W. The authors' compliments

Freshwat. Biol. 1974, Volume 4, pages 369–398

A survey of stream invertebrates in the Cow Green basin (Upper Teesdale) before inundation

P. D. ARMITAGE, ANGELA M. MACHALE *and* DIANE C. CRISP
Freshwater Biological Association, Cow Green Laboratory

Manuscript accepted 18 September 1973

Summary

In 1967 a programme was initiated by the Freshwater Biological Association to study fish populations within the proposed Cow Green reservoir basin and in the Tees downstream of the dam, before and after impoundment. This paper describes the result of a supporting study on aquatic invertebrates covering the pre-impoundment period 1967–70.

The benthic faunas of six streams in the reservoir basin, the Tees below Cauldron Snout and Maize Beck, a tributary of the Tees below the dam, were studied. Species list are presented for each habitat and changes in seasonal and annual abundance are discussed.

All areas sampled lie at altitudes between 440 and 550 m O.D. and are situated amongst moorland and limestone grassland. Conditions in the streams ranged from slow-flowing peaty reaches to small streams with moss-covered bottoms and larger stony rivers and streams with relatively unstable bottoms.

Samples were taken in riffles and pools using the 'kick' method wherever possible. An attempt was made to quantify kick-sample catches by comparing them with shovel-sample catches which cover a known area of stream bottom. It was found that 10·5 kicks gave a catch equivalent to the populations of 1 m^2, giving a population density of about 1200 animals/m for the reservoir-basin riffles.

Over 120 taxa were recorded, 100 of which were at the species level. In the reservoir-basin streams, 116 taxa were found with seventy-one in Maize Beck and fifty-six in the Tees below Cauldron Snout. Ephemeroptera were the most abundant group in the reservoir basin and Maize Beck faunas with *Rhithrogena semicolorata*, *Heptagenia lateralis* and Baetidae being the most abundant forms, although *Ecdyonurus* spp. especially *E. dispar* were much more common in Maize Beck. In other groups *Leuctra* spp. and *Gammarus pulex* were very common. In the Tees below Cauldron Snout *Limnaea peregra*, Chironomidae and Baetidae formed the bulk of the fauna and Plecoptera were uncommon. Amongst the reservoir basin streams Weelhead Sike supported the largest number of species and species groups (eighty-one), and all the streams had forty-nine or more taxa represented.

Correspondence: Dr P. D. Armitage, Moor House, Field Station, Garrigill, Alston, Cumberland, England.

Information on seasonal changes in the numbers of those species or species groups composing 90% or more of the total fauna is presented. Faunal density was high in May with Ephemeroptera, particularly Ecdyonuridae, and the plecopteran *Leuctra inermis* being the most abundant forms. In August, the numbers of animals appeared to fall and common members of the community were Baetidae, Diptera, *Leuctra fusca* and Ecdyonuridae. In October, Ecdyonuridae particularly *R. semicolorata*, were most abundant.

A comparison of the bottom fauna of riffles and pools was made and more animals were found in riffles than in pools.

The effect of gravel extraction on the bottom fauna of the Tees was examined. A severe drop in the numbers of animals was observed after extraction. Diptera were the first group to return to their pre-disturbance density. Elminthidae and Annelida were worst affected and slowest to recover.

The fauna of the area is discussed and possible reasons for its relative species richness are put forward. Habitat diversity and chemical richness appear to be the most likely reasons for the relatively large number of species found.

Introduction

A Freshwater Biological Association programme to study fish populations within the proposed Cow Green reservoir basin and in the Tees downstream of the dam, both before and after impoundment, began in 1967 and is continuing (Crisp, Mann & McCormack, in preparation). The present paper describes the results of a supporting study on aquatic invertebrates.

Some information on the aquatic invertebrates of the Tees is given by Butcher, Longwell & Pentelow (1937) and Macan (1957) but most of their studies were made downstream of the present study area. In addition, there is published information about the Plecoptera (Brown, Cragg & Crisp, 1964), Ephemeroptera (Crisp & Nelson, 1965), Simuliidae (Phillipson, 1957; Davies & Smith, 1958) and some other aquatic invertebrates (Nelson, 1965) on and around the Moor House National Nature Reserve which is immediately upstream of the Cow Green reservoir basin. It was considered desirable, however, that a survey of the invertebrate fauna of the Cow Green basin and the Tees below the dam site should be made, and the present paper describes the results obtained during the period (1967–70) before impoundment.

Limitations on the time and resources available restricted the frequency and amount of sampling particularly between 1967 and 1969, with inevitable effects on the quality of the results. In spite of this, much information was obtained. Species lists for the study area are presented with particular reference to those sites where regular fish studies were in progress. Comparisons of faunal composition and relative abundance are made and an attempt to estimate the absolute abundance of invertebrates at the sampling stations is described.

The study area

The Cow Green site is situated in Pennine moorland and is surrounded by blanket bog and limestone grassland. The climate of the nearby Moor House National Nature Reserve described by Manley (1936) and Millar (1964) is characterized by high wind speeds, the average annual speed being about 24 k.m.h., and low average annual temperatures of about 5°C. The average annual rainfall at Moor House is 1800 mm.

Two main areas were studied, the Tees below Cauldron Snout and Maize Beck, and the reservoir basin.

The Tees below Cauldron Snout

The waterfall of Cauldron Snout is situated about 180 m downstream of the Cow Green dam (completed in June 1970). Below the falls there is a large pool and from this point the Tees is a fast-flowing stream up to about 1·5 m deep and 20–30 m wide during normal flow. The bottom is composed chiefly of large boulders. The Tees is possibly unique in the British Isles in attaining its relatively large size at an altitude in excess of 400 m. A little less than 200 m downstream from the foot of the falls the Tees is joined by a major tributary, Maize Beck. At its confluence with the Tees the size and general characteristics of Maize Beck are similar to those of the Tees itself. The main differences are the smaller boulders and less stable bottom in Maize Beck.

The reservoir basin

The term reservoir basin is used to describe that part of the Tees which has been inundated together with those tributaries which join the Tees between NY 787312 and NY 813289 (Fig. 1).

Throughout the upper part of its course through the reservoir basin (from NY 783312 to about NY 813289) the Tees was a fast-flowing river about 20 m wide with

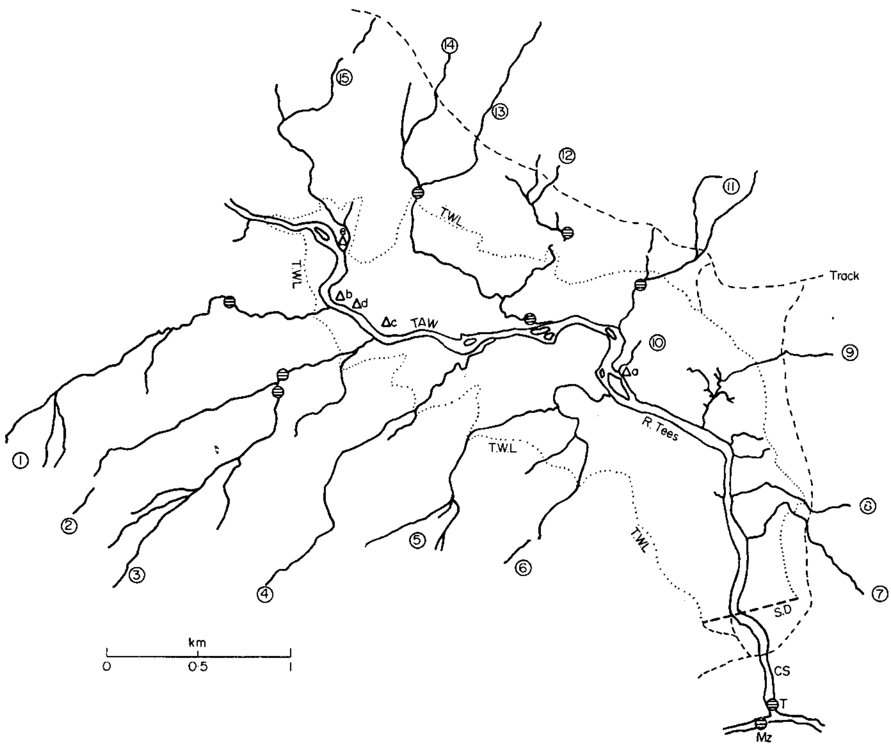

Fig. 1. The study area. Encircled numbers represent streams: 1, Mattergill; 2, Lodgehill; 3, Rowantree; 4, Cockle; 5, Furness Lodge; 6, Whitespot; 7, Red; 8, Nameless; 9, Slapestone; 10, Cow Green; 11, Weelhead; 12, Near Hole; 13, Dubby Sike East Grain; 14, Dubby Sike; 15, Sledge. Hatched circles indicate sampling stations in running water; △, standing water stations. T.W.L. top water level of proposed reservoir, S.D. dam site, T, Tees, below Cauldron Snout (CS), Mz, Maize Beck.

Table 1. List of regular sampling sites with their National Grid references, altitudes, drainage areas, and calcium ion content of the water at the sampling site (Ca^{++} data from Crisp *et al.*, in preparation)

Site	Nat. Grid. Ref.	Altitude of site (M.O.D.)	Altitude of source (M.O.D.)	Drainage area above site (ha)	Calcium (ppm)
Mattergil Sike (MS)	NY 784307	520	640	91	5·1 (Oct. 1969)
Lodgegill Sike (LS)	NY 787303	530	686	59	4·8 (Oct. 1969)
Rowantree Sike (RS)	NY 787303	530	701	72	5·2 (Oct. 1969)
Dubby Dike (DS)	NY 794313	500	518	76	10·4 (Oct. 1969)
Near Hole Sike (NrHS)	NY 802312	500	518	44	14·4 (Oct. 1969)
Weelhead Sike (WS)	NY 807308	470	518	83	23·2 (Oct. 1969)
Tees above Weel (TAW)	NY 799306	470	772	5200	10·6 (July 1968)
Lower Dubby Sike (LDS)	NY 802306	470	518	212	—
Maize Beck (MzB)	NY 814284	440	709	3800	15·8 (15·8 Oct. 1968)
Tees below Cauldron Snout (TBCS)	NY 814284	440	772	5868	18·3 (15·8 Oct. 1968)

a stony bottom and a water depth generally not exceeding 1·0 m. This region has been referred to as the 'Tees above the Weel' (TAW). From NY 804306 to the dam site at about NY 813289 the Tees was deep (up to 2·0 m) and slow-flowing with steep peaty banks and this reach of the river was known as the 'Weel'.

Along its north-eastern margin the Tees within the reservoir basin was joined by three tributaries which flowed down from the lower slopes of Herdship Fell, and four or five small tributaries which rose around the foot of Widdybank Fell. On its south-western margin the Tees within the reservoir basin received three tributaries which rose on Meldon Hill at altitudes between 640 m and 685 m O.D., and two smaller tributaries which rose on the lower slopes of Meldon Hill.

Table 1 lists the sampling sites with grid-references and elevation. The sampling stations on these streams were situated where regular fish studies were in progress. The distance of each station from the source is shown on the profiles of the streams in Fig. 2. Data on stream temperature, chemistry and discharge are given in Crisp *et al.* (in preparation). Each station is briefly described below.

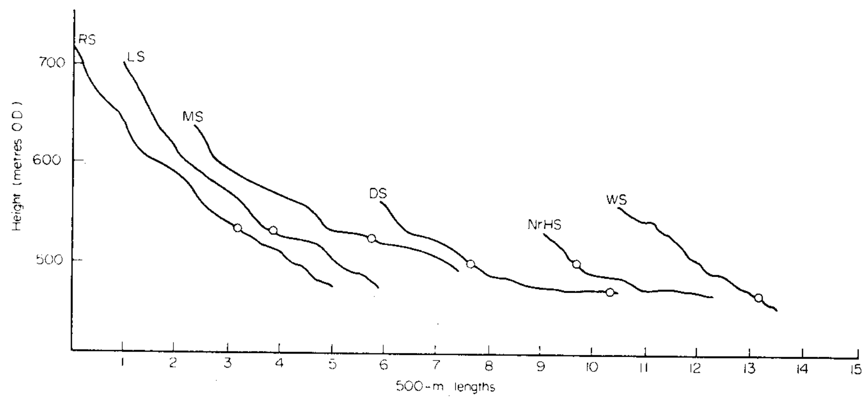

Fig. 2. Profiles of the six sampled streams in the reservoir basin. (Horizontal axis indicates 500-m lengths).

Weelhead Sike

A small stream about 1·0 m wide at the sampling site with a bed of gravel and bare rock. The stream rises at 518 m and flows over limestone and sandstone and obtains most of its water from limestone sources. The sampling area contains pools up to 30 cm deep but consists chiefly of shallower pools and riffles over exposed limestone.

Near Hole Sike

A small stony stream arising at 518 m. The gradient is slight and the bed consists of gravel boulders and live rock. Moss and *Potamogeton* sp. cover the bottom in some areas. The maximum width of the stream in the sampling reach is 90 cm and the largest stones do not exceed 20 cm in diameter. Depth varies from about 1 to 30 cm in riffles and pools under normal flow conditions.

Dubby Sike

The stream arises at 518 m. The gradient is slightly greater than in Near Hole Sike and the bed consists of stones and gravel, the largest stones being about 30 cm in diameter. The maximum width of the stream in the sampling area is 1·4 m and the station consists of a series of pools connected by riffles and small waterfalls with a similar depth variation as found in Near Hole Sike. Both Dubby and Near Hole Sike receive water from limestone sources but not as much as did Weelhead Sike. At its lower end near its junction with the Tees, Dubby Sike becomes a slow-flowing peaty-bottomed stream referred to in this paper as 'lower Dubby Sike' (LDS).

Lodgegill and Rowantree Sikes

The streams arise at 686 and 701 m respectively and join together at 503 m O.D. Just above their confluence, both streams have vertical waterfalls about 1–4 m high. The sampling area in Lodgegill consists of a series of riffles (between 1 and 5 cm deep) and pools (up to 30 cm deep) with a bed of large boulders (up to 75 cm in diameter), stones and gravel. The maximum width is 2·0 m. Rowantree Sike is similar but in places bare rock is exposed. Both streams have steep gradients and are fed mostly by surface drainage with the result that at times of spate, discharge fluctuations are rapid and the water becomes very discoloured with peaty material.

Mattergill Sike

The stream is similar in general characteristics to the preceding two. It rises at 640 m O.D. and again is fed chiefly by surface drainage. The sampling area consists at its upper and lower ends of a series of pools between 20 and 30 cm deep amongst large boulders, up to 75 cm in diameter, connected by small waterfalls. The central area has a maximum width of 4·0 m and consists of a nearly level stretch about 10 m long containing a shallow pool, about 10 cm deep, and a riffle, the beds of which are composed of coarse to medium gravel.

A few standing water habitats were sampled in the reservoir basin. These are listed below with grid references.

(A) A still, weeded reach with a soft peaty bottom at the foot of the old course of Cow Green Sike (NY 806303).

(B) Ditch draining into the Tees near the TAW station at (NY 790307).

(C) Peaty pool opposite Lodgegill Sike foot (NY 792304).

(D) Pool near TAW area (NY 791307).

(E) Pool near the foot of Sledge Sike (NY 792311).

Methods

Samples were taken in May, August and October. The main sampling method used throughout the survey was the kick method (Hynes, 1961). The operator kicked and stirred up the stream bed for 60 sec upstream of a net 25 cm in diameter with a mesh of 10 threads per cm. Where conditions permitted, the same place was kicked continuously for the 60-sec period but in some places this was not possible so shorter period kicks were combined to give the required 60-sec sample.

Where large boulders and flat slabs of limestone composed the substratum it was not possible to take kick samples and in such places invertebrates were collected from the electro-fishing nets. As large numbers of invertebrates were collected by this method with one or two groups predominant, the samples were not considered to be representative of the bottom fauna. These samples had obvious validity in composing species lists but not necessarily in assessing the percentage composition of the invertebrate fauna.

Table 2. The mean number of invertebrates per 60-sec. kick ×10 for all the regularly sampled streams, based on collections made between 1967 and 1970 in May, August and October. The data for NrHS and TBCS are from 1970 and NrHS was sampled only in August and October. The streams have been divided into three groups, MS–RS torrential streams, DS–WS slower flowing streams and TAW–MzB larger streams. Widespread, common and rare species are listed in parts (a), (b), and (c) of the Table and the contribution each part makes to the total catch is shown in part (d) (+, one animal/ten kicks; ●, present but data insufficient for quantification)

(a) Widespread species occurring in 10, 9 and 8 streams only

Species	MS	LS	RS	DS	LDS	NrHS	WS	TAW	TBCS	MzB
Rhithrogena semicolorata (Curt.)	288	192	208	106	13	20	29	377	17	145
Leuctra inermis Kempny	109	115	227	101	68	15	138	50	14	131
Heptagenia lateralis (Curt).	196	115	235	72	13	2	11	1	2	3
Baetis tenax Eaton	25	41	486	20	3	5	4	11	+	13
Baetis rhodani (Pict.)	25	49	71	28	86	105	32	21	59	58
Chironomidae	12	9	9	11	165	50	45	6	126	25
Baetis pumilus (Burm.)	1	14	63	29	12	105	103	1	+	3
Ecdyonurus dispar (Curt.)	29	9	12	2	6	15	5	59	35	119
Dicranota sp.	16	6	15	19	14	7	28	12	2	7
Simuliidae	16	11	93	21	22	42	2	7	1	21
Hydroptila spp.	18	1	2	12	4	165	21	9	2	2
Baetis spp.	10	5	77	9	5	15	15	4	6	8
Ecdyonurus spp.	11	4	32	16	3	2	2	5	+	79
Leuctra moselyi Morton	38	16	32	25	4	2	5	20	+	8
Elmis aenea (Müll.)	8	3	46	5	9	35	22	6	3	4
Ecdyonurus torrentis Kimmins	6	4	32	16	3	2	2	5	2	12
Ameletus inopinatus Eaton	3	15	10	6	1	12	+	1	4	17
Hydracarina	5	7	1	8	5	12	7	2	2	9
Isoperla grammatica (Poda)	4	2	8	10	14	5	2	3	5	3
Rhyacophila dorsalis (Curt.)	4	2	3	2	2	5	1	1	8	3
Gammarus pulex (L.)	15	18	164	17	11	762	284	+	–	4
Chloroperla torrentium (Pictet)	39	43	51	46	35	2	34	3	–	12
Leuctra hippopus (Kempny)	7	14	6	24	24	80	42	1	–	4
Leuctra fusca (L.)	28	5	18	12	4	–	3	5	5	15
Nemoura cambrica (Stephens)	5	15	22	34	1	–	1	+	+	7
Lumbricidae sp. ind.	28	6	19	4	3	–	4	1	5	2

Table 2 *continued*

(a) *continued*

Species	MS	LS	RS	DS	LDS	NrHS	WS	TAW	TBCS	MzB
Amphinemura sulcicollis (Stephens)	13	3	8	6	10	–	1	14	1	13
Plectrocnemia geniculata (McLachlan)	4	2	12	3	2	10	3	–	10	1
Polycentropus flavomaculatus (Pict.)	3	1	–	3	8	10	1	2	7	4
Hydraena gracilis Germ.	2	–	1	1	11	2	11	1	+	+
Paraleptophlebia submarginata (Steph.)	4	4	3	1	7	7	+	–	+	+
Diptera indet.	3	1	1	+	1	–	1	7	2	+
Eiseniella tetraedra (Savigny)	1	+	3	+	–	2	+	+	3	1
Baetis scambus Eaton	4	2	2	3	–	–	1	18	22	21
Stylodrilus heringianus (Clap.)	+	–	–	1	1	7	1	1	9	16
Plectrocnemia conspersa (Curt.)	4	6	–	5	1	7	7	+	–	2
Nemoura spp.	1	2	16	3	–	+	7	+	–	+
Oreodytes spp.	10	–	2	3	1	5	1	1	–	3
Deronectes spp.	4	2	–	3	1	2	4	+	–	+
Ephemerella ignita (Poda)	1	+	1	+	–	–	+	7	1	5
Perlodes microcephala (Pictet)	2	+	–	1	2	–	+	1	1	2
Leuctra/*Capnia* spp.	+	+	–	2	4	–	1	+	+	1
Amphinemura spp.	2	+	+	1	–	–	+	+	+	1

(b) Common species occurring in 7, 6, 5, and 4 streams only

Species	MS	LS	RS	DS	LDS	NrHS	WS	TAW	TBCS	MzB
Limnius volckmari Panz.	2	–	–	–	5	+	9	48	42	2
Helodes marginata F.	1	1	11	8	–	7	7	–	–	+
Drusus annulatus (Stephens)	10	1	1	5	–	–	+	3	–	3
Protonemura meyeri (Pictet)	5	1	6	1	–	–	–	+	+	+
Amphinemura standfussi Ris	4	1	5	2	–	–	+	1	–	1
Tipulidae spp. indet	2	+	–	+	1	–	+	+	–	+
Dinocras cephalotes (Curt.)	–	1	3	–	–	15	32	4	–	1
Nemoura cambrica/*erratica*	+	7	16	15	–	2	3	–	–	–
Esolus parallelepipedus (Müll.)	+	–	–	–	5	–	16	4	6	4
Protonemura praecox (Morton)	+	6	9	+	–	–	–	–	+	1

Table 2 *continued*

(b) *continued*

Species	MS	LS	RS	DS	LDS	NrHS	WS	TAW	TBCS	MzB
Ancylus fluviatilis (Müll.)	1	–	–	–	–	2	+	+	9	1
Nemoura erratica Claassen	1	+	7	3	1	–	1	–	–	–
Hemerodroma sp.	1	–	2	–	1	2	1	–	–	2
Tubifex tubifex (Müll.)	–	–	–	+	1	–	2	1	3	1
Ecdyonurus venosus (Fabr.)	1	–	1	–	1	–	–	2	1	1
Siphlonurus lacustris Eaton	–	+	3	+	–	–	+	+	–	+
Pedica sp.	–	+	–	1	2	–	+	+	–	+
Taeniopteryx nebulosa (L.)	+	–	–	1	1	–	–	+	+	+
Simulium brevicaule Dorier & Grenier	●	●	–	●	–	–	●	●	–	●
Lymnaea (*Radix*) *peregra* (Müll.)	–	–	–	–	2	22	2	+	275	–
D. annulatus/*E. guttulata*	4	+	–	2	–	–	–	17	1	–
Brachycentrus subnubilus (Curt.)	1	–	–	–	–	–	+	14	1	6
Leuctra nigra (Olivier)	–	1	1	1	–	12	–	–	–	1
Rhyacodrilus coccineus (Vejd.)	–	–	–	–	1	5	–	1	7	3
Plectrocnemia sp.	+	–	–	2	–	2	+	–	–	4
Lumbriculus variegatus (Müll.)	–	–	–	+	–	–	3	1	+	1
Ecclisopteryx guttulata (Pict.)	3	+	–	+	–	–	–	+	–	1
Pericoma sp.	+	–	–	+	–	–	+	+	–	+
Diura bicaudata (L.)	+	+	–	–	–	–	+	+	–	+
Capnia bifrons (Newman)	–	–	–	–	+	15	33	–	–	+
Limnephilidae	–	–	–	+	26	–	+	–	+	–
Nemoura avicularis Morton	–	–	–	7	+	2	2	–	–	–
Peloscolex ferox (Eisen)	–	–	–	–	2	5	–	1	2	–
Perla bipunctata Pictet	–	+	–	–	–	–	–	4	1	3
Caenis sp.	–	–	–	–	2	–	–	1	+	1
Sialis sp.	+	–	–	–	1	+	1	–	–	–
Haliplus sp.	+	–	–	1	–	–	+	+	–	–
Tricladida	+	–	–	+	+	–	+	–	–	–
Simulium monticola Friederichs	●	●	–	–	–	–	–	–	●	●
Simulium latipes Meigen	●	●	–	●	–	–	●	–	–	–
Lerbertia porosa Thor.	●	–	–	–	–	–	●	●	–	●

Table 2 *continued*

(c) Species occurring in 3, 2 or 1 stream only. Occurrence shows the stream or streams in which the species was taken with numbers per kick ×10 in brackets

Species	Occurrence			Species	Occurrence	
Centroptilum luteolum (Müll.)	DS (1)	LDS (130)	TAW (+)	*Riolus* sp.	MrHS (+)	WS (+)
Capnia vidua Klapalek	MS (+)	WS (10)	MzB (+)	Psychodidae	DS (+)	WS (+)
Riolus subviolaceous (Müll.)	LDS (1)	NrHS (5)	WS (4)	*Simulum nitidifrons* Edwards	WS (●)	MzB (●)
Oulimnius sp.	MS (+)	NrHS (7)	TBCS (2)	*Sperchon glandulosus* Köen	MS (●)	TBCS (●)
Leptophlebiidae	MS (1)	LS (4)	LDS (1)	*Hygrobates fluviatilis* Ström.	TAW (●)	TBCS (●)
Lumbriculidae	MS (+)	NrHS (2)	WS (1)	*Hygrobates foreli* Ström.	MS (●)	TBCS (●)
Corixidae	LDS (1)	NrHS (2)	WS (+)	*Atractides nodipalis* Thor.	TAW (●)	TBCS (●)
Protonemura sp.	LS (+)	LDS (2)	TBCS (+)			
Rhyacophila obliterata McLachlan	MS (+)	LS (+)	RS (2)	*Cyrnus trimaculatus* (Curt.)	LDS (19)	
Centroptilum pennatulum Eaton	MS (+)	LS (1)	TAW (+)	*Anabolia nervosa* (Curt.)	LDS (5)	
Paraleptophlebia sp.	LS (+)	DS (+)	LDS (1)	Dytiscidae	NrHS (5)	
Simulium variegatum Meigen	LS (●)	TBCS (●)	MzB (●)	Philopotamidae	NrHS (2)	
				Neureclipsis timaculata (L.)	LDS (1)	
Leptophlebia marginata (L.)	LDS (24)	NrHS (32)		*Limnodrilus hoffmeisteri* Clap.	WS (1)	
Habrophlebia fusca (Curt.)	LDS (9)	NrHS (42)		*Tubifex ignotus* (Stolc.)	WS (+)	
Oulimnius tuberculatus (Müll)	LDS (14)	TAW (+)		*Glossiphonia complanata* (L.)	NrHS (+)	
Brachyptera risi (Morton)	RS (10)	TBCS (+)		*Leuctra geniculata* (Stephens)	TAW (+)	
Paraleptophlebia cincta (Retz)	LS (2)	LDS (1)		*Nemurella picteti* Klapalek	DS (+)	
Capnia sp.	WS (3)	MzB (+)		*Ephemera danica* Müll.	LDS (+)	
Riolus cupreus (Müll.)	LDS (3)	WS (+)		*Agapetus* sp.	TAW (+)	
Tubificidae	LS (1)	TBCS (1)		*Oxyethira simplex* Ris	DS (+)	
Caenis rivulorum Eaton	TBCS (1)	MzB (1)		*Goera pilosa* Fabr.	LS (+)	
Hydropsychidae	RS (1)	TBCS (+)		*Nemotelus* sp.	DS (+)	
Lepidostoma hirtum (Fabr.)	NrHS (+)	WS (1)		*Lymnaea (Galba) truncatula* (Müll.)	WS (+)	
Clinocera sp.	RS (1)	WS (+)		*Lymnaea (Stagnicola) palustris* (Müll.)	WS (+)	
Zonitoides nitidus (Müll.)	RS (1)	WS (+)		*Pisidium casertanum* (Poli)	LDS (+)	
Pisidium obtusale Lamarck	DS (+)	WS (1)		*Pisidium hibernicum* (Westerlund)	WS (+)	
Wormaldia occipitalis (Pict.)	WS (+)	MzB (+)		*Simulium reptans* L.	MzB (●)	
Chaetopteryx villosa (Fabr.)	TAW (+)	WS (+)		*Sperchon brevirostris* Koen.	MS (●)	
Limnodrilus sp.	TAW (+)	WS (+)		*Atractides tener*. Thor.	MzB (●)	
Atrichopogon sp.	DS (+)	WS (+)				

Table 2 *continued*

(d) Numbers of animals in groups A, B and C as a percentage of T (total catch per kick ×10) in each stream. Numbers of taxa in each stream and number of samples

	MS	LS	RS	DS	LDS	NrHS	WS	TAW	TBCS	MzB
Group A	96·3	96·1	96·0	93·3	68·5	89·2	86·9	86·7	50·1	95·4
Group B	3·5	2·5	3·1	6·6	5·8	5·3	11·1	13·2	49·1	4·5
Group C	0·2	1·4	0·9	0·1	25·7	5·5	2·0	0·1	0·8	0·1
T	1043	774	2074	741	845	1707	1014	765	707	821
Total no. of taxa	68	56	49	65	68	55	81	69	56	71
No. at species level	53	46	38	48	49	38	62	55	46	60
Total no. of samples:										
in 'riffles'	17	13	6	19	4	2	10	16	5	24
in 'pools'	15	8	2	11	5	2	16	5	3	7

Table 3. List of species and species groups taken in pools and ditches in the reservoir basin

Species	Station
Tubifex tubifex	A B C
Limnodrilus sp.	A
Stylodrilus heringianus	B
Lumbriculidae indet.	D
Enchytraeidae indet.	A
Eiseniella tetraedra	C
Lumbricidae indet.	B D E
Gammarus pulex	B
Nemoura cinerea (Retz.)	B
Nemoura avicularis	B
Nemoura cambrica	B
Leuctra nigra	B
Leuctra fusca	B
Leuctra moselyi	B
Rhithrogena semicolorata	B
Leptophlebia marginata	B
Centroptilum luteolum	B
Ameletus inopinatus	A
Siphlonurus lacustris	A B
Velia sp.	B
Sigara sp. *dorsalis/distincta/falleni* grp	D
Arctocorisa carinata (C. Sahlb.)	C
Callicorixa wollastoni (D & S)	B C D E
Sialis sp.	B C E
Plectrocnemia conspersa	B
Plectrocnemia geniculata	B
Hydroptila sp.	B
Halesus radiatus (Curtis)	A B
Limnephilidae spp. indet.	B
Chironomidae spp indet.	A B C D E
Atrichopogon sp.	E
Dixa sp.	B
Chaorborus sp.	C D E
Anophelini spp. indet.	C
Haliplus sp.	A B
Deronectes sp.	B D
Dytiscidae indet.	B C E
Hydrachnellae spp. indet.	A B
Lymnaea (Galba) truncatula	B D
Lymnaea (Radix) peregra	B
Lymnaea (Stagnicola) palustris	B
Pisidium subtruncatum Malm.	A
Pisidium spp. indet.	D

A, weeded area at foot of Cow Green Sike; B, ditch near TAW station; C, pool opposite Lodgegill sike foot; D, pool near TAW; E, pool near foot of sledge sike.

Two main types of habitat were sampled at each site. These were classified as 'riffles', shallow fast-flowing water over gravel and stones, and 'pools', deeper slow-flowing water. This classification was fairly arbitrary because during spates the flow of water through pools was quite rapid.

Additional non-quantitative samples were taken in standing water, pools and drainage ditches by general sweeps with a pond net. A portable light trap was used on two occasions to obtain adult Trichoptera for identification.

Results

Table 2 lists the species found in all the running-water habitats sampled and Table 3 lists those species found in standing water.

A total of 123 species and species groups were found in the study area during the period 1967–70. In the six regularly sampled streams of the reservoir basin, 116 species and species groups were found. Weelhead Sike with eighty-one supported the largest number of taxa. In Maize Beck and the Tees below Cauldron Snout seventy-one and fifty-six taxa were found, respectively.

Figure 3 shows the number of animals in riffles and pools which composed 80% or more of the fauna in the three areas, reservoir basin, Maize Beck and the Tees below Cauldron Snout (TBCS). In the case of TBCS the figures are derived from only one year (1970) and rather few samples (five riffles and three pools). Therefore, in order to obtain a better idea of faunal structure, a comparison of percentage composition is presented in Table 4 between samples taken in 1968 and 1969 from the electro-fishing nets and those taken in 1970 by kick sampling. Figures 4 and 5 show variations in annual and seasonal abundance for the major groups. The distribution and seasonal abundance of the predominant species will be described under the appropriate group headings.

Table 4. Comparison of the percentage composition of the major faunal groups taken in kick samples (1970) and in electro-fishing nets in the Tees below Cauldron Snout (1968/1969)

Species	TBCS 1968/1969	TBCS 1970
Limnaea peregra	6·26	39·49
Ancylus fluviatilis	0·36	1·21
Elmis aenea	0·75	1·68
Limnius volkmari	—	5·79
Chironomidae	0·09	17·52
Rhyacophila dorsalis	0·23	1·10
Ecdyonurus dispar	12·25	4·80
E. torrentis	4·43	0·03
Rhithrogena semicolorata	7·78	2·43
Ephemerella ignita	5·05	0·12
Baetis rhodani	33·59	8·20
Baetis scambus	9·34	3·01
Amphinemura sulcicollis	3·91	0·35
Leuctra inermis	0·91	1·91
Total percent	84·95	87·64

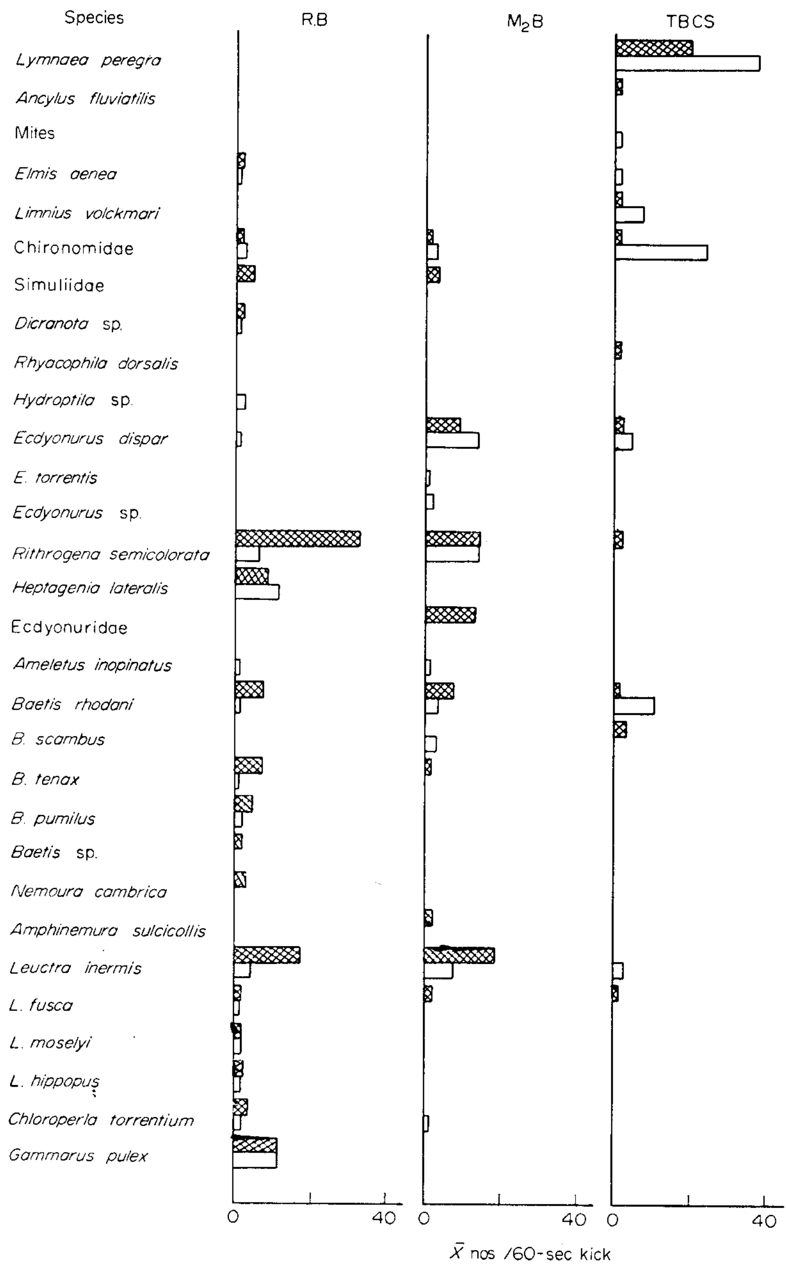

Fig. 3. Species and species groups composing about 80% of the fauna in each of the 3 main areas, reservoir basin (RB), Maize Beck (MzB) and the Tees below Cauldron Snout (TBCS). Riffles, cross-hatched; pools, plain.

Tricladida

These were found in nearly all the reservoir basin streams in riffles only, at a low density of 0·08 animals/kick. It was not possible to identify the specimens due to damage during sampling. No triclads were found in Maize Beck or in TBCS.

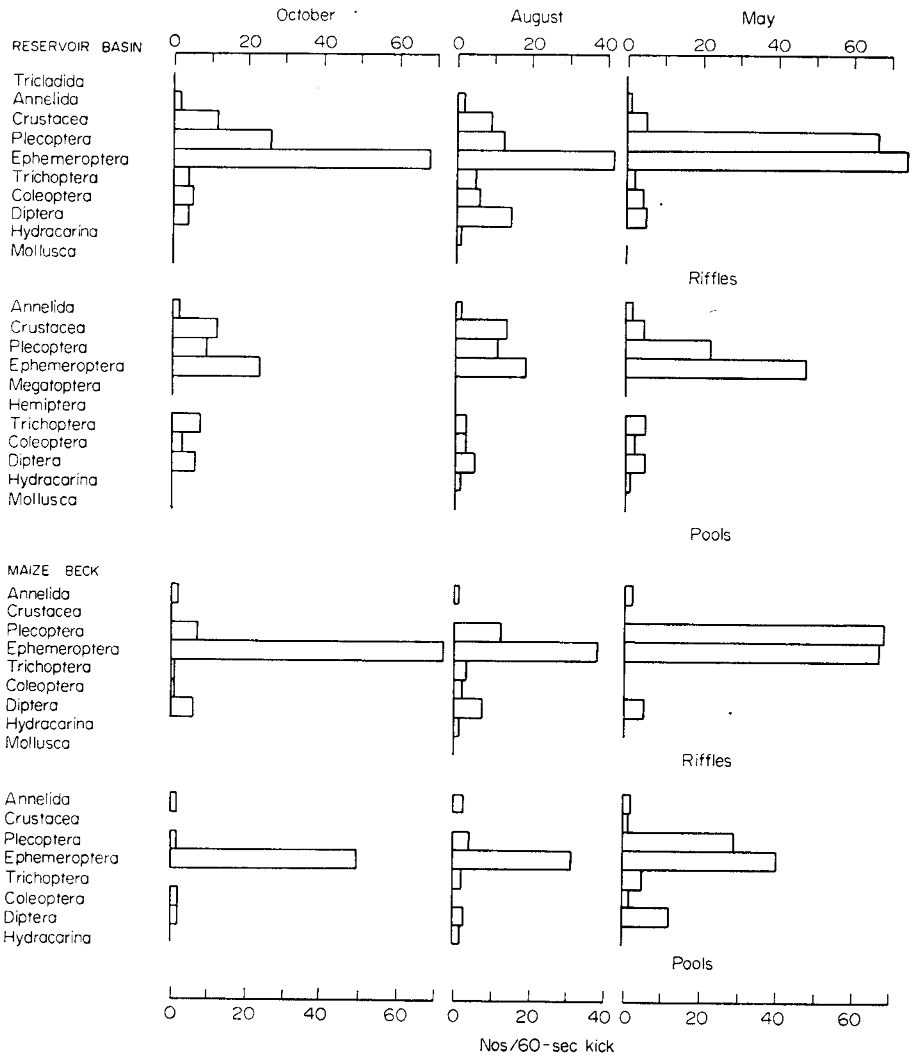

Fig. 4. Seasonal variation in abundance of major taxonomic groups in riffles and pools in the reservoir basin streams and in Maize Beck.

Annelida

In the reservoir basin ten species and species-groups were found and Weelhead Sike contained seven of these. Lumbricidae, especially *Eiseniella tetraedra*, were the most abundant group but representatives of the Tubificidae, Lumbriculidae and Enchytraeidae were also found. A single specimen of *Glossiphonia complanata* was taken during electro-fishing in Near Hole Sike in October 1969. This record extends the reported occurrence (Butcher *et al.*, 1937) of this species in the Tees.

In Maize Beck six species were found, but here *Stylodrilus heringianus* was the most abundant species followed by *Rhyacodrilus coccineus* and Lumbricidae. In TBCS the situation was similar but the population densities were in general, higher.

Annelids in the three areas appeared to be poorly represented numerically, possibly because the sampling method tended to fragment the more delicate species.

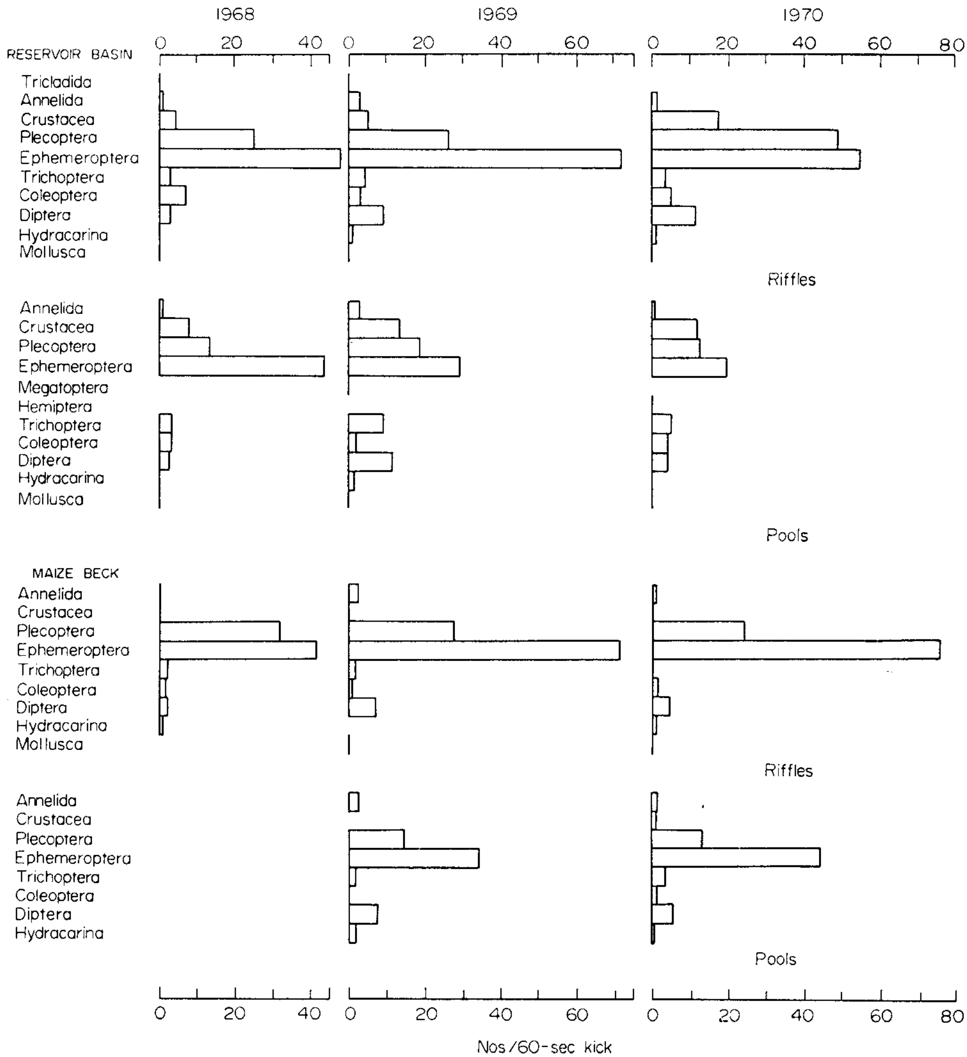

Fig. 5. Annual variation in abundance of major taxonomic groups in riffles and pools in the reservoir basin streams and in Maize Beck.

Crustacea

No detailed investigation of micro-crustacea was made in the pre-impoundment period and the only macro-crustacean was *Gammarus pulex* and this was found in all the reservoir basin streams and in Maize Beck but not in TBCS. In the reservoir basin it was most abundant in Weelhead, Rowantree and Near Hole Sikes. The difference in densities was quite marked. Thus, in 1970 the mean numbers per kick were thirty-four in Weelhead Sike, seventy-six in Near Hole Sike and twelve in Rowantree Sike as compared to only one specimen per kick in Mattergill, Lodgegill and Dubby Sikes. *G. pulex* was scarce in Maize Beck.

Plecoptera

The group was well represented in the area with twenty-three species in the reservoir basin, nineteen in Maize Beck and eleven in TBCS.

In the reservoir basin, the most abundant species was *Leuctra inermis* with a mean value for riffles and pools of eleven/kick. Other common species, *Nemoura cambrica, Chloroperla torrentium, Leuctra fusca, L. moselyi,* and *L. hippopus* occurred at a density of about two/kick and were found in every regularly sampled stream. These values are based on May, August and October samples and in fact there was considerable variation in seasonal abundance particularly of *Leuctra* spp. The pattern of seasonal succession agrees with the observations of Butcher *et al.* (1937), Hynes (1961), Brown *et al.* (1964), Egglishaw & Mackay (1967) and Minshall (1969), (see Table 5). The only specimen of *Leuctra geniculata* taken during the survey was found in August in the Tees above the Weel. Its discovery in TAW extends the reported occurrence (Butcher *et al.*, 1937) of the species in the Tees.

Isoperla grammatica was the most abundant carnivore and occurred in every reservoir-basin stream at a density of one–two animals/kick. *Dinocras cephalotes*, another carnivore, was restricted to three stations and was most common in Weelhead Sike, a stream with a relatively stable bottom. This agrees with Hynes' (1941) observations that *D. cephalotes* is more common than *Perla bipunctata* on stable substrata. The inability of *Diura bicaudata* to co-exist with *Perlodes microcephala* reported by Hynes (1941) and discussed in Arnold & Macan (1969), is not entirely borne out by this study. The species occurred together in three out of five streams though the density of *P. microcephala* was generally a little higher (0·8/kick) than that of *D. bicaudata* (0·01/kick).

In Maize Beck, the common species were the same as in the reservoir-basin. *D. bicaudata* was absent and the three most numerous carnivores were *P. bipunctata, I. grammatica,* and *P. microcephala.*

L. inermis was the most common species in TBCS but its density, about three/kick, was much lower than in the other streams. Of the carnivorous species *I. grammatica*, was the most common with *P. microcephala* and *P. bipunctata* present in small numbers.

The plecopteran fauna was therefore very rich, twenty-two out of the twenty-five species recorded by Brown *et al.* (1964) from the nearby Moor House Nature Reserve being found in the three main study areas. Of the three species not found in the present study, *Nemoura cinerea* (Retzius) is generally restricted to tarns, bog pools and mossy trickles at stream heads, and *Chloroperla tripunctata* (Scopoli) and *Protonemura montana* Kimmins have been described as rare (Brown *et al.*, 1964). Two species, *L. geniculata* and *Capnia bifrons* were found in the present study but not by Brown *et al.* (1964). One specimen of *L. geniculata* was taken in a deep pool with little to no flow in a backwater of the Tees above Weel area, and *C. bifrons* was found only in Weelhead Sike in riffles and pools. *T. nebulosa*, associated with chalk streams in Lincolnshire (Langford & Bray, 1969) was most common in the moderately calcareous waters of Dubby Sike but was not found in the most calcareous streams Near Hole and Weelhead Sikes.

Ephemeroptera

This group was the most abundant in every reservoir basin stream and in Maize Beck and was very common in TBCS.

In the reservoir basin twenty species were represented, sixteen of which were found at 'lower Dubby Sike' and the remaining streams contained from eleven to thirteen species. The three most abundant forms were *Rhithrogena semicolorata, Heptagenia lateralis* and *Baetis rhodani* at densities of eighteen, ten, and five/kick respectively. Together these three species made up about 49 % of the total reservoir basin fauna and 73 % of the ephemeropteran fauna, and were found in every stream.

Baetidae were represented by four species of *Baetis* all of which were found in all the streams. *B. pumilus*, however, was much more abundant in the slow-flowing stable-bottomed Weelhead Sike than in any other regularly sampled stream. *B. scambus* was only found in the summer but the other three species were found throughout the year with *B. tenax* most common in the August samples. In addition two other baetids, *Centroptilum luteolum* and *C. pennatulum*, occurred but rarely and at very low densities.

The Ecdyonuridae were represented by five species, *R. semicolorata, H. lateralis, Ecdyonurus dispar, E. venosus*, and *E. torrentis*, and the first two of these were the most abundant. *E. dispar* occurred in all the streams at a density of about one/kick. *E. torrentis* was also found in all the streams at a lower density. *E. venosus* occurred only rarely in Dubby Sike, Rowantree Sike and in the Tees above the Weel.

Leptophlebiidae were represented throughout the reservoir basin in quieter reaches of the streams but were not found in the survey of the Ephemeroptera of the Moor House National Nature Reserve by Crisp & Nelson (1965). Amongst the Siphlonuridae, *Ameletus inopinatus*, reported (Macan, 1951) as abundant and widespread in Lake District mountain streams was found in all the reservoir basin streams with late instars occurring only in the May samples. This indicates only one hatching period per year, as reported by Larsen (1968) from a river in Norway; not two, one in the autumn and one in the spring as observed by Gledhill (1959) in the English Lake District. *Siphlonurus lacustris* occurred only very rarely in four of the reservoir basin streams usually in pools, in contrast to its widespread occurrence in streams of the Moor House Reserve (Crisp & Nelson, 1965). This suggests a sporadic occurrence as reported by Macan (1957).

Caenis sp.? *rivulorum* was found rarely at 'lower Dubby Sike' as was *Ephemera danica*. This last species was taken only in the electro-fishing nets and its discovery extends its reported occurrence (Butcher *et al.*, 1937) in the Tees.

In Maize Beck the most numerous species was again *R. semicolorata* with *B. rhodani* second in abundance. In TBCS on the other hand, *B. rhodani* was the most abundant ephemeropteran with *E. dispar* the next most common species. This agrees with the reported distribution of *R. semicolorata* as being more characteristic of small stony streams (Macan, 1957), Maize Beck fitting this description better than TBCS. Also *E. dispar* is generally more common in rivers than in streams (Macan, 1957, 1961). *B. scambus* was more abundant in the larger streams, the Tees and Maize Beck than anywhere in the reservoir basin and was generally found only in the August samples (see Table 5). This agrees with observations by other authors (Macan, 1957; Minshall & Kuehne, 1969), and the distribution and occurrence of the Ephemeroptera in the whole study area generally agrees with the schematic representation of succession down the length of a stream presented in Macan (1957).

Trichoptera

A large number of the larvae collected, particularly the Limnephilidae, could not be identified to species level as late instars are needed for certain identification. Despite

Table 5. Seasonal variation in percentage composition of major species and species groups in riffles (R) and pools (P) of the reservoir basin streams and Maize Beck

Species	Reservoir Basin						Maize Beck					
	May		August		October		May		August		October	
	R	P	R	P	R	P	R	P	R	P	R	P
Annelida	1	2	2	2	2	3	1	3	1	4	2	–
Gammarus pulex	4	7	12	26	10	22	+	2	–	–	–	–
Protonemura meyeri	+	–	+	–	3	–	–	–	–	–	+	–
Amphinemura sulcicollis	1	–	1	–	+	1	4	1	+	–	+	–
Nemoura cambrica/erratica	4	2	+	+	6	2	3	–	–	–	–	–
Leuctra fusca	–	–	4	5	+	+	–	–	10	6	–	–
Leuctra inermis	29	16	+	–	3	1	38	24	1	–	1	–
Leuctra hippopus	+	+	–	–	5	7	+	+	–	–	2	–
Leuctra moselyi	+	–	4	10	+	+	–	–	7	1	–	–
Chloroperla torrentium	6	6	–	+	1	1	2	4	–	–	–	–
Ecdyonurus spp.	1	2	4	3	1	9	31	17	23	24	26	38
Heptagenia lateralis	7	27	10	16	3	8	–	1	1	1	1	–
Rhithrogena semicolorata	25	11	+	+	42	16	1	18	6	4	47	48
Ameletus inopinatus	–	3	–	+	–	1	1	4	–	–	+	–
Baetis pumilus	5	6	4	2	1	+	+	–	+	2	+	–
Baetis scambus	–	–	+	+	–	–	–	–	4	23	+	–
Baetis rhodani	5	3	9	2	4	2	7	4	14	12	6	4
Baetis tenax	+	+	17	4	1	+	2	+	4	1	+	2
Baetis spp.	+	+	3	+	1	+	1	+	2	1	+	–
Ephemerella ignita	–	–	+	+	–	–	–	–	4	–	–	–
Trichoptera	2	3	4	6	3	12	1	7	5	6	1	2
Coleoptera	3	2	7	6	3	3	+	1	3	3	2	–
Dicranota sp.	1	1	2	1	2	3	+	1	2	1	2	–
Chironomidae	1	4	2	8	+	1	3	8	3	3	+	–
Simuliidae	1	–	11	–	+	1	+	–	7	1	6	–
Hydracarina	+	1	1	2	+	+	+	1	1	4	+	2
Total percent	96	96	97	93	91	93	95	96	98	97	96	96

+, <1%.

these limitations a total of twenty-one taxa were found in the reservoir basin ranging from six in Rowantree Sike to eleven in Weelhead Sike. *Hydroptila* was the most abundant and widespread genus but never occurred at really high densities, the mean value for riffles and pools being about 1·5/kick. The remaining species commonly occurring belonged mainly to the Polycentropodidae and Rhyacophilidae. Besides *Rhyacophila dorsalis*, a common and widespread species, *R. obliterata* was also found occurring only in Mattergill, Lodgegill and Rowantree Sikes. *R. obliterata* is described by Hickin (1967) as being locally common in hilly districts in North Britain. The Limnephilids, *Drusus annulatus* and *Ecclisopteryx guttulata* were also fairly common. The remaining species were sporadic in occurrence.

In Maize Beck the most abundant species was *Brachycentrus subnubilus* and in TBCS the polycentropid *Plectrocnemia geniculata* was the most common form with *R. dorsalis* and *Polycentropus flavomaculatus* also common.

In all three areas Trichoptera made up only about 3–4% of the total fauna.

The distribution of the Polycentropodidae agrees in general with that reported by Edington (1964). *Plectrocnemia conspersa* was more common in the smaller streams. *P. flavomaculatus* was more common in the rivers and *P. geniculata* appeared to be intermediate, being only slightly more common in rivers than in streams.

In addition to larvae collected by kick sampling the species listed below were recorded as adults from light traps at 'lower Weelhead Sike' and at TBCS in August 1970.

5 August 1970 'lower Weelhead Sike': *Potamophylax latipennis* (Curtis); *Limnephilus sparsus* Curtis; *Polycentropus flavomaculatus* (Pictet).

18 August 1970 TBCS: *P. latipennis*; *Tinodes waeneri* (L.); *Polycentropus flavomaculatus*; *Plectrocnemia conspersa*; *Phyacophila dorsalis.*

None of these species is new to the area as a whole and all have been recorded by Nelson (1971) above 530 m in the Moor House National Nature Reserve, but *T. waeneri*, *P. latipennis* and *L. sparsus* are here recorded for the first time from the reservoir basin and the Tees below Cauldron Snout.

Coleoptera

A total of twelve species was found in the reservoir basin, with seven in Maize Beck and five in TBCS. Elminthids, particularly *Elmis aenea*, were the most common forms. In TBCS, however, *Limnius volckmari* was most abundant. Two rarer species *Riolus cupreus* and *R. subviolaceous* were both found only in quieter reaches in 'lower Dubby Sike', Weelhead Sike and Near Hole Sike and occurred only in small numbers. Certain species, e.g. *Hydraena gracilis* and *Helodes marginata*, were more common in reservoir-basin streams, *Oreodytes* sp. on the other hand was more abundant in Maize Beck.

Coleoptera were most numerous in TBCS where they formed 8·7% of the total fauna in riffles and pools, whilst in the reservoir basin and Maize Beck they formed only 4 and 1% respectively.

Diptera

Chironomidae and Simuliidae were the main dipterans in the three areas, although in TBCS Simuliidae were not apparently very numerous. In the reservoir basin simuliids were much more common in Dubby, Mattergill, Lodgegill, and Rowantree Sikes, than in the slower-flowing Weelhead and Near Hole Sikes. Chironomids in contrast were common in all the reservoir basin streams. The simuliid larvae for 3 of the survey years, 1967, 1968, and 1970 have been identified. Because of confusion over the taxonomy of *Simulium latipes* and *S. naturale* these have been run together under the former species. The chironomid larvae were not identified but the vast majority belonged to the sub-family Orthocladiinae. *Dicranota* spp. larvae were widespread occurring in moderate numbers in all the sampled areas.

Hydrachnellae

A total of six species were found: four in TBCS, four in the reservoir-basin and two in Maize Beck. The group was widespread throughout the area occurring at a density of 0·5–1/kick.

Mollusca

Eight species were found, all of which were represented in the reservoir basin. *Ancylus fluviatilis* was the only mollusc present in Maize Beck, and TBCS contained only *Limnaea peregra* and *A. fluviatilis*. Generally, molluscs were unimportant numerically in the reservoir-basin and Maize Beck but in TBCS they made up 39% of the total fauna. This high percentage, based on the 1970 kick samples, could in part, be due to the completion of the dam wall that summer, but samples taken in 1969 from the electro-fishing nets (an unsuitable method for molluscs) also had a high proportion of molluscs—13%. This may be because the Tees, although carrying much water, has a greater range of flow-conditions including several deep pools which would favour development of *Limnaea peregra*.

Of the lamellibranchs found, *Pisidium casertanum*, *P. hibernicum* and *P. obtusalis*, all are common throughout the British Isles (Ellis, 1962).

The three remaining gastropods, *L. truncatula*, *L. palustris* and *Zonitoides nitidus* were all rare, occurring generally only in Weelhead Sike, though *Z. nitidus* also occurred in Rowantree Sike. Both the *Limnaea* species are common soft-water forms (Boycott, 1936) and *Z. nitidus* is not considered to be truly aquatic though it is sometimes found submerged (Macan, 1969).

Comparison of the bottom fauna of riffles and pools

Differences in the numbers of animals taken in riffles and pools were quite marked for certain species. Generally speaking numerical densities were higher in riffles, this agrees with Egglishaw & Mackay's (1967) observations on the fauna of the Shelligan Burn. Also, the number of species found was slightly higher in riffles than in pools. The values for the reservoir basin being 105 and 100 taxa in riffles and pools respectively, and for Maize Beck the corresponding values were fifty-five and forty-two. Data on the distribution of the more abundant species are presented in Table 5.

Rhyacophila dorsalis was the only trichopteran to occur at greater densities in riffles than in pools. Most baetids, *Rhithrogena semicolorata*, Elminthidae, Simuliidae, and all Plecoptera were more abundant in riffles and Chironomidae, Dytiscidae, Leptophlebiidae, *Heptagenia lateralis* and *Ameletus inopinatus* were always more common in pools.

These observations above agree in general with Egglishaw & Mackay (1967), although there was no obvious shift in concentration of *Ecdyonurus* spp. from pools in April to riffles in September as reported by them, and *Dicranota* larvae were found more commonly in riffles than in pools in the present study.

Table 6. The $\bar{X}$ number of animals per 60-sec kick and percentage composition of the fauna at Tees above Weel before (1967 and 1968), during (1969) and after (1970) gravel extraction

Groups	May 1968		May 1969		May 1970		Aug. 1967		July 1968		Aug. 1969		Aug. 1970	
	$\bar{X}$	%	$\bar{X}$	%	$\bar{X}$	%	$\bar{X}$	%	$\bar{X}$	%	$\bar{X}$	%	$\bar{X}$	%
Annelida	1·3	0·6	—	—	—	—	3	3·4	1	0·8	—	—	0·5	1·3
Plecoptera	61·6	29·2	8·5	13·6	11·3	27·9	34	38·4	17·3	13·4	2·0	6·9	4·0	10·3
Ephemeroptera	132·6	62·8	52·5	84·0	27·0	66·7	37·6	42·5	69·0	53·3	26·5	91·4	26·5	67·9
Trichoptera	1·6	0·8	—	—	—	—	3·0	3·4	10·3	7·9	—	—	2·0	5·1
Coleoptera	11·6	5·5	1·0	1·6	0·6	1·5	6·0	6·8	22·3	17·2	—	—	1·5	3·8
Diptera	2·3	1·1	0·5	0·8	1·3	3·2	4·6	5·2	9·0	6·9	0·5	1·7	4·5	11·6
Hydrachnellae	—	—	—	—	—	—	—	—	0·6	0·5	—	—	—	—
Mollusca	—	—	—	—	0·3	0·7	0·3	0·30	—	—	—	—	—	—
Total	211	100	62·5	100	40·5	100	88·5	100	129·5	100	29·0	100	39·0	100

The effect of gravel extraction on the bottom fauna of the River Tees

During May 1969 kick samples were taken in the Tees at NY 791307 where gravel extraction was in progress and during August 1969 similar samples were taken from an area where gravel extraction had been completed. The 1969 samples were then compared with samples taken in 1967 and 1968 from similar but undisturbed sites in the Tees above the Weel. Further samples were taken in the disturbed area in May and August 1970 to observe the recovery of the bottom fauna. In the autumn of 1970 the area was inundated following completion of the dam in June.

Table 6 shows the mean number of animals per kick in riffles and the percentage composition of the benthic fauna in terms of major taxonomic groups for the period 1967–70.

Quantitative assessment of a change in bottom fauna as a result of gravel extraction is difficult because of the variation between samples. In general, however, the gravel extraction appears to have caused a decrease in both abundance and diversity of the bottom fauna. The samples taken before disturbance gave catches ranging from 21 to 328 individuals/kick, and representing from ten to twenty-four species or groups, whilst in 1969 the catches ranged from twenty-two to seventy individuals representing seven to nine species or groups. The post-disturbance catches ranged from twenty-two to sixty-four individuals of five to thirteen groups.

In every year Ephemeroptera were the most abundant group and during the gravel extraction their percentage in the catch increased, though their numbers were reduced. The preponderance of this group is probably attributable to its relatively greater activity and hence faster colonization of disturbed areas. The same argument applies to Plecoptera which were second in abundance. Diptera also appeared to have made a quick recovery both in terms of numbers and percentage composition, and was the only group to have reached its pre-disturbance density (4·5/kick) by August 1970 and its percentage of the total catch had also increased.

The Coleoptera, chiefly elminthids, appeared to recover more slowly than the Diptera. These beetles lay their eggs between May and June (Holland, 1972) and the gravel extraction would have had a catastrophic effect on the new generation. The Diptera (Chironomidae, Tipulidae and Simuliidae), in contrast, have an extended emergence and egg-laying period and would have contributed to recruitment in the disturbed area in the late summer and autumn of 1969. This could account for the relatively quick recovery of the Diptera. The Trichoptera have the same advantage as the Diptera in having an extended emergence period and their recovery also appeared to be fairly rapid. The Annelida in contrast were severely affected by the disturbance, probably owing to their intimate association with the substratum, and their recovery was extremely slow.

These observations indicate that the populations of those species which have aquatic larvae and which spend part of their life-history out of water for breeding recovered faster from substratum disturbances than purely aquatic forms.

Absolute abundance

The 60-sec kick method of sampling is a simple but effective method of obtaining samples of invertebrates from stony and gravelly stream-beds with a wide size-range of substratum particles. Despite three changes of operator between 1967 and 1970 the results from the kick samples were very consistent; this agrees with Morgan & Egglishaw's (1965) observations on the method. However, few comparable samples can be taken at any one place on any occasion because of rapid changes in the substratum and the time required for sorting, so that the results from kick sampling are unlikely to be precise enough to measure any but the most gross differences in population density between streams, sampling sites or sampling dates. Even so, taken over a number of years, the results from this method could be used to obtain very approximate average values for population density provided there was some means of converting the numbers of animals taken in kick samples into numbers of animals present per square metre of stream bed.

The shovel sampler (Macan, 1958) takes a sample of the top few centimetres of substratum from a known area of stream-bed but because of the presence of large stones in the beds of most of the streams in the Cow Green area it was found unsuitable for general use in this project. However, in certain areas the shovel sampler could be used effectively and parallel trials of kick and shovel sampling were made in an attempt to derive a suitable factor for the conversion of kick sample catches to numbers per square metre. The mesh aperture of the nets used in both methods was 1 mm.

Each pair of kick and shovel samples were taken in areas with similar substrata (fine to medium gravel with sand), preferably close together. Ten pairs of samples were taken in May 1970 and four in June from riffles, and one pair in June was taken in a pool. Both sets of samples were taken by different operators but a chi-square test (Table 7) revealed little difference in the proportion of kick to shovel catches

Table 7. Variation in shovel and kick-sample catches made by two operators with reference to total catches and catches of Ephemeroptera and Plecoptera. (Null hypothesis that there is no difference in the proportions of shovel to kick-sample catches between operators, P = % probability that null hypothesis is true with 1 degree of freedom)

	χ^2	P
A. Total catch	0·065	80
B. Plecoptera	0·860	30–50
C. Ephemeroptera	0·130	70

between months when considering the total catch. Further tests showed that for Ephemeroptera and Plecoptera, together comprising 92% of the total catch, Ephemeroptera differed less than the Plecoptera from the expected ratio of kick to shovel catches between months. The ratios for the major groups in each month are compared with the expected ratio for that month in Table 8. The results show that in May, departures from the expected ratio were uncommon in Trichoptera and Ephemeroptera, occurred to some extent in Plecoptera and Coleoptera and were very common in Diptera. In June very similar results were obtained, deviations from the expected ratio were uncommon in Trichoptera, Ephemeroptera and Plecoptera, and were the rule in Diptera. The pooled chi-square value again reflects heterogeneity amongst the groups.

The relation between the kick and shovel samples was investigated using regression analysis, and the regression equations for total catch, Ephemeroptera and Plecoptera

Table 8. Significance of deviations from the expected ratio of kick to shovel catches for major groups and total catch. (P = % probability that the null hypothesis that no deviations occur is true)

Group	May			June		
	χ^2	d.f.	P	χ^2	d.f.	P
Trichoptera	0·14	1	70	0·26	1	50–70
Ephemeroptera	0·09	1	70–80	0·14	1	70
Plecoptera	1·01	1	30	0·24	1	50–70
Diptera	8·12	1	<1	4·51	1	2·5
Coleoptera	0·60	1	30–50	—		
Total	9·96	4	<1	5·15	3	10–25

Table 9. (a) Percentage composition of kick and shovel samples in May and June 1970

Group	May		June	
	Shovel	Kick	Shovel	Kick
Plecoptera	24	28	3	4
Ephemeroptera	64	66	90	89
Trichoptera	1	1	4	3
Coleoptera	3	2	2	–
Diptera	8	3	1	4
Mollusca	–	+	–	–
Totals	100	100	100	100

(b) Chief contributors to totals

Sp. or spp. group	Shovel (%)	Kick (%)
May		
Leuctra inermis	22	24
Chloroperla torrentium	–	3
Rhithrogena semicolorata	61	62
Coleoptera	3	2
Chironomidae	7	2
Total	93	93
June		
Leuctra inermis	–	1
Leuctra moselyi	–	1
Ephemerella ignita	10	6
Rhithrogena semicolorata	7	15
Heptagenia lateralis	4	3
Ecdyonuridae indet.	62	57
Baetis scambus	6	7
Agapetus sp.	3	1
Coleoptera	2	–
Chironomidae	–	3
Total	94	94

and the remaining major groups considered as a whole are given in Table 10, together with *P* values and 95% confidence limits of the regression coefficient *b*.

Table 10. Components of the regression equations of 'kick' versus 'shovel' catches for total catch and for major groups

	a	b	95% limits
Total catch	3·67	*** 1·9200	±0·4120
Ephemeroptera	3·07	*** 1·9409	±0·3792
Plecoptera	4·66	** 1·2976	±0·9525
Diptera/Trichoptera and Coleoptera	1·64	n.s. 0·6229	±3·1415

***$P<0\cdot001$; **P 0·02–0·01; n.s. non-significant.

The value of the total catch regression coefficient lies between 2·3320 and 1·5080. This means that one kick sample represents approximately 1·5–2·3 shovel samples. Since a shovel sampler samples an area of 500 cm² this gives the area covered by a kick as roughly between 750 and 1150 cm², hence, about 10·5 kicks give a catch equivalent to the population of 1 m². These results are intended to give only a rough quantification of kick sample values. It should be stressed that the ratios of the catches of different animal groups vary considerably and these results refer mainly to Ephemeroptera which formed the major part of catches in both May and June. Table 9 shows the percentage composition of the major groups in both months.

There have been few attempts to compare sampling methods in stony streams. Macan (1958) made a comparison of catches by stone lifting and by shovel sampler and discussed the selectivity of the two methods, and Albrecht (1959) has reviewed methods for the quantitative sampling of running waters. Hynes (1961) compared stramin (kick) samples with a shovel device and estimated that one stramin sample consisting of ten kicks collected the animals from about one third to half a square metre, this indicates that one kick sample roughly covers an area of about 400 cm². In 1965 Morgan & Egglishaw studied the validity of kick samples on a stony substratum in Allt Leathan, Scotland and obtained very consistent results. In this case the kick sample covered an area of 1104 cm². Of the two kick sampling methods of Hynes (1961) and Morgan & Egglishaw (1965), the latter is the most similar to that used in the present study.

Using the conversion factor of 10·5 on the total catches for riffles and pools in the reservoir basin, Maize Beck and TBCS, one obtains respective population densities of 1028, 864, and 742 animals per m². Owing to the relatively small number of samples taken in TBCS and Maize Beck the figures for these two areas are slightly questionable and only indicate the order of magnitude of the benthic invertebrate population in these two streams.

From Hynes' (1961) data on the Afon Hirnant and those of Morgan & Egglishaw (1965) on Allt Leathan the mean number of animals per square metre can be calculated. Hynes' results based on 13 months' sampling give an estimate of 1437 animals per m². Morgan & Egglishaw's data give a value of 666 animals per m² in January but since they estimate a 3·1 increase in numbers in the summer this gives a range from 666 to 2064 animals.

In the present study the corresponding value for reservoir basin riffles based on 3 years sampling in May, August and October lies between 1000 and 1600 animals per m^2.

Discussion

The results of the present survey showed that the stream faunas were relatively rich in species compared with other surveys in upland Britain. All the streams sampled in this study lie at elevations between 440 and 530 m O.D. and are subject to rigorous climatic conditions. Despite this, over 120 taxa were recorded, 100 of them at the species level. Hynes (1961) recorded about ninety taxa in the Afon Hirnant, Egglishaw & Mackay (1967) recorded about fifty taxa in three streams they studied in Scotland, and Minshall & Kuehne (1969) recorded only sixty-two taxa along the length of the river Duddon with only twenty-one of these present at altitudes above 450 m O.D. None of these authors identified Simuliidae or Elminthidae. Arnold & Macan (1969) recorded fifty-four taxa from a Shropshire hill stream at altitudes between 200 and 446 m O.D. Morgan & Egglishaw (1965) are the only authors to have recorded more than 130 taxa and this was the result of a survey of fifty streams in Scotland, the highest at an altitude of 350 m.

The general composition of the fauna and seasonal variations in abundance of certain species agree well with observations by the above authors and it is the species richness of the Cow Green fauna which distinguishes it from the fauna of other areas. Possible reasons for this richness are discussed below.

The study area contained a wide range of habitats which varied from large rivers to small streams. The Tees is possibly unique in the British Isles in attaining its relatively large size at an altitude in excess of 400 m. Conditions ranged from spate-prone streams with loose bottoms to more-or-less stable streams with moss-covered boulders, and slow-flowing streams with peaty bottoms. This range of conditions and habitats provides niches for a great variety of species from those typical of fast-flowing streams to other forms such as *Nemurella picteti*, *Neureclipsis bimaculata* and *Pisidium* spp. more characteristic of slower-flowing water, and to forms commonly found in larger streams e.g. *Leuctra geniculata* and *Baetis scambus*. 'Montane' species such as *Ameletus inopinatus* and *Capnia vidua* are also represented.

In general the 'flashy' streams supported fewer taxa (seventy-nine) than did the others (104) due to probably to the greater variety of conditions found in the latter streams. An example is seen in Dubby Sike whose lower half was slow-flowing and meandering, compared with the upper half which had a moderate flow with a stony bottom. In contrast Mattergill, Lodgegill and Rowantree Sikes were very similar for the greater part of their lengths. Despite the greater number of taxa in the less flashy streams, the actual numbers of animals in riffles of both types of stream were very similar being 1260 and 1354/m^2 in 1969 and 1460 and 1449/m^2 in 1970 in the stable-bottomed and flashy streams respectively.

The variation in water chemistry between streams particularly with regard to Ca^{++} content is wide (Crisp *et al.*, in preparation) ranging from 23 ppm in Weelhead and Near Hole Sikes to 9 ppm in Mattergill, Lodgegill and Rowantree Sikes. Dubby Sike was intermediate with about 13 ppm. These differences correlate with the presence of *Riolus subviolaceous* and *R. cupreus* in Weelhead and Near Hole Sikes since both species are associated with calcareous waters (Holland, 1972). Similarly, the greatest number of mollusc species (also generally associated with calcareous waters) were found in Weelhead Sike, although this could in part have been related to the less flashy nature of this stream compared with those entering from the west.

Having given some possible reasons above for the species richness of the fauna at Cow Green it remains to consider why the Pennine streams are richer than others studied in the British Isles.

Gradients of the Cow Green streams are generally less than those of the upper reaches of the Lake District and Scottish streams. An example of this is seen in Gaitscale Gill (Minshall & Kuehne, 1969) which drops about 500 m in 2 km whereas Lodgegill Sike, the steepest at Cow Green, drops only 200 m in 2·7. The more gentle gradient could result in reducing overall spate-velocity with less catastrophic consequences on the fauna.

The chemical richness of the water influences the bottom fauna (Egglishaw & Morgan, 1965) and it is possible that the Cow Green streams are chemically richer than the upper reaches of the Lake District and Scottish streams. Certainly the Cow Green streams are richer in calcium ions than the river Duddon whose highest level was 7·1 ppm (Minshall & Kuehne, 1969), and the three Scottish streams studied by Egglishaw & Mackay (1967) where the highest Ca^{++} level was 8·22 ppm in the Shelligan Burn. Boycott (1936) considered 20 ppm as being the lower limit of hard water, this then would make Weelhead Sike a hard-water stream. On Mann's (1955) classification most of the Cow Green streams would be considered intermediate in hardness since they fall between 7 and 24 ppm. Similarly, the total cation content of the Duddon water never exceeds 0·5 mEq/l whereas the value for Troutbeck, a tributary of the Tees in the Moor House National Nature Reserve, is much higher at 1·175 mEq/l (Goreham, 1956).

The stream catchments at Cow Green particularly on the western side comprise much eroding peat. Crisp (1966) estimated that 11–20% of the catchment of the Rough Sike, a stream on the Moor House Reserve, consisted of eroding peat. Although most of the particles would be washed away down the stream a certain amount would be trapped under stones thus increasing the organic-matter content of the substratum. Egglishaw (1969) clearly demonstrated that where there was an increase in plant detritus there was also an increase in the variety of the bottom fauna.

It is possible that a combination of the above features has resulted in the relative richness of the Cow Green fauna. Thienemann's (1954) ecological principle that the greater the diversity of the conditions in a locality the larger is the number of species which make up the biotic community applies very well to this study area.

In spite of its inadequacies, the present work has helped to bridge the gap between studies on the Moor House Reserve and the survey of the Tees by Butcher *et al.* (1937). It has given a good species list with data on the distribution of species within the study area, and a general indication of relative and absolute abundance. These data will be of value for comparison with the situation which develops after impoundment. The comparison will be of particular value in the regions below the dam. Greater changes can be expected in TBCS than in the reservoir basin streams above Top Water level, and the unregulated Maize Beck will provide a useful control since the species composition of the faunas in both TBCS and Maize Beck was similar before impoundment though the proportions of certain species, particularly Mollusca and Diptera, were higher in the Tees.

Acknowledgments

The authors wish to acknowledge the facilities provided by, the Northumbrian River Authority, the fishery owners, Mr P. B. Oughtred and the Raby Castle and Strathmore Estates, the Tees Valley and Cleveland Water Board, Mr T. Buffey, and the Nature Conservancy at Moor House for laboratory space.

Our thanks are also give to Dr D. Holland for his help with the identification of the Coleoptera, Mr P. Hiley for his comments on our Trichoptera collection, Dr M. Ladle and Mr T. Gledhill for the identification of the oligochaetes and water-mites, and Mr R. S. Wotton for identifying the Simuliidae collected during the survey.

We are also grateful to Mr H. C. Gilson and Mr E. D. LeCren for their support and advice, Dr J. M. Elliott for statistical advice, and to Dr T. T. Macan and Dr D. T. Crisp and other members of the Ferry House staff for their comments and assistance.

References

ALBRECHT M.L. (1959) Die quantitative Untersuchung der Bodenfauna fliessender Gewässer (Untersuchungsmethoden und Arbeitsergetnisse) *Z. Fisch.* **8**, 481–550.

ARNOLD F. & MACAN T.T (1969) Studies on the fauna of a Shropshire hill stream. *Fld Stud.* **3**, 159–184.

BOYCOTT A.E. (1936) The habitats of freshwater Mollusca in Britain. *J. Anim. Ecol.* **5**, 116–186.

BROWN V.M., CRAGG J.B. & CRISP D.T. (1964) The Plecoptera of the Moor House National Nature Reserve, Westmorland. *Trans. Soc. Br. Ent.* **16**, 123–134.

BUTCHER R.W., LONGWELL J. & PENTELOW F.T.K. (1937) Survey of the River Tees. III. The non-tidal reaches—chemical and biological. *Tech. Pap. Wat. Pollut. Res. Lond.* **6**, pp. xiii–189.

CRISP D.T. (1966) Input and output of minerals for an area of Pennine moorland: the importance of precipitation, drainage, peat erosion and animals. *J. appl. Ecol.* **3**, 327–348.

CRISP D.T., MANN R.H.K. & MCCORMACK J. (In preparation) The populations of fish at Cow Green, Upper Teesdale, prior to impoundment.

CRISP D.T. & NELSON J.M. (1965) The Ephemeroptera of the Moor House National Nature Reserve, Westmorland. *Trans. Soc. Br. Ent.* **16**, 181–187.

DAVIES L. & SMITH C.D. (1958) The distribution and growth of *Prosimulium* larvae (Diptera: Simuliidae) in hill streams in Northern England. *J. Anim. Ecol.* **27**, 335–348.

EDINGTON J.M. (1964) The taxonomy of the British polycentropid larvae (Trichoptera). *Proc. Zool. Soc. Lond.* **143**, 281–300.

EGGLISHAW H.J. (1969) The distribution of benthic invertebrates on substrata in fast-flowing streams. *J. Anim. Ecol.* **38**, 19–33.

EGGLISHAW H.J. & MACKAY D.W. (1967) A survey of the bottom fauna of streams in the Scottish Highlands. III. Seasonal changes in the fauna of three streams. *Hydrobiologia*, **30**, 305–334.

ELLIS A.E. (1962) British freshwater bivalve molluscs. *Linnean Society Synopses of the British Fauna No.* 13.

GLEDHILL T. (1959) The life-history of *Ameletus inopinatus* (Siphlonuridae, Ephemeroptera). *Hydrobiologia*, **14**, 85–90.

HICKIN N.E. (1967) *Caddis Larvae. Larvae of the British Trichoptera.*, Hutchinson, London.

HOLLAND D.G. (1972) A key to the larvae, pupae and adults of the British species of Elminthidae. *Scient. Publs. Freshwat. Biol. Ass.* **26**, 1–58.

HYNES H.B.N. (1941) The taxonomy and ecology of the nymphs of British Plecoptera with notes on the adults and eggs. *Trans. R. ent. Soc. Lond.* **91**, 459–557.

HYNES H.B.N. (1961) The invertebrates fauna of a Welsh mountain stream. *Arch. Hydrobiol.* **57**, 344–388.

LANGFORD T.E. & BRAY E.S. (1969) The distribution of plecoptera and ephemeroptera in a lowland region of Britain (Lincolnshire) *Hydrobiologia*, **34**, 243–271.

LARSEN R. (1968) The life-cycle of Ephemeroptera in the lower part of Aurland River in Sogn and Fjordane, Western Norway. *Norsk ent. Tidsskr.* **15**, 49–59.

MACAN T.T. (1951) The taxonomy of the British species of Siphlonuridae (Ephem). *Hydrobiologia*, **3**, 84–92.

MACAN T.T. (1957) The Ephemeroptera of a stony stream. *J. Anim. Ecol.* **26**, 317–342.

MACAN T.T. (1958). Methods of sampling the bottom fauna in stony streams. *Mitt. int. Ver. Limnol.* **8**, 1–21.

MACAN T.T. (1961) A key to the nymphs of the British species of Ephemeroptera. *Scient. Publs. Freshwat. Biol. Ass.* **20**, 1–64.

MACAN T.T. (1969) A key to the British fresh- and brackish-water gastropods. *Scient. Publs. Freshwat. Biol. Ass.* **13**, (3rd edit.), 1–46.

MAITLAND P.S. (1966) *Studies on Loch Lomond. 2. The Fauna of the River* Endrick. Blackie & Son Ltd, London.

MANLEY G. (1936) The climate of the northern Pennines: the coldest part of England. *Q. Jl. R. met. Soc.* **62**, 103–115.

MANN K.H. (1955) The ecology of the British freshwater leeches. *J. Anim. Ecol.* **24**, 98–119.

MILLAR A, (1964) Notes on the climate near the upper forest limit in the northern Pennines. *Q. Jl For.* **48**, 239–246.

MINSHALL G.W. (1969) The Plecoptera of a headwater stream (Gaitscale Gill, English Lake District). *Arch. Hydrobiol.* **65**, 494–514.

MINSHALL G.W. & KUEHNE R.A. (1969) An ecological study of invertebrates of the Duddon, and English mountain stream. *Arch. Hydrobiol.* **66**, 169–191.

MORGAN N.C. & EGGLISHAW H.J. (1965) A survey of the bottom fauna of streams in the Scottish Highlands. Part 1. Composition of the fauna. *Hydrobiologia*, **25**, 181–211.

NELSON J.M. (1965) A seasonal study of aerial insects close to a moorland stream. *J. Anim. Ecol.* **34**, 573–579.

NELSON J.M. (1971) The invertebrates of an area of Pennine moorland within the Moor House Nature Reserve in Northern England. *Trans. Soc. Br. Ent.* **19**, 173–235.

PHILLIPSON J. (1957) The effect of current speed on the distribution of the larvae of blackflies (*Simulium variegatum* (Mg.) and *S. monticola* Fried. (Diptera)) *Bull ent. Res.* **48**, 811–819.

THIENEMANN A. (1954) Ein drittes biozönotisches Grundprinzip. *Arch. Hydrobiol.* **49**, 421–422.