation).

[b] Based on number of occurrences of higher numbers on oiled artificial substrates than on controls out of a maximum of 8 possible dates (e.g. *E. aurivillii* occurred in higher numbers on oiled artificial substrates than on controls 6 out of 8 times for an index value = .750 and a "positive, moderate" response designation).

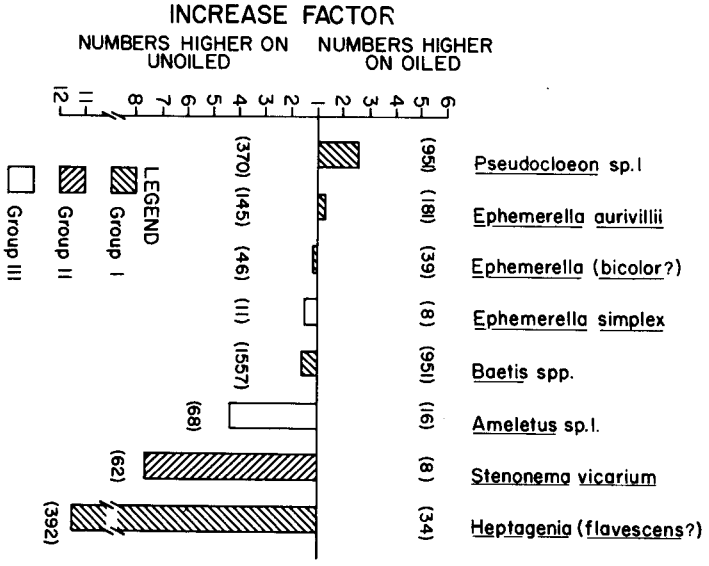

Figure 1. Responses of Ephemeroptera to crude oil. Numbers in parentheses are totals occurring on oiled (top) and control (bottom) artificial substrates. See text for explanation of Groups I, II, III.

given in studies on the effects of oil on Ephemeroptera or the data for species were inconclusive (e.g. U.S.E.P.A. 1973).

Of the three species assessed (Table 5), *Heptagenia (flavescens?)* offers the most potential, provided its identification is correct. Numbers of *H. (flavescens?)* should be reduced by oil contamination. *Stenonema vicarium* should be less useful because, although it was obviously reduced in number by the oil treatment (Fig. 1), it occurred in lower numbers and less frequently than *H. (flavescens?)*. *Ephemerella aurivillii* should increase in numbers as a result of oil contamination although the minimal response shown in this study detracts from its usefulness as an indicator.

Toxic lighter fractions of oil are short-lived (Moore and Dwyer 1974). Thus is is unlikely that they are involved in the responses described here because of the relatively long colonization periods involved in this study. Responses by the three species

Table 4. Distribution of Ephemeroptera in the 0-<25% occurrence group on oil-treated and control artificial substrates.[a]

Species	None found on: Oiled Artificial Substrates	Control
Stenonema pulchellum	x	
Stenonema ithaca	x[b]	
Rhithrogena sp. 1	x[c]	
Epeorus sp. 1		x[c]
Siphlonurus sp. 1	x[b]	
Leptophlebia cupida or *nebulosa*	x[c]	
Paraleptophlebia sp. 1	x	

[a] *Stenonema (fuscum?)* - one specimen on each type of substrate
Stenacron (pallidum?) - approximately twice as many on control substrates (12) as oiled (7) but only present on two sampling dates.

[b] One specimen only.

[c] Present on one artificial substrate only.

assessed as indicators are probably linked to increased food or to changes in the quality of the substrate. *E. aurivillii* usually occurred in higher numbers on oiled than control artificial substrates, the differences being greatest during the first two months of colonization in 1972 and 1973 (Table 6). Extensive algal growth occurred on the oiled artificial substrates during these periods (Rosenberg and Wiens 1976). *E. aurivillii* is known to eat diatoms and filamentous algae (Shapas and Hilsenhoff 1976) and could be exploiting this additional food resource on the oiled artificial substrates. Numbers of *S. vicarium and H. (flavescens?)* were almost always dramatically higher on control artificial substrates than on oiled (Table 6). Heptageniidae need clean water and clean substrates with direct access to interstices (Dodds and Hisaw 1924). *S. vicarium* can withstand some organic enrichment providing the dissolved oxygen concentration is >5 mg l^{-1} (Lewis 1978). Persistence of residues in the oiled artificial substrates (Table 1) and the large amount of organic matter resulting from algal growth probably created an unfavorable habitat for these mayflies on oiled artificial substrates. More information on the autecology of species is required to explain fully the responses of Ephemeroptera observed in this study.

Table 5. Evaluation of some species of Ephemeroptera as potential indicators of oil contamination.

Species	Response Category	Agreement with Criteria: Taxonomically Sound	Widely Distributed	Numerous	Predicted Usefulness as Indicator
Ephemerella aurivillii	Positive (moderate)	Yes. (Burks 1953, Allen & Edmunds 1965, Edmunds *et al.* 1976).	Yes. Holarctic, generally distributed in Nearctic; found north into Alaska (Needham *et al.* 1935, Burks 1953).	Yes. (this study). Infrequent in Barton and Wallace (1978).	Moderate-high
Stenonema vicarium	Negative (strong)	Yes. (Burks 1953, Lewis 1978).	Yes. Mainly Nearctic; mostly in east and central U.S.A. and Canada (Edmunds *et al.* 1976).	Moderately (this study, Barton and Wallace 1978).	Moderate-high
Heptagenia (flavescens?)	Negative (strong)	Probably. Species complexes exist in this genus and some nymphs have not been described (Edmunds *et al.* 1976).	Yes. Holarctic and widely distributed in Nearctic (Needham *et al.* 1935).	Yes. (this study)	High

Table 6. Numbers of *Ephemerella aurivillii*, *Stenonema vicarium*, and *Heptagenia (flavescens?)* on oil-treated (O) and untreated (U) artificial substrates.[a]

Date Artificial Substrates Installed	No. of Days of Colonization	Numbers of Individuals					
		Ephemerella aurivillii		*Stenonema vicarium*		*Heptagenia (flavescens?)*	
		U	O	U	O	U	O
July 14, 1972	28	5	25	14	0	46	3
	56	4	7	13	0	10	5
	132	4	6	32	0	63	1
	335	34	33	6	0	67	4
Sept. 8, 1972 (Set A)	229	65	18	7	1	17	1
(Set B)	229	25	26	0	3	80	4
July 12, 1973	28	4	27	14	0	36	2
	57	4	27	7	4	74	14

[a] Total number on three artificial substrates.

RESUME

Des substrats artificiels furent trempés dans de l'huile brute et placés dans la Trail River (T.N.-O.) pour des périodes allant jusqu'à un an. On a généralement trouvé moins de larves d'éphéméroptères, moins de taxons et moins de variétés sur les substrats huilés que sur les substrats non huilés. Les populations de larves accusaient des différences notables sauf en ce qui concerne les substrats qui restèrent submergés le plus longtemps (335 jours). Les populations d'*Heptagenia (flavescens* Walsh?), de *Stenonema vicarium* (Walker), d'*Ameletus* sp. 1, ainsi que des *Baetis* spp. accusèrent une diminution en raison d l'huile alors que les populations de *Pseudocloeon* sp. 1 et d'*Ephémérella aurivillii* Bengtsson augmentèrent. Les populations d'*E. (bicolor Clemens?)* et d'*E. simplex* McDunnough ne subirent par de changements. L'*Heptagenia (flavescens?)* se révéla le meilleur indice du faible niveau de pollution des eaux dû à l'huile et aux produits dérivés du pétrole. Ajoutons que les *S. vicarium* et les *E. aurivillii* peuvent aussi s'avérer utiles. Les réactions de ces trois espèces à la pollution par l'huile dépendent de la présence de nourriture et de la qualité du substrat.

ZUSSAMENFASSUNG

Künstliche Substrate wurden mit Rohöl durchtränkt and im Trail River N.W.T. bis zu einem Jahr ausgesetzt. Ephemeropterennymphen kamen gewöhnlich an geölten Substraten in Kleineren Mengen, niedrigeren Taxa und in geringerer Vielfalt zum Vorschein, als an ungeölten Substraten. Die Nymphengemeinschaften wiesen bedeutende Underschiede auf. Nur die Substrate, die die längste Zeit im Fluß waren, (335 Tage), zeigten keinerlei Unterschied. Die Zahlen von *Heptagenia (flavescens* Walsh?), *Stenonema vicarium* (Walker), *Ameletus* sp. 1 und *Baetis* spp. verringerten sich als Reaktion auf das Öl, während *Pseudocloeon* sp. 1 und *Ephemerella aurivillii* (Bengtsson) zunahmen. *E. (bicolor* Clemens?) und *E. simplex* (McDunnough) blieben vom Öl unbeeinflußt. *H. (flavescens?)* erwies sich als der beste Indikator einer leichten Verschmutzung der aquatischen Systeme durch Öl und Petroleumprodukte, obwohl *S. vicarium* und *E. aurivillii* ebenfalls brauchbar sein mögen. In der vorliegenden Arbeit soll die Reaktion der genannten drei Arten auf Ölverschmutzung in Beziehung gesetzt werden zu dem Vorhandensein von Nahrung und zur Qualität des Substrats.

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