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THE EFFECT OF PARTIAL AND TOTAL DROUGHT ON THE MACROINVERTEBRATE COMMUNITIES OF THREE SMALL DANISH STREAMS

Torben MOTH IVERSEN, Peter WIBERG-LARSEN, Søren BIRKHOLM HANSEN & Frode S. HANSEN

Freshwater Biological Laboratory, University of Copenhagen, 51 Helsingørsgade, DK-3400 Hillerød, Denmark

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Abstract

Three cases of partial or total drought were studied. A two weeks' stop of water flow with reduced water level and stagnant water was survived by most stream species. Only the population of *Baetis rhodani* Pict. was almost eliminated.

An unprecedented drought of 2-3 months reduced numbers of stream species. The differential effects are discussed in relationship to the behaviour, life cycle and physiology of the individual species.

After the drought many invaders were found, but most disappeared rapidly. Only *Asellus aquaticus* L. maintained a population in the stream.

In an intermittent stream with 3-4 months' drought no changes were observed, and many species were the same as those which survived in the second stream.

It is concluded that the consequences of an increasing frequency of drought, for example due to increasing ground water use, will depend on the species normally present and on the season and duration of the drought.

Introduction

In recent years the use of groundwater and stream water for drinking water and artificial irrigation has expanded in Denmark, and further expansion can be expected. The water flow of streams will thereby be reduced, and more streams will dry up, partially or totally, during the summer. The literature on the ecological consequences is sparse (see Hynes, 1970 for references). The present paper describes the effect of varying degrees of drought on the macroinvertebrate communities of three small Danish streams.

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Description of localities

Milling Baek, a 130 m long outlet from the lake Slåen Sø, is situated in Mid-Jutland, Denmark (9° 36′ 88″ E, 56° 7′ 40″ N). The lake has a gross phytoplankton production of 30-50 g C m^{-2} y^{-1} and a mean chlorophyll concentration of about 3 μg l^{-1} (Vandkvalitetsinstituttet, 1976). The width of the stream is about 1.5-2.5 m during normal flow, and the bottom consists of sand, gravel and stones.

In connection with rebuilding of the dam, which controls the outflow from the lake, the water flow was stopped from 10 to 24 October 1976. During these two weeks the stream width decreased by about half and the water in the stream became stagnant. The stream did not dry up totally. As the lake is springfed and the water flow normally continuous, the rebuilding of the dam created an experimental situation, which can simulate the course of a short-term stop of water flow.

Orned Baek is about 6 km long and a tributary of the river Suså on Zealand, Denmark (11° 53′ - 12° 09′ E, 55° 20′ 45″ N). It rises in woodland, but drains mostly agricultural land. The stream is slightly polluted by domestic sewage. The investigation took place in the middle section, where the stream width during winter and spring is about 1.1 m. The substratum is gravel with a few small stones.

Due to extremely low precipitation the stream dried up at the end of July 1976 and remained dry for 2-3 months. It had not dried up at least during the preceding five years (Poul Andersen, personal communication).

Ravnstrup Skovgrøft is also situated in the Suså watershed (11° 44′ E, 55° 20′ N). The stream is about 300 m long, springfed and runs through a beech forest. During

the winter and spring its width is about 1.8 m, and the substratum is mud and sand overlain by soaked fallen beech leaves. Its velocity never exceeds 5 cm sec^{-1}. The stream dries up regularly during the summer. In 1976 the stream was totally dry for about 4 months (June-October).

Material and methods

The investigations of the three streams took place from spring 1976 until spring 1977.

In Milling Baek and Orned Baek the invertebrate fauna was sampled by the kicking technique (Morgan & Egglishaw, 1965). A net was placed tightly on the substratum, and the substratum in front of the net was disturbed intensely using the feet. The whole width of the stream was sampled in this way, and two or three samples were taken on each occasion. This method provides information on species composition as well as a relative estimate of population densities.

In Ravnstrup Skovgrøft the current was too slow for the above method to be used. Instead three 1 l jars were filled with fallen beech leaves. This method only provided information on species composition.

Results

Milling Baek

The fauna of Milling Baek was dominated by *Gammarus pulex, Baetis rhodani, Limnius volckmari, Hydropsyche angustipennis* and *Potamopyrgus jenkinsii* (Table 1). On two occasions prior to the stop of water flow a total of 40 and 34 taxa were found (Fig. 1), of which 30 taxa were common to the two sampling dates.

Immediately after the water flow recommenced, the number of taxa increased to 49 (Fig. 1). This was mainly due to taxa from lake Slåen Sø such as Hirudinea, *Leptophlebia vespertina, Cloeon dipterum,* Zygoptera, Polycentropidae, Limnephilidae and Hydracarina. Most of these disappeared rapidly, and in March 1977 36 taxa were found with 30 taxa in common with the two September samples.

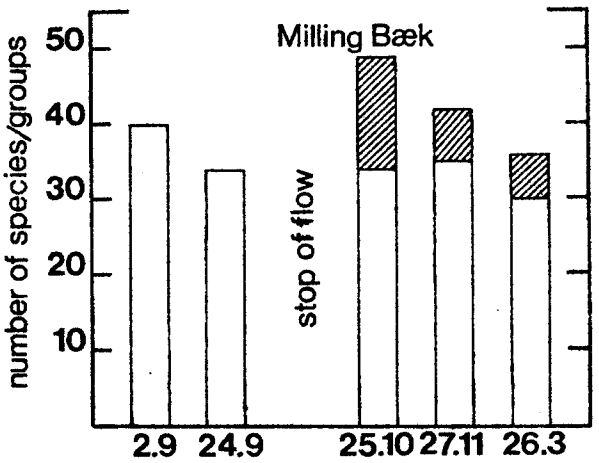

Fig. 1. Numbers of macroinvertebrate taxa recorded in Milling Baek 1976-77. The hatched area indicates numbers of taxa not found in September before the stop in water flow.

No taxa disappeared completely after the cessation of water flow. However, certain quantitative changes in population densities took place. *Baetis rhodani* almost disappeared (Table 1). Measurements of head capsule widths revealed that the population in September consisted of many small individuals. Therefore, the decline in population density could not be due to emergence.

The populations of *Gammarus pulex* and *Potamopyrgus jenkinsii* did not decline with a higher rate during the cessation of water flow, than in the period before (Table 1).

Limnius volckmari and *Hydropsyche angustipennis* declined with a higher rate (Table 1). The density of *Hydropsyche angustipennis* increased again. An instar analysis showed that this was not due to hatching of eggs, as no first and few second instar larvae occurred in November

Table 2. An instar analysis of Hydropsyche angustipennis collected in Milling Baek 1976-77.

Instar	Width of head capsule (mm)	02.09.76	24.09.76	25.10.76	27.11.76	26.03.77
I	0.17-0.28	86	33	3	0	0
II	0.29-0.40	203	101	3	7	1
III	0.47-0.67	216	84	9	33	25
IV	0.74-1.13	178	128	4	40	21
V	1.20-1.62	38	20	5	37	18

Table 1. The composition of the macroinvertebrate community in Milling Baek 1976-77. Water flow was stopped for two weeks in October 1976. Each number represents the result of one kick sample.

	02.09.76		24.09.76		25.10.76		27.11.76		26.03.77	
Turbellaria										
Dendrocoelum lacteum (O.F.M.)		1			2	1		1		
Dugesia lugubris (O. Sch.)		1	3				2		1	
Polycelis sp.	6	6	5	8	11		6	7	4	4
Oligochaeta										
Stylaria lacustris (L.)									1	
Naididae	75	33	41	38	6	1	4	8	5	7
Enchytraeidae		2							1	7
Tubificidae	58	19	4	37	29	65	11	30	9	10
Lumbriculidae	8	5	4	1	8	10		4	4	2
Eiseniella tetraedra (Savigny)	4	4	5	6	4	1	3	1	2	1
Hirudinea										
Glossiphonia complanata (L.)			1		1	2	1			
Helobdella stagnalis (L.)					3	2	9			
Piscicola geometra (L.)					1					
Erpobdella octoculata (L.)				1	1					
Erpobdella testacea (Sav.)					1					
Crustacea										
Asellus aquaticus L.			1	1	13	8	8	2	2	
Gammarus pulex L.	315	298	128	176	154	138	42	34	24	61
Plecoptera										
Leuctra fusca L.	3	6	2						6	2
Nemoura cinerea Retz.	4	3	10	4	36	31	82	40	10	11
Ephemeroptera										
Baetis rhodani Pictet	131	99	57	69	1		3			1
Cloeon dipterum L.					7	1				
Leptophlebia vespertina (L.)					104	45				
Odonata										
Erythromma najas (Hansem.)						1				
Zygoptera					3	1				
Neuroptera										
Sialis lutaria L.					1					
Coleoptera										
Orectochilus villosus Müller	21	8	8	8			2	3		
Helodes minuta L.	9	2	1		2	6	1	1		

Table 1, cont.

Oulimnius tuberculatus P. Müll.	25	19	15	12	22	22	15	7	8	14
Limnius volckmari Panz.	335	334	351	282	128	134	176	78	102	119
Trichoptera										
Rhyacophila fasciata Hag.	2	3	5	3		1		2		
Polycentropus flavomaculatus Pict.	2	5	2		3	2	1			
Polycentropidae					5	7				
Lype phaeope Steph.					1					
Hydropsyche angustipennis Curt.	485	267	190	190	15	9	63	57	30	35
Athripsodes sp.	9	22	21	17	24	11	35	9	35	17
Notidobia ciliaris L.		1					1	3	1	
Limnephilidae					37	35	4	1	3	1
Diptera										
Telmatoscopus sp.		1					1	4	4	
Pericoma fallax Eat.	1				5	1				
Pericoma nubila (Meig.)							1			
Ceratopogonidae	22	20	19	14	13	8	27	9	18	16
Simuliidae	13	1	1						1	
Tanypodinae	41	32	40	41	258	176	37	21	7	9
Prodiamesa olivacea (Mg.)	5	8								
Orthocladinae	40	7	14	6	17	18	3	6	31	24
Tanytarsini	7	6		2	37	26	11	6	2	
Chironomini	5	2	4		65	108	4	7	4	
Tipulidae	1			1	1	1				
Dicranota sp.	39	38	2	4	1	8	4	5	7	
Limoniidae	7	1	4	4	6	1	7	2	2	1
Limnophora sp.					4		1			
Brachycera										1
Acarina										
Hydracarina					3	2				
Mollusca										
Theodoxus fluviatilis L.							2		3	2
Bithynia tentaculata L.		1						1		2
Potamopyrgus jenkinsii Smith	678	678	223	286	154	84	3419	542	359	193
Valvata cristata Müll.							2		1	
Ancylastrum fluviatilis O.F.M.	5	2	1	1	10	5	4	1		
Radix peregra Müll.			1							
Physa fontinalis L.		1			1	1	1	1		
Bathyomphalus contortus L.					1					
Anisus vortex L.					1	1	1			
Planorbis carinatus Müll.										1
Pisidium sp.	21	30	45	32	41	27	27	2	21	16
Sphaerium corneum L.		2				1	1	1		1
Total number of specimens	2377	1962	1211	1250	1242	1018	4022	896	716	571

(Table 2). The low number in the October samples was probably an artefact, caused by inefficient sampling.

Nevertheless, both *Limnius volckmari* and *Hydropsyche angustipennis* had a relatively high population density after the stop of water flow.

Orned Baek

In April 1976 the fauna of Orned Baek was dominated by Oligochaeta (44%) and Chironomidae (45%). *Nemoura cinerea* and *Elmis aenea* were also abundant (Table 3), and a total of 33 taxa were recorded (Fig. 2).

After an unprecedented drought of 2-3 months 34 taxa were recorded, 21 of which were in common with the April samples. *Gammarus pulex, Hydropsyche angustipennis* and *Goera pilosa* had disappeared and were not found on the subsequent sampling occasions (Table 3). *Asellus aquaticus* and species of Hirudinea and Coleoptera appeared after the drought. Most of the new species disappeared rapidly again, but *Asellus aquaticus* maintained itself in the stream throughout the investigation period.

Elmis aenea had the same density after the drought, and the low density in March 1977 may be due to other factors. *Nemoura cinerea* appeared to have increased its population density compared with the period before the drought. As total numbers of invertebrates were low in March 1977 compared with April 1976, this could be due to lack of competition.

The numbers of Crustacea were low, but the finding that *Gammarus pulex* was replaced by *Asellus aquaticus* after the drought was supported by observations performed by the local water board (Poul Andersen, personal communication). Throughout 1975 and the spring 1976 (a total of 7 observations) *Gammarus pulex* was characterized as frequent, and no Asellus were found. *Gammarus pulex* had been common in Orned Baek at least since 1972, and its disappearance after the drought was striking.

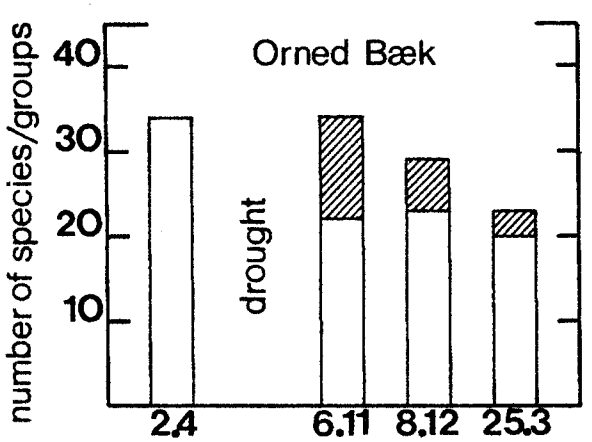

Fig. 2. Numbers of macroinvertebrate taxa recorded in Milling Baek 1976-77. The hatched area indicates numbers of taxa not recorded in April 1976 before the drought.

Ravnstrup Skovgrøft

The litter fauna of Ravnstrup Skovgrøft was characterized by species common in springs and forest brooks *(Eiseniella tetraedra, Nemoura cinerea, Anacaena globulus, Helodes minuta, Pedicia rivosa* and *Beraea pullata)* as well as species common in temporary pools (*Cyphon* sp.). The character of temporary pool was supported by the occurrence of *Aedes* sp. upstream of the sampling locality.

The dominating components of the community were Tubificidae, *Eiseniella tetraedra, Asellus aquaticus, Beraea pullata* and *Pisidium* sp. (Table 4). None of these taxa disappeared after the drought of 3-4 months' duration. The differences found in the relative abundances due to the sampling method involved can not be regarded as significant. A supplementary sampling in March 1977 supported these findings. It can therefore be concluded that these taxa are adapted to live in localities likely to dry up for 3-4 months.

Discussion

The three streams studied can be regarded as three progressive stages.

In Milling Baek water flow was stopped and water level fell, but there was still water, although stagnant. Most species maintained quite a high population density after the arrestation in water flow (Table 1), and it can be concluded that a major part of the invertebrate fauna is able to survive a short period of stagnant water.

The only exception was *Baetis rhodani,* which decreased significantly and almost disappeared. Species of *Baetis* are known to be rheophilous and *Baetis vernus* dies in stagnant water even with high oxygen concentrations (Ambühl, 1959). This may also be the case for *Baetis rhodani* and might explain the findings in Milling Baek.

In Orned Baek the effect of an unprecedented drought was studied. Of the invertebrates in an active stage during the drought, Oligochaeta, *Elmis aenea* and *Pisidium* sp. survived the drought (Table 3). Hynes (1958, 1961) in a similar study of Afon Hirnant, Wales also found that

Table 3. The composition of the macroinvertebrate community in Orned Baek 1976-77. The stream was dry July-September 1976. Each number represents the results of three kick samples.

	2.4.76	6.11.76	8.12.76	25.3.77
Oligochaeta				
Naididae	663	329	197	39
Tubificidae	159	497	219	96
Enchytraeidae		2		
Hirudinea				
Glossiphonia complanata (L.)	1	1		
Helobdella stagnalis (L.)		3		
Herpobdella octoculata (L.)	1.	3		1
Dina lineata (O.F. Müll.)		11	7	
Crustacea				
Asellus aquaticus L.		4	3	5
Gammarus pulex L.	9			
Insecta				
Plecoptera				
Nemoura cinerea Retz.	21	19	239	183
Ephemeroptera				
Procloeon pseudorufulum Kimm.		1	1	
Hemiptera				
Nepa cinerea L.	1			
Velia caprai Tam.		3		
Coleoptera				
Haliplus	1	33	6	1
Hydroporus sp.	2	1	1	
Deronectes halensis Fabr.	6	6	7	1
Ilybius sp.		1		
Hydraena sp.		1	2	
Laccobius biguttatus Gerh.		3		
Helodes minuta L.		5		
Elmis aenea P. Müll.	77	133	44	9
Trichoptera				
Hydropsyche angustipennis Curt.	2			
Goera pilosa Fbr.	3			
Limnephilus extricatus McL.	2	23	8	1
Limnephilus rhombicus L.		1	8	
Limnephilus lunatus Curt.				1
Limnephilus sp.	1			
Potamophylax sp.		1	1	
Limnephelidae	2	7	17	1
Diptera				
Pericoma sp.	4	22	6	4
Telmatoscopus sp.	3	5	2	6
Psychoda sp.	1			
Dicranota sp.	1	1	1	
Limoniidae	2			
Adelphomyia sp. (?)	4			
Limnophila sp.	2	12	13	3
Tipula sp.		4	1	
Ceratopogonidae	14	199	97	10
Simuliidae	9		1	
Tanypodinae	4	12	24	3
Tanytarsini	41	8	93	9
Chironomini	209	116	168	85
Metriocnemus hygropetricus Kieff.				1
Thienemanniella sp.	1			
Prodiamesa olivacea (Mg.)	1			
Orthocladinae	583	11	125	27
Cyclorrhapha			3	
Acarina				
Hydracarina	5		5	5
Mollusca				
Bithynia tentaculata L..				3
Pisidium sp.	15	28	11	11
Total number of specimens	1850	1506	1310	505

Table 4. The composition of the macroinvertebrate community in Ravnstrup Skovgrøft 1976. The stream was dry June-October. Each number represents the result of three litter samples.

	01.04.76	08.12.76
Oligochaeta		
Naididae		2
Tubificidae	229	26
Enchytraeidae	8	6
Stylodrilus sp.	11	11
Rhynchelmis sp.	16	20
Lumbriculidae	1	
Lisiniella tetraedra (Savigny)	50	116
Crustacea		
Asellus aquaticus L.	24	70
Plecoptera		
Nemoura cinerea Retz.	61	77
Coleoptera		
Agabus chalconotus Panz.	1	
Ilybius sp.		3
Hydraena sp.	2	2
Anacaena globulus Payk.	1	
Chaetarthia seminulum Erbst. (?)		1
Helodes minuta L.	1	
Cyphon sp.	3	5
Diptera		
Teimatoscopus sp.	9	1
Pericoma sp.	3	3
Pedicia rivosa L.	1	
Ormosia sp.	1	
Limnophila sp.	15	6
Eriopterini	9	16
Tipula sp.		1
Ceratopogonidae	7	20
Simuliidae	1	
Tanypodinae	11	
Chironomidae	3	
Orthocladinae	72	79
Cyclorrhapha		3
Trichoptera		
Beraea pullata Curt.	75	11
Limnephilidae		3
Mollusca		
Anisus spirorbis L.	4	33
Pisidium sp.	309	53
Total number of specimens	929	569

Oligochaeta and Elminthidae survived. The survival of *Pisidium* sp. could be expected from its burrowing way of life.

Gammarus pulex did not survive the drought. Similarly Mauch (1963) observed that many gammarids were desiccated and killed, when the water level of the Mosel, Germany, sank. In a small stream in Germany Engelhardt (1951) found that *Gammarus pulex* survived a few weeks after the water had disappeared, but finally died. It might therefore be concluded that *Gammarus pulex* will be able to survive a short drought, but a drought of more than a month will wipe out the population.

Of the insects with flight period and egg-laying during the drought, Ceratopogonidae and Chironomidae maintained a considerable population. It is unknown, whether they have survived as eggs, larvae or adults or colonized from neighbouring streams.

The survival of *Nemoura cinerea,* which also occurs abundantly in the intermittent stream Ravnstrup Skovgrøft (Table 4), is of particular interest. In Denmark it has a univoltime life cycle with normal emergence in May-July (Bengston, 1972; F. S. Hansen, unpublished data) and the flight period is May-August, but a few adults have been recorded from medio October (Kaiser, personal communication).

The eggs of *N. cinerea* are placed in water (Khoo, 1964), and as water did not reappear until October, it can be concluded, that *N. cinerea* survived in the two brooks, and did not colonize from neighbouring streams.

Once placed in water eggs of some stoneflies can survive at least 12 days' subsequent desiccation, but eggs of *N. cinerea* have not been investigated. According to Khoo (1964) the eggs of *N. cinerea* undergo diapause. The total incubation period is 2-4 months depending on temperature, and the hatching period can be up to 5 months. These findings fit well with the ability of *N. cinerea* to survive long summer droughts.

In contradiction to the results given by Khoo (1964), Brittain (1974) found no evidence of egg diapause of *N. cinerea.* The incubation period is directly related to temperature, and there is no indication of delayed hatching (Brittain, personal communication). If these findings are valid for the two brooks studied, the very small nymphs have survived the drought by burrowing into the substratum, as is known for a.o. *Capnia* sp. (Khoo, 1964).

It is clear from the present results that *N. cinerea* successfully survives droughts. However, further experiments with the eggs and small nymphs are needed to clarify, how the survival takes place.

Within the Trichoptera drought survival appears to be associated with the eggs. *Hydropsyche angustipennis* and *Goera pilosa* both deposit their eggs below the water surface, whereas almost all Limnephilidae deposit their eggs on land (Thienemann, 1923; Nielsen, 1942). Oviposition of *Hydropsyche angustipennis* and *Goera pilosa* was probably prevented by the drought. In Ravnstrup Skovgrøft Limnephilidae occurred together with *Beraea pullata,* which also is thought to oviposit on land (Nielsen, 1942).

In Milling Baek and Orned Baek many new species appeared after the normal stream situation had been re-established (Figs. 1 and 2). Most, however, disappeared rapidly again. According to Mann (1959) *Dina lineata* is only found in places that dry up more or less regularly. Increasing frequency of drought would probably favour such a species.

Asellus aquaticus appears to be the only species which, after invasion, maintained a population in Orned Baek,

at least throughout this study. The lack of competition from *Gammarus pulex* was probably the reason for its success.

Asellus aquaticus was an important component of the fauna of Ravnstrup Skovgrøft (Table 4), and appears well adapted to the life in intermittent streams. It survives in water-saturated air for a considerable period (Lagerspetz & Lehtonen, 1961) and moves into the substratum to avoid desiccation.

It can be concluded that drought implies considerable changes in the macroinvertebrate community. The magnitude of the changes depends on the degree and duration of the drought. However even a short, partial drought such as in Milling Baek affects certain invertebrates. Which species will be affected depends partly on the season and duration of the drought, and partly on the physiology and biology of the species normally present.

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