With compliments

THE EFFECT OF CHINA-CLAY WASTES ON STREAM INVERTEBRATES

P. M. Nuttall & G. H. Bielby

Cornwall River Authority, Western Road, Launceston, Cornwall, Great Britain

ABSTRACT

A survey of the macro-invertebrate fauna of rivers receiving china-clay wastes was carried out during 1971–72. *Rivers polluted by clay waste supported a sparse population of few species. Rooted vegetation was absent, although clean headstreams and unpolluted reaches supported a rich community of aquatic plants. Control streams supported thirty-six times the density of animals found at clay-polluted stations. The composition of species was greater in unpolluted rivers, moorland headstreams and at stations downstream of sewage outfalls compared with clay-polluted reaches.* Baetis rhodanii; Perlodes microcephala *and the burrowing forms Tubificidae, Naididae and Chironomidae were in greater abundance in clay-polluted reaches. China-clay pollution either eliminated or reduced the abundance of several species frequent in control streams. The poor incidence of plants and macro-invertebrates from rivers receiving china-clay waste was associated with the deposition of fine inert solids derived from the clay extraction process rather than turbidity or abrasion caused by particles in suspension.*

INTRODUCTION

The moorland areas of Cornwall and Devon are formed of granite which is usually white and composed of feldspar, quartz and mica. It is the decomposition of feldspar by a process known as kaolinisation which produces china-clay. More than 90% of the china-clay so far mined in Britain has come from the granite massif north of St. Austell, but the area on the south-west slopes of Dartmoor above Plymouth has also been important (Hudson, 1969).

Generally, the clay deposits are broken by water-jet and the resulting slurry pumped to a sand separation plant. Eight tons of waste, mainly composed of

Environ. Pollut. (5) (1973) pp. 77–86—

coarse quartz sand, are obtained in the production of one ton of marketable clay (HMSO, 1948). This sand is stockpiled as large tips, which are well-known landmarks in the area. The clay and water mixture is next pumped through a series of de-watering tanks. More refining processes extract fine sand and mica from the slurry before it is stored in tanks, prior to being dried (Fig. 1).

Much water is used to extract, transport and refine china-clay and the amount discharged as wastes contains sand, mica and clay in suspension, the proportions depending on the details of the industrial process and whether the effluent is treated before discharge. Seepage and overflow from the mica dams and settlement

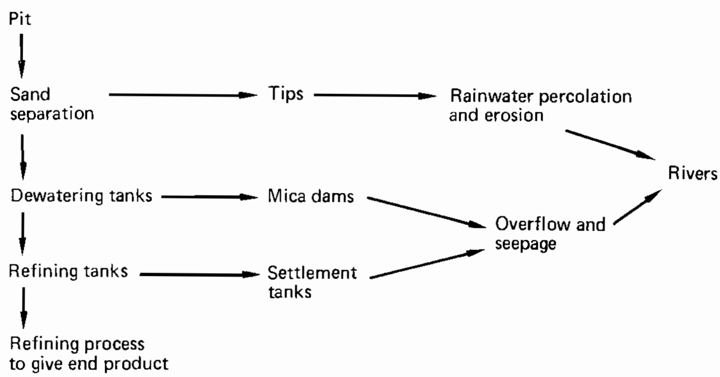

Fig. 1. Diagram of the china-clay extraction process.

tanks constitute the major effluent which affects water quality in a number of rivers. The St Austell, Par and Bodelva rivers, however, received effluent directly from the extraction process without it having first undergone settlement. Suspended solids in these rivers were consequently much higher than in other rivers in the area (Table 1).

Previous work on the biological effects of china-clay waste includes that of Pentelow (1949), who reported that 'sea-trout pass regularly up the River Fal through reaches badly polluted by clay, to spawn in the clean head streams.' He also reported finding ephemeropteran nymphs in the Tory Brook when the waters were running milk-white with china-clay suspension.

Herbert *et al.* (1961) recorded cases of gill-damage in *Salmo trutta* from china-clay polluted reaches of the River Fal. These workers also showed that the bottom fauna in the control streams was, on average, 3.3 times greater than in the polluted part of the Fal and nineteen times greater than in the polluted part of the Par. Howell & Shelton (1970) showed that china-clay waste has had a marked effect on the bottom fauna of St Austell and Mevagissey Bays by replacing suspension-feeding forms, common outside the clay deposits, with a rich community of deposit-feeding animals.

In this paper we describe a survey made over the period 1971–72 to determine the composition and distribution of the bottom fauna of both clean and polluted parts of the Plym, Yealm, Tory Brook, East Looe, Fowey, Fal, St Austell, Crinnis and Par rivers and their tributaries. It is not intended that the work, which is essentially preliminary in character, should be a comprehensive assessment of existing faunal conditions. The main objective was to study to what extent changes in suspended solids and sediments, brought about by the discharge of china-clay waste, were reflected in the benthos.

TABLE 1

SUSPENDED SOLIDS CONCENTRATIONS (PPM) FROM RIVERS RECEIVING CHINA-CLAY EFFLUENT. DATA SUMMARISED FROM ANALYSES MADE BY THE CORNWALL RIVER AUTHORITY DURING THE PERIOD 1971–72

Station	*River system*	*Number of samples*	*Mean (ppm)*	*Maximum value*	*Minimum value*
2	Yealm	4	4	5	<1
3	Piall	4	50	120	8
5	Yealm	4	8	15	1
10	Tory Brook	10	384	2780	28
13	Plym	8	44	297	8
14	Plym	10	49	277	4
16	Plym	6	44	218	2
17	East Looe	1	13	—	—
18	East Looe	1	11	—	—
27	Fowey	1	8	—	—
28	Fowey	1	7	—	—
33	Par	12	4170	5980	2264
34	Bodelva	11	35231	62972	1372
35	Crinnis	11	25	64	3
37	St Austell	12	14106	25508	13
38	St Austell	10	46689	91268	16950
42	Fal	8	240	1210	44
44	Fal	10	211	606	45

DESCRIPTION OF THE AREA

The rivers investigated and the sampling stations are shown in Fig. 2. In general, the streams rise 152·5 to 274·5 m above sea-level and first flow through peat moorland where the water tends to have an acidic pH; the lower reaches flow through woodland and meadow. The stream beds consist of boulders, stones and gravel but, in polluted stretches, deposits of china-clay waste have resulted in the silting and in-filling of the natural river substrate. Other factors which no doubt influenced the distribution of the invertebrate fauna have been observed on the River Plym, where large quantities of sand and gravel have washed into the river over recent years from the erosion of old mine working deposits, and the discharge of zinc into a tributary of the River Fal from a china-clay bleaching process. Care was taken to isolate these associations from tabulated results of the effect of china-clay.

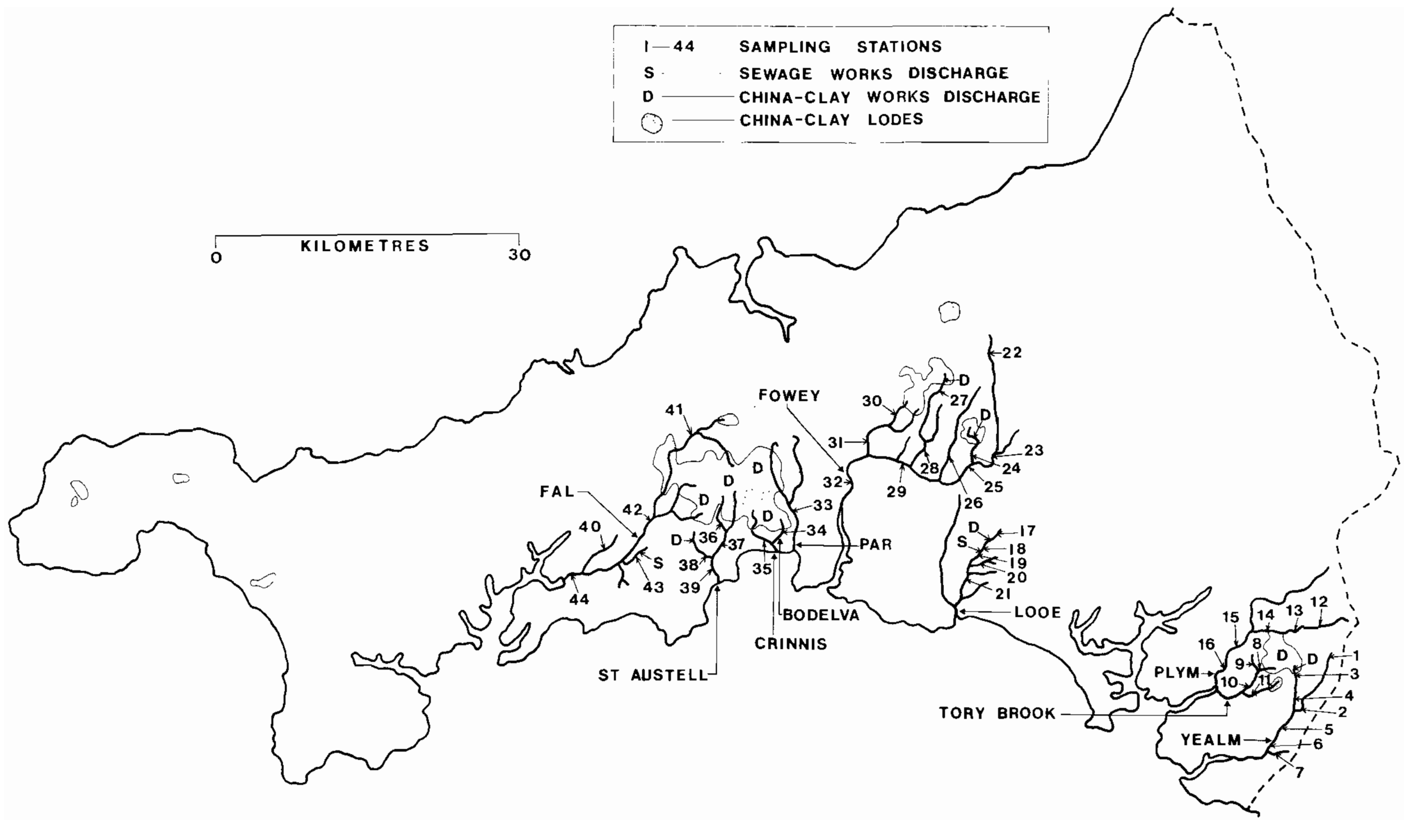

Fig. 2. Rivers and sampling stations.

Table 1 summarises suspended solids concentrations on rivers over the period 1971–72 from data supplied by the Cornwall River Authority. Concentrations range from <1 ppm from unpolluted stations to 91,268 ppm on the Polzooth tributary of the St Austell river. Fifteen samples were associated with a condition of high suspended solids concentration and particulate mineral deposition of clay wastes, eight with a reduced effect of china-clay effluent and twenty-seven with an unpolluted condition. A further three samples were associated with sewage enrichment, two with moorland drainage and one with an estuarine habitat. A further three samples (stations 29, 30 and 31) were inconclusively associated with moorland drainage, and were isolated from the tabulated results.

METHODS

A total of 59 samples was taken at 44 stations during the winter (January–February) of 1971, and summer (July–August) of 1972. Samples were taken with a closed, triangular net (64 mesh/cm^2) at the riffle sections of rivers. The bed of the river was disturbed by kicking and allowing the current to carry the dislodged material into the net (Elliott, 1971). By slowly moving upstream for a fixed period of two minutes, this technique ensured collecting a representative quantity of material over a large bottom area. Samples thus obtained were washed from the net into a collecting tray, concentrated using part of the collecting net and put into a polythene container with 4% formalin as preservative.

In the laboratory, samples were individually washed with tap-water in an Endecott sieve (140 mesh/cm^2) and then transferred to a large sorting tray (35 × 26 cm), marked out by grid lines into six equal divisions. Animals were picked out from 1 or 1–6 of the divisions according to the amount of material present, and placed in a petri dish for counting. Large animals and members of each species present in the sample were also removed and placed in a separate petri dish for identification.

RESULTS

The majority of control stations supported a rich community of submergent and emergent aquatic plants (dominated by *Potamogeton* spp., *Myriophyllum* sp. and *Ranunculus* sp.), moss (*Fontinalis* sp.) and filamentous algae (usually *Mougetia* sp.). However, where the suspended solids concentration was high (>2000 ppm) or where particulate mineral silting of the substrate had occurred, rooted vegetation was absent. Towards the end of August 1972, suspended solids concentrations were much reduced on previous levels at stations 8, 27 and 37 although the substrate remained heavily silted, and it was observed that dense growths of the alga *Stigeoclonium* sp. had developed as a blanket weed over the deposits of clay.

TABLE 2

THE RELATION BETWEEN THE INCIDENCE OF POLLUTION AND SPECIES ABUNDANCE EXPRESSED AS A PERCENTAGE OF THE TOTAL NUMBERS

Species	*Total stations* 59 *samples*	*Clean stations* 27 *samples*	*Clay-polluted* 21 *samples*
Phagocata vitta	0·48	0·53	0·72
Polycelis felina	1·68	2·25	1·09
Naididae	6·08	5·42	7·72
Tubificidae	24·53	22·11	34·23
Lumbriculus variegata	0·23	0·42	—
Eiseniella tetraedra	0·02	0·03	*P*
Piscicola geometra	*P*	*P*	—
Glossiphonia complanata	0·03	0·06	—
Erpobdella octoculata	0·19	0·30	—
Asellus aquaticus	0·06	0·06	—
Asellus meridianus	0·05	0·10	—
Gammarus pulex	0·15	0·27	—
Chloroperla torrentium	0·21	0·39	—
Leuctra fusca	1·38	1·63	—
Leuctra geniculata	0·15	0·28	—
Leuctra hippopus	0·44	0·44	0·52
Leuctra inermis	0·52	0·55	—
Leuctra moselyi	0·10	—	*P*
Leuctra nigra	0·20	0·37	—
Amphinemura sulcicollis	0·60	0·48	0·14
Protonemura meyeri	1·82	1·78	1·95
Dinocras cephalotes	0·18	*P*	—
Perla bipunctata	*P*	*P*	—
Diura bicaudata	*P*	—	—
Isoperla grammatica	0·04	0·06	—
Perlodes microcephala	1·24	0·91	2·16
Brachyptera putata	0·09	0·17	0·06
Baetis muticus	0·05	0·10	—
Baetis rhodani	13·36	11·00	20·62
Caenis macrura	0·07	0·12	—
Ecdyonurus dispar	0·55	0·06	—
Ecdyonurus venosus	0·40	0·72	0
Rhithrogena semicolorata	2·85	4·09	2·25
Ephemerella ignita	2·48	4·39	0·25
Ephemera danica	0·06	0·11	—
Paraleptophlebia submarginata	*P*	*P*	—
Siphlonurus lacustris	0·06	0·10	—
Glossosoma cf. *G. intermedium*	0·18	0·33	—
Hydropsyche instabilis	1·08	1·78	0·14
Hydroptilidae	0·18	0·06	0·55
Limnephilidae	1·58	2·23	0·68
Wormaldia subnigra	*P*	*P*	—
Polycentropus kingi	0·51	0·40	0·52
Agapetus cf. *A. ochripes*	0·13	0·24	—
Rhyacophila dorsalis	1·57	1·04	1·96
Sericostoma personatum	1·08	1·37	—
Silo cf. *S. nigricornis*	0·05	0·09	—
Chironomidae	9·95	7·14	15·18
Medetera sp.	0·13	*P*	0·48
Clinocera sp.	0·12	0·21	—
Hemerodroma sp.	1·02	0·32	0·79
Atherix sp.	0·67	1·01	0·44

P = present.

continues opposite

TABLE 2 (*continued*)

THE RELATION BETWEEN THE INCIDENCE OF POLLUTION AND SPECIES ABUNDANCE EXPRESSED AS A PERCENTAGE OF THE TOTAL NUMBERS

Species	*Total stations 59 samples*	*Clean stations 27 samples*	*Clay-polluted 21 samples*
Simuliidae	4·16	5·66	0·37
Nemotelus sp.	*P*	*P*	—
Tabanus sp.	*P*	—	*P*
Dicranota sp.	1·69	2·63	0·52
Tipula sp.	*P*	*P*	*P*
Agabus sp.	*P*	*P*	—
Hydroporus sp.	*P*	—	*P*
Oreodytes sp.	0·08	0·10	—
Elmis aenea	1·40	1·81	1·54
Limnius volckmari	4·05	3·54	4·12
Gyrinus sp.	0·20	0·37	*P*
Libellula sp.	0·05	0·10	—
Hydracarina	0·07	0·13	—
Ancylastrum fluviatile	0·40	0·41	*P*
Hydrobia jenkinsi	8·91	9·62	—
Limnaea pereger	*P*	—	*P*
Pisidium sp.	0·15	0·13	—

P = present.

Table 2 gives a list of the species found, together with their average densities, calculated from all samples. A total of 69 taxa were identified, of which 48 were at species level. One or more species of stonefly and mayfly nymphs were found at 35 stations, and this would indicate the absence of any gross or continuous pollution by organic or toxic wastes (Hawkes, 1962). The further nine stations were found to be represented either by a total absence of macro-fauna or by a low density of animals with a low species diversity. Each of these nine stations was associated with china-clay discharge causing silting of the substrate or heavy particulate suspension with consequent silting.

The relationship between habitat, mean species composition and mean density is given in Table 3. On average, control stations supported 36 times more animals

TABLE 3

THE RELATION BETWEEN HABITAT, MEAN SPECIES COMPOSITION AND MEAN DIVERSITY

Habitat	*Headstreams*		*China-clay polluted*		*China-clay affected*		*Clean (control)*		*Sewage enriched*		*Estuarine*	
Number of samples	2	2	13	15	8	8	27	27	3	3	1	1
Mean density of of animals	181		22		412		783		1513		30	
Mean species diversity		15		3		10		16		15		4
Maximum values	238	15	124	8	806	12	2384	22	2625	18	—	—
Minimum values	123	15	0	0	132	5	210	11	580	11	—	—

than clay polluted stations, and double the number of animals supported by stations on rivers receiving a reduced level of china-clay effluent. The composition of species was greater in clean rivers, moorland headstreams and stations downstream of sewage outfalls than in rivers which received china-clay discharges.

The relationship between the abundance of species and incidence of pollution is given in Table 2. The density of Naididae, Tubificidae, Chironomidae, *Baetis rhodani* and *Perlodes microcephala* increased significantly ($P < 0{\cdot}01$), whereas *Hydrobia jenkinsi, Dicranota* sp., Simuliidae, *Sericostoma personatum,* Limnephilidae, *Hydropsyche instabilis, Ephemerella ignita, Rhithrogena semicolorata, Leuctra fusca* and *Polycelis felina* were either absent or significantly reduced ($P < 0{\cdot}05$) at stations associated with china-clay waste pollution.

SEASONAL OCCURRENCE

An insight into the seasonal occurrence of some of the more common species may be gained from Table 4. In general, the differences are a reflection of life-history phenomena. The majority of animals were taken in both winter and summer collections.

TABLE 4

THE SEASONAL OCCURRENCE OF THE MORE COMMON SPECIES EXPRESSED AS A PERCENTAGE OF THE TOTAL NUMBERS

Habitat	*China-clay polluted*		*Control*	
	Winter	*Summer*	*Winter*	*Summer*
Number of samples	9	14	14	13
Polycelis felina	1·83	0·46	0·46	4·17
Oligochaeta	36·52	46·65	31·03	21·50
Baetis rhodani	23·97	17·76	12·07	9·85
Perlodes microcephala	4·68	*P*	1·44	0·53
Chironomidae	8·33	21·04	7·71	6·53
Simuliidae	0·80	—	6·88	4·34
Dicranota sp.	*P*	*P*	2·11	3·18
Hydrobia jenkinsi	—	—	8·56	10·77
Sericostoma personatum	—	—	2·20	0·45
Limnephilidae	0·95	*P*	3·43	0·94
Hydropsyche instabilis	0·30	—	2·64	0·86
Ephemerella ignita	—	0·46	1·92	7·04
Rhithrogena semicolorata	4·89	—	6·99	0·98
Leuctra fusca	—	—	—	3·38
Total others	17·73	13·63	12·56	25·66

P = present.

DISCUSSION

Turbidity and the consequent absence of plants have been suggested as the primary effect of pollution by inert solids, and the elimination of animals as only a secondary effect (Surber, 1953). High turbidity produced by finely-divided inorganic material does not, by itself, adversely affect the bottom fauna in a shallow lotic environment (Hamilton, 1961). However, the effect of settling out of solids is to destroy, or, in mild cases, to alter, the vegetation and this would produce a corresponding change in the fauna. Jones (1949, 1958) has concluded that a reason for the lack of rooted plants in the River Rheidol was the shifting nature of the bed, caused by the deposition of mine-grit, and Edwards (1969) has indicated that high silt loads in rivers through recently-accelerated soil erosion have caused a general decline in the aquatic macrophyte vegetation. Indeed, sediments falling to the stony bed of a river have a direct effect upon animals by filling-up the interstices between stones, thus depriving cryptic animals of their refuge. Percival & Whitehead (1929) have shown that the density of a faunal community is related to the amount of shelter available. Under conditions of slow flow loose sediments coat the stones and render ineffective the various hold-fast mechanisms of the stone-fauna, all of which rely on the presence of a firm surface. This would explain the reduced density of Simuliidae from clay-polluted stations (Table 2). These larvae attach themselves by means of a circlet of hooks to a silken mat spun on to stones (Hynes, 1970) and presumably are unable to establish themselves successfully on unstable clay deposits. Wu (1931) showed that the distribution of *Simulium* depended on the amount of silting permitted by the current. Similarly, clay deposition has a deleterious effect on the feeding mechanisms of the net-spinning caddis *Hydropsyche instabilis* and the carnivore *Polycelis felina*, which lays mucus strings to trap its prey. The numbers of both these species were reduced at stations polluted by clay wastes.

In such a situation, all, or most of, the typical river fauna disappears to become replaced by burrowing or tube-building forms. However, no special 'pollution fauna' develops. The survivors are river creatures consisting of a selection of the species normally found in unpolluted reaches although the surviving species may be more abundant. The increased density of Tubificidae, Naididae and Chironomidae at stations polluted by china-clay waste is certainly correlated with the increase in silt deposition. Learner *et al.* (1971) observed an abundance of naidids associated with the presence of fine solids of coal origin blocking the interstices between stones, and Hynes (1966) has noted that naidids are essentially inhabitants of soft substrata in the depositing regions of rivers. Hamilton (1961) and Nuttall (1972) found an increased density of Tubificidae and Chironomidae in rivers affected by sand deposition, and Chutter (1969) recognised that changes in the invertebrate fauna may occur according to the amount of sand and silt in the watercourse, even without the biotope being smothered.

The abundance of *Baetis rhodani* and *Perlodes microcephala* at polluted stations cannot be so clearly attributed to the effect of clay wastes. Percival & Whitehead (1929) have shown that the Baetidae are more common on loose stones than other microhabitats. Macan (1962, 1963) has pointed out that *B. rhodani* lives on the top of stones, rather than in the crevices or beneath stones, and would therefore be less affected by silting than other members of the stone fauna. In contrast to the gastropods, which were absent from clay-polluted stations, both the Baetidae and Perlodidae are essentially carnivorous (Hynes, 1970), so that an absence of encrusting algae and plant material in the river bed need not be a severe limitation on their distribution. Maitland (1962) observed large numbers of *B. rhodani* downstream of sewage works where dense silting had occurred, and noted that as the silted appearance of the substrate disappeared, the normal fauna reappeared. He concluded that 'the immediate effect of the sewage on the invertebrate fauna was due more to the effect of silt and sewage fungus than the lack of oxygen in the water'.

ACKNOWLEDGEMENT

We would like to thank Dr A. F. H. Marker, at the Freshwater Biological Association's River Laboratory, for the identification of algal samples. We are most grateful to the staff of the Cornwall River Authority who aided us in a number of ways, and for permission to publish data from records of the Authority. The opinions expressed in this paper are the writers' and do not necessarily agree with those of the Cornwall River Authority.

REFERENCES

CHUTTER, F. M. (1969). The effects of silt and sand on the invertebrate fauna of streams and rivers. *Hydrobiologia,* **34,** 57–76.
EDWARDS, D. (1969). Some effects in siltation upon aquatic macrophyte vegetation in rivers. *Hydrobiologia,* **34,** 29–37.
ELLIOTT, J. M. (1971). Some methods for the statistical analysis of samples of benthic invertebrates. *Scient. Publs Freshwat. biol. Ass.,* **25,** 126–7.
HAMILTON, J. D. (1961). The effect of sand-pit washings on a stream fauna. *Verh. int. Verein. theor. angew. Limnol.,* **14,** 435–9.
HAWKES, H. A. (1962). Biological aspects of river pollution. In *River Pollution,* 2, *Causes and effects,* ed. by L. Klein, 311–432. London, Butterworths.
HERBERT, D. W., ALABASTER, J. S., DART, M. C. and LLOYD, R. (1961). The effects of china clay wastes on trout streams. *Int. J. Air Wat. Pollut.,* **5,** 56–74.
HMSO (1948). *China clay.* Board of Trade Working Party Report, London.
HOWELL, B. R. & SHELTON, R. G. J. (1970). The effect of china clay on the bottom fauna of St Austell and Mevagissey Bays. *J. mar. biol. Ass. U.K.,* **50,** 593–607.
HUDSON, K. (1969). *The history of English china clays.* Newton Abbott, David & Charles.
HYNES, H. B. N. (1966). *The biology of polluted waters.* 3rd edn, Liverpool University Press.
HYNES, H. B. N. (1970). *The ecology of running waters.* 1st edn, Liverpool University Press.
JONES, J. R. E. (1949). An ecological study of the river Rheidol: North Cardiganshire, Wales. *J. Anim. Ecol.,* **18,** 67–88.
JONES, J. R. E. (1958). A further study of the zinc-polluted river Ystwyth. *J. Anim. Ecol.,* **27,** 1–14.
LEARNER, M. A., WILLIAMS, R., HARCUP, M. & HUGHES, B. D. (1971). A survey of the macro-fauna of the river Cynon, a polluted tributary of the river Taff (South Wales). *Freshwater Biol.,* **1,** 339–67.
MACAN, T. T. (1962). Biotic factors in running water. *Schweiz. Z. Hydrol.,* **24,** 386–407.
MACAN, T. T. (1963). *Freshwater ecology.* London, Longmans.
MAITLAND, P. S. (1962). The fauna of the river Endrick in relation to local water use. *Wat. Waste Treat. J.,* 78–86.
NUTTALL, P. M. (1972). The effect of sand deposition upon the macro-invertebrate fauna of the river Camel, Cornwall. *Freshwater Biol.,* **2,** 181–6.
PENTELOW, F. T. K. (1949). Fisheries and pollution from china-clay works. *Rep. Salm. Freshwat. Fish., Lond.,* **31.**
PERCIVAL, E. & WHITEHEAD, H. (1929). A quantitative study of the fauna of some types of streambed. *J. Ecol.,* **17,** 282–314.
SURBER, E. W. (1953). Biological effects of pollution in Michigan waters. *Sewage ind. Wastes Engng.,* **25,** 79–86.
WU, Y. F. (1931). A contribution to the biology of *Simulium. Pap. Mich. Acad. Sci.,* **13,** 543–99.