THE UNIVERSITY OF ASTON IN BIRMINGHAM

ECOLOGICAL STUDIES ON: (a) THE USE OF COLONISATION SAMPLERS IN RELATION TO BIOLOGICAL SURVEILLANCE OF RIVER WATER QUALITY; (b) THE REQUIREMENTS OF FRESHWATER GASTROPODA.

Antony John Watton Ph.D. 1982

Summary

Some of the factors affecting colonisation of a colonisation sampler, the Standard Aufwuchs Unit (S. Auf. U.) were investigated, namely immersion period, whether anchored on the bottom or suspended, and the influence of riffles.

It was concluded that a four-week immersion period was best. S. Auf. U. anchored on the bottom collected both more taxa and individuals than suspended ones. Fewer taxa but more individuals colonised S. Auf. U. in the potamon zone compared to the rhithron zone with a consequent reduction in the values of pollution indexes and diversity. It was concluded that a completely different scoring system was necessary for lowland rivers.

Macroinvertebrates colonising S. Auf. U. in simulated streams, lowland rivers and the R. Churnet reflected water quality. A variety of pollution and diversity indexes were applied to results from lowland river sites. Instead of these, it was recommended that an abbreviated species - relative abundance list be used to summarise biological data for use in lowland river surveillance.

An intensive study of gastropod populations was made in simulated streams. Lynnaea peregra increased in abundance whereas Potamopyrgus jenkinsi decreased with increasing sewage effluent concentration. No clear-cut differences in reproduction were observed.

The presence/absence of eight gastropod taxa was compared with concentrations of various pollutants in lowland rivers. On the basis of all field work it appeared that ammonia, nitrite, copper and zinc were the toxicants most likely to be detrimental to gastropods and that P. jenkinsi and Theodoxus fluviatilis were the least tolerant taxa.

96h acute toxicity tests of P. jenkinsi using ammonia and copper were carried out in a flow-through system after a variety of static range finding tests. P. jenkinsi was intolerant to both toxicants compared to reports on other taxa and the results suggested that these toxicants would affect distribution of this species in the field.

Key Words: colonisation sampler; pollution; Gastropoda; tolerance.

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by

ANTONY JOHN WATTON, B.Sc. (Leicester)

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1. INTRODUCTION

Pollution is a word which is difficult to define succinctly despite its common usage. Holdgate (1971) defines it as "something present in the wrong place, at the wrong time, in the wrong quantity". But what can be defined as wrong? Howell says that the observation of pollution depends on the observation of environmental damage. However it is difficult to define damage. "Natural" streams may show signs of "pollution". Huet (1951) found that afforestation of the Belgian Ardennes with spruce and cedar adversely affected small trout-streams. Edwards (1972) defines pollution as "the release of substances or energy to the environment by man in quantities that damage his health or resources". This implicates man as the sole cause of pollution but still retains a subjective element in the use of damage. Pollution is probably best defined in sociological rather than ecological terms. A court of law does not accept ecological damage as proving pollution. On the other hand pollution is considered to have occurred if the water's quality in relation to a specific use is impaired. Even this cannot really be considered as a clear and concise definition of pollution. Although in many cases water quality may be affected for a number of uses, in other cases it may be regarded as satisfactory for many uses but polluted for others. However, in general, the greater the pollution, the fewer uses that can be satisfied.

Pollutional effects of effluents can be broadly categorised into four areas - deoxygenation, toxicity, eutrophication and physical effects resulting from the addition of solids. The dissolved oxygen concentration is most frequently lowered by micro-organisms using up oxygen in the bio-degrading of organic wastes. In addition, reducing agents such as the ferrous ion and sulphites have a similar effect. The potential number of toxicants which can be discharged into a water course are enormous. These can broadly be divided into (1) non-metallic inorganics such as ammonia, cyanide, chlorine and pH; (2) metals; (3) non-pesticidal organic chemicals including detergents and phenols, and (4) pesticides. Of the first group, ammonia is perhaps the most common pollutant. It is present in most waters as a normal biological degradation product of proteins, although the concentrations may be very small and subsequent nitrification may occur. Probably the most common

source of ammonia is sewage effluent although large quantities can be produced by industries such as those producing coal gas, coke and fertilisers (EIFAC, 1970). The use of chlorination in sewage treatment, cooling water systems and other industrial process waters leads to the release of considerable quantities of chlorine into the aquatic environment. Other members of group (1) generally originate from industrial or mining effluents as do the metals. The metals most commonly monitored by water authorities are cadmium, chromium, copper, nickel and zinc (Hawkes, 1974). Origins of the group (3) pollutants are also frequently industrial but oil and petroleum products can get into a water course from road run-off or spills and phenolic wastes can originate from livestock dips and human and animal wastes (EIFAC, 1972). In addition to industry, pesticides run into rivers off agricultural and afforested land where a wide range of organochlorines and organophosphates have been used since the second world war for control of insect pests, weeds and fungi. Herbicides are also used in the control of weeds in water courses themselves.

It is now technologically feasible to oxidise organic wastes to a high degree so that the biochemical oxygen demand (BOD) is low and serious deoxygenation avoided. However, they will contain a high proportion of plant nutrients N and P and in rivers with little dilution these may give rise to problems with algal and weed growth (Hawkes, 1974). This problem is the one of eutrophication. Solids can be discharged into a river from sewage works, mining operations and china clay processing. In large quantities they can cause turbidity and/or silting of the river bed providing an unstable substratum.

In the past freshwater pollution has been monitored largely by physico-chemical methods as sampling is easy and rapid. Surveillance is still principally carried out by this method in Britain; in early 1981 the Severn-Trent Water Authority (STWA) had 781 minor sampling sites (sampled quarterly), 513 routine sites (sampled monthly), 81 key sites (sampled fortnightly) and 23 special sites (sampled weekly)(Fenlon and Young, 1981). However, chemical surveillance has drawbacks in that water chemistry cannot be strictly defined. Natural river waters differ considerably both

qualitatively and quantitatively in chemical composition. Furthermore such methods cannot detect all pollution and short-term discharges may be released between successive samplings as the sampling frequencies given above clearly imply. Only automatic chemical monitoring stations which sample every 15 mins. can reasonably be expected to detect such discharges but these are expensive to run and monitor for only a limited number of variables. On the other hand a biological community can integrate the effect of a discharge if it is sufficiently long. Surprisingly little field work has been carried out on this aspect of pollution. Changes in the water which adversely affect the amenities of a river are associated with changes in the stream biota. The principal problem with biological surveillance is that it is difficult to detect what specific aspect or aspects of a pollutant affect particular species in a community and how an effect on one species indirectly affects another. This creates problems in finding which pollutant is at a detrimental level. Another problem with biological surveillance is that it usually does not provide information quickly so that possible action such as closing down a water intake works for domestic use can be taken.

Biocoenotic responses of indicator value induced by polluting discharges are summarised by Hawkes (1978) as:

(1) appearance or disappearance of individual species of indicator value,
(2) reduction in the number of taxa,
(3) changes in the populations of individual species,
(4) changes in the proportional species composition of the community,
(5) changes in the degree of heterotrophy-autotrophy and,
(6) changes in the degree of productivity.

Benthic communities best reflect pollution since only they are characteristic of a particular biotope. Fish, for example, can swim away from pollution. Alabaster (1964) showed that several species of fish kept in an artificial channel avoided water that was too hot for them. Of the benthic organisms macroinvertebrates have the advantage over algae in that they are more easily identified,

and over macrophytes in having more species and being more widely present in rivers. The larger porportion of work on indicator organisms in the past has been based on correlating the occurrence and abundance of organisms in rivers with concomitant environmental conditions. The value of using such organisms would be greatly enhanced by knowledge of their specific ecological requirements - it was on this premise that the work on gastropods was initially based.

According to Hawkes (1978) two types of situation should be recognised in the application of biological surveillance. In the monitoring of river water quality in relation to a specific use at a given point or the effect of a specific discharge on a river seasonal ecological surveys will provide the necessary data. However, when a whole river system is being monitored the vast amount of data generated requires simplification for comparisons between sites to become feasible. Basically, two types of index - pollution indexes and diversity indexes - have been developed to this end.

Pollution indexes measure the response of key species or taxa to pollution. The saprobien system of Kolkwitz and Marsson (1902, 1908, 1909) was probably the earliest example of these and has since undergone several numerical developments (Knopp, 1954, 1955; Pantle and Buck, 1955a, b; Zelinka and Marvan, 1961). Some pollution indexes such as the Trent Biotic Index (Woodiwiss, 1964), Lothians Index (Graham, 1964, 1965) and the B.M.W.P. Score (Dept. of Environment, 1979) are purely qualitative weighting different taxa according to their presumed tolerance towards pollution but taking no account of abundance. On the other hand the Chandler Score (Chandler, 1970) also takes account of relative abundance.

Diversity describes the variety of species present (Southwood, 1978) and, in contrast to pollution indexes, diversity indexes do not weight species in relation to their tolerance of pollution. Diversity can be classified into three types according to Whittaker (1972):

(1) α - diversity: the diversity of species within a community or habitat,

(2) β - diversity: a measure of the size and extent of change in species along a gradient from one habitat to others.

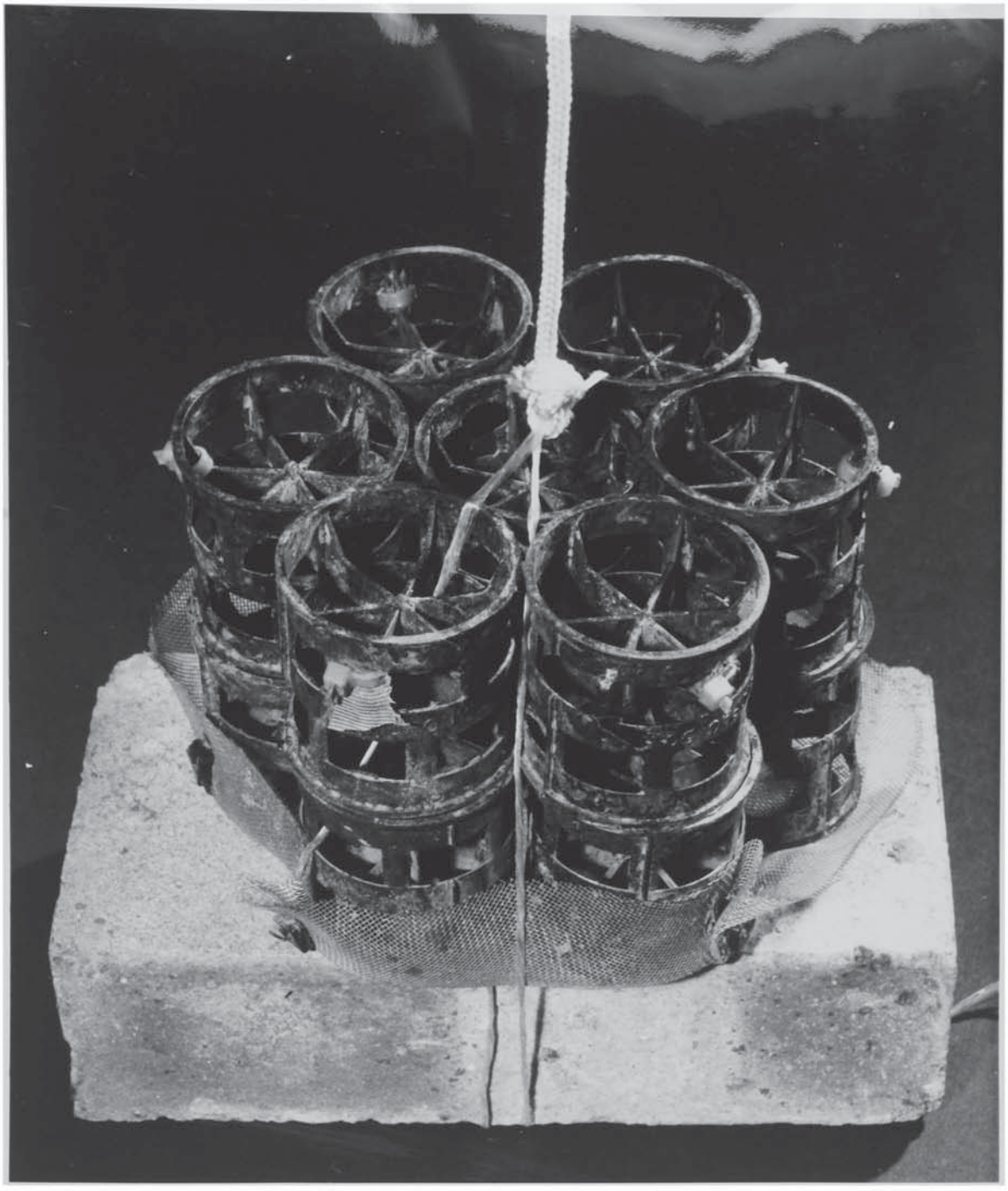
(3) γ - diversity: the richness in species of a range of habitats in a geographical area.

The first two have both been applied to biological surveillance indexes of the second alternatively being known as similarity indexes which, when methods of sorting such as the widely acclaimed principal component analysis (Southwood, 1978) are applied, allow similar samples to form groups while separating off from less similar samples. Diversity indexes fall into two categories: those based on a model where the equalitility of the species/abundance relationship will be a reflection of an underlying distribution, e.g. Logarithmic series (Fisher et al., 1943) and Prestons Index (1948) and non-parametric indexes which make no assumptions about any underlying distribution. Of these the Shannon-Weaver Index (1947) has been by far the most regularly used index in freshwater biology. Their use in monitoring pollution relies on a discharge placing stress on a community and thereby reducing its diversity. However organic pollution may alleviate stress at least for some species.

Biological surveillance of lowland rivers with no riffles creates major problems in sampling. It is difficult to sample the natural substratum - grabs and air lifts are among the methods used - and samples tend to have low diversity. Hynes (1960) states that apart from a few carnivores such as the alderfly Sialis only scavengers are present. In warm weather, because of the sluggish current, the dissolved oxygen content may fall to a low level at night when photosynthesis is not occurring and this may account for the absence of some species. However, the unstable nature of the substratum is probably largely responsible for the low diversity. Certainly many macroinvertebrates such as ecdyonurids cling to or shelter under stones. For such rivers the use of colonisation samplers has proved useful. These are structures which are not a natural part of the river but are immersed in it for a period of time during which colonisation takes place. They have been used for a variety of purposes in the past in both upland and lowland rivers with the majority of studies on the former. Shelford and Eddy (1929), Moon (1935) and Wene and Wickliff (1940) were among the first to use colonisation samplers and since then a wide range of

structures including baskets of rubble (Henson, 1955; Mason et al., 1967; Hilsenoff, 1969), multiplate samples (Hester and Dendy, 1962; Arthur and Horning, 1970), conservation webbing (Simmons and Winfield, 1971) and filter bed media (Girton, 1980) have been used. The advantages of colonisation samplers are that they provide a stable substrate, uniformity is assured and they are easily retrieveable. Disadvantages are that they are subject to loss or vandalism, they only record the community that develops during the immersion period, thereby reducing the value of the collected community as indicators of prior conditions (EPA, 1973), and they provide a restricted selective microhabitat so that the colonising community is unrepresentative of the natural one. However the final disadvantage does not apply to their use in biological surveillance as the prime aim is to yield comparative biological data relating to the incidence of pollution and not to sample the natural benthic community. It is because of the ability of colonisation samplers to collect more species than the natural substratum and their ability to yield comparative data in biological surveillance that they were adopted as the sampling method for lowland rivers in this research.

Colonisation samplers have been used in the biological monitoring of pollution for some time, but rarely in lowland rivers. A variety of substances have been tried, including brush boxes (Scott, 1958), rock-filled samplers (Henson, 1965; Mason et al., 1967) and multiplate samplers (Arthur and Horning, 1969). Girton (1980) compared the use of several different colonisation samplers in different water qualities in artificial channels at Checkley, Staffs. and in the R. Tean upstream and downstream of Checkley sewage works. He came to the conclusion that a sampler consisting of 14 Biopac 50E, more generally used as filter-bed media, clipped together above a mesh base was best on the basis of practicability for field use and because it was more readily standardised (Girton and Hawkes, 1979). This later became called the Standard Aufwuchs Unit (S.Auf.U.) (Plate 1.1) since it was colonised by the aufwuchs community. On the basis of this recommendation the S.Auf.U. was adopted in preference to other colonisation samplers for further study on the viability of its use in biological surveillance.



1.1 : THE STANDARD AUF/UCHS UNIT (S.AUF.U.) ATTACHED TO AN ANCHORING HOUSE BLOCK

Community response is theoretically the most informative response to pollution in biological surveillance, but it is very complex. The community is greatly influenced by the natural physico-chemical properties of a river. Indirect effects of pollution can manifest themselves and these may vary from site to site because of differences in the "natural" community. Consequently surveys of populations of given species, often referred to as indicator species, are easier in practice but the choice of species is critical. Hellawell (1978) lists the following cirteria as possibly being helpful in the selection of an indicator species:

(1) economic importance as a resource, nuisance or pest,
(2) abundant data on their physiology and ecology,
(3) cosmopolitan distribution,
(4) ready accumulation of pollutants in a way that reliably reflects their environmental levels,
(5) ease of sampling,
(6) occupation of similar niches throughout their range,
(7) limited genetic variability,
(8) ease of culture in the laboratory and
(9) numerical abundance at some sites.

The Gastropoda were selected for this research on the basis of several of the above criteria. They have a cosmopolitan distribution in lowland rivers as can be deduced from "the Atlas of the Non-Marine Mollusca of the British Isles" (Kerney, 1976) and are a common coloniser of S.Auf.U. They readily accumulate heavy metals, are numerically abundant at some sites and are easy to keep in the laboratory.

A review of past work reveals that the value of gastropods as indicator species varies greatly with the type of pollution and the species. Snails are generally sensitive to heavy metals, particularly zinc, copper, mercury and silver (Wurtz, 1962). The R. Ystwyth in Wales was still devoid of molluscs 35 years after the termination of lead mining. The water was still carrying $0.7mgl^{-1}$ of zinc. High pH can be detrimental to snails as can chloride wastes and organic molecules such as petroleum, naphthenic acids, alkyl benzene sulphonate as pesticides (Harman, 1974). Organotins and organoleads are very

toxic to snails and their eggs (Muirhead-Thomson, 1971). In contrast snails can generally tolerate very low oxygen levels. Pulmonates can use atmospheric air and exist in anaerobic wastes for prolonged periods of time. Prosobranchs require oxygen in the water but have been collected from environments with very little. Physa spp. and Planorbis spp. are tolerant of organic pollution (Ortman, 1909; Baker, 1922) but they can be equally common in unpolluted waters and consequently are of little value as indicator organisms. On the other hand Potamopyrgus jenkinsi cannot tolerate much organic pollution (Hawkes, 1977) and may be a valuable indicator organism if its erratic population changes can be understood. Other species such as Pleurocera spp. and Goniobasis spp. (Ortman, 1909) and Bithynia tentaculata (Baker, 1922) have also been reported to be eliminated by organic pollution. It may be concluded that as pollution can severely affect the gastropod biota they have potential as indicator organisms. The problem is unravelling when, how and why they are affected. The aim of the work on gastropods was an attempt to get close to answering some of these questions.

2. LITERATURE REVIEW

2.1 Factors affecting Colonisation of Colonisation Samplers

Colonisation samplers have been used for many years, those of Shelford and Eddy (1929), Moon (1935) and Wene and Wickliff (1940) are among the earliest described. The aim of this section, however, is not to describe the history or structure of such samplers but the factors affecting their colonisation which are pertinent to this thesis. Girton (1980) provides an excellent review of the history and structure of colonisation samplers.

2.1.1 Immersion Period

Recommended immersion periods where the recommendation does not exceed or equal the duration of the experiment are shown in Table 2.1.1. It is clear that recommended immersion times for embedded samplers tend to be less than those for other samplers; values for embedded samplers range from 3d (Townsend and Hildrew, 1976) to 4 weeks (Moon, 1935) while those for others range from 3d (Bournaud et al., 1978) to 7 weeks (Dickson and Cairns, 1972). Many other investigators have recommended immersion times beyond or equal to the duration of their experiments (Wene and Wickliff, 1940; Mason et al., 1967; Ulfstrand, 1968; Coleman and Hynes, 1970; Crisp and Gledhill, 1970; Mason et al., 1973; Nilsen and Larimore, 1973; Ulfstrand et al., 1974; Allan, 1975; Voshell and Simmons, 1977). It appears to be widely held that 4 to 6 weeks immersion is necessary (Girton, 1980).

Numbers of taxa collected on colonisation samplers have been found to increase for as long as 8 weeks (Mason et al., 1967; Shaw and Minshall, 1978; Girton, 1980). At the other end of the scale, Wise and Mollis (1979) obtained peak numbers of taxa after 9d but it was only a 19d experiment. Most workers appear to have obtained peak numbers of taxa around 3 to 5 weeks, e.g. Dickson and Cairns (1972), Pearson and Jones (1975), Stauffer et al., (1976), Roby et al. (1978), Girton (1980). Pearson and Jones (1975) found that numbers of individuals increased for 115 d and then declined. Mason et al. (1973) and Girton (1980) obtained continuous increases throughout 8 week experiments. In contrast, Roby et al. (1978) obtained peak

AUTHOR ↓	TYPE OF SAMPLER →	RECOMMENDED IMMERSION PERIOD		
		Embedded	Other	
Townsend & Mildrew (1976)		3d		
Bournaud et al. (1978)			3d	Basket
Waters (1964)		4-10d		
Pearson & Jones (1975)		10-15d		
Lapchin (1977)		2wk		
Roby et al. (1978)			2-4wk	Basket
Nilsson & Sjostrom (1977)		17d		
Stauffer et al. (1976)			22d	Basket
Loon (1935)		4wk		
Girton (1980)			4wk	S.Auf.U.
Woodiwiss (1978)			4-6wk	Basket
I.P.A. (1973)			6wk	All
Simmons & Winfield (1971)			6wk	Basket
Cover & Harrel (1976)			6wk	Multiplate
Dickson & Cairns (1972)			7wk	Webbing

TABLE 2.1.1 : RECOMMENDED IMMERSION PERIODS FOR COLONISATION SAMPLERS QUOTED IN THE LITERATURE WHERE THE RECOMMENDATION DOES NOT EXCEED THE DURATION OF THE EXPERIMENT ON WHICH IT IS BASED

numbers after only 2-4 weeks. They discovered that time was a less important factor influencing numbers than the quantity of detritus which accounted for over 50% of the variation in numbers. Many workers have obtained peak numbers of individuals between 4 and 8 weeks, e.g. Dickson and Cairns (1972), Nilsen and Larimore (1973), Meier et al. (1979), Shaw and Minshall (1980), Girton (1980). Previous work on S.Auf.U. by Girton (1980) showed that numbers of Asellus aquaticus, Corophium curvispinum, Bithynia tentaculata and Polycelis tenuis tended to increase throughout the 8 week immersion period whereas other taxa appeared to reach peak numbers beforehand. Crangonyx pseudogracilis peaked after 4 weeks, Leptoceridae after 5 weeks and Gammarus pulex, Caenis moesta, Coleoptera and Viviparus viviparus after 6 weeks. Further taxa such as Ephemerella ignita, Chironomini and Orthocladiinae showed erratic changes in abundance.

No trend in variation in either numbers of taxa or individuals between replicate samplers with immersion time appears to exist (Dickson and Cairns, 1972; Pearson and Jones, 1975; Meier et al., 1979; Shaw and Minshall, 1980). Various workers have found very different trends with diversity. Mason et al. (1973) and Stauffer et al. (1976) obtained a decrease throughout whereas Cover and Harrell (1978) and Meier et al. (1979) found diversity to increase with time in general. Roby et al. obtained peak diversity at 2-4 weeks followed by fluctuations while Dickson and Cairns (1972) found no observable trend at all.

Several attempts to fit models to describe colonisation of colonisation samplers have been made. Perhaps the one that has received the most attention is the equilibrium model of MacArthur and Wilson (1963) which was developed to describe the colonisation of island faunas and the attainment of stable communities thereon. Cairns et al. (1969) first tested this model by studying colonisation of polyurethane substrata by freshwater protozoans. Dickson and Cairns (1972), Stauffer et al. (1976) and Girton (1980) all subsequently discovered that their macroinvertebrate data fitted the model reasonably well. In contrast, Sheldon (1977) preferred an empirical power function to describe colonisation of his spoiling trays. However, he was attempting to describe colonisation by individuals not taxa like the previous three authors.

2.1.2 Depth of Sampler

The U.S. Environmental Protection Agency (EPA) in 1973 recommended that in deeper waters colonisation samplers should be suspended above the river bed 1-2m below the surface. Mason et al. (1973) agreed with this stating that placement of samplers on the bottom resulted in a loss of control of the substrate composition essential for comparing communities collected by samples at stations subjected to differing water quality. In contrast, Radford and Hartland-Rowe (1971) recommended natural substrates buried in the river bed as they thought that sampling in the water column did not adequately sample the benthos and biased the collections for algal grazers. Using limestone filled substrates suspended in the water column Mason et al. (1973) found no significant difference in total numbers of individuals with depth but that the occurrence of some species was related to depth, e.g. the caddisfly Cyrnellus fraternus was more abundant at depths exceeding 1-2m whereas the mayfly Stenonema interpunctatum was more abundant in samplers near the surface. Numbers of taxa collected varied little with depth. In a similar experiment using log substrates Nilsen and Larimore (1973) found the standing crop collected to decline 54cm depth>11cm>96cm (near the bottom), the first two depths having significantly greater values than the latter. Total numbers of individuals declined 54cm>96cm>11cm but differences were not significant. However hydropsychids and arachnids were significantly more abundant at 54cm than 96cm, Nais elinguis, chironomid larvae and Taeniopteryx nivalis were significantly more abundant near the bottom and Aeolosoma near the surface. Crossman and Cairns (1974) found surface samplers to be selective for certain groups of aquatic insects such as beetles, mayflies and caddises with a consequent reduction in diversity. Therefore they recommended the use of benthic colonisation samplers which also collected Gastropoda and Diptera.

2.1.3 Colonisation by Drift

Drift is regarded as the most important source of colonisers of an area of river bed (Bishop and Hynes, 1969; Brusven, 1970; Williams and Hynes, 1976). Williams and Hynes (1976) found that drift accounted for 41.4% of the fauna recolonising a denuded stream substrate whereas aerial sources, movement up from the substrate

and upstream migration accounted for 28.2%, 19.1% and 18.2% of the colonisers respectively. The distance that invertebrates drift is short (Waters, 1965; Elliott, 1967; McLay, 1970). Elliott (1971) found that the relationship between the catch in a drift net (Y_x) and the distance from the release point (Xm) was well described by the regression equation:

$$Y_x = Ae^{-RX}$$

where R is the constant relative rate of return of invertebrates to the bottom of the stream, and A is the number of invertebrates released. The mean drift distance of a wide range of taxa was found to be less than 10m. Elliott (1967 and 1971) and Minshall and Winger (1968) found a correlation between flow rate and quantity of drift. Stoneburner and Smock (1979) also found drift to be correlated with benthic density in complete contrast to Elliott (1967).

Chironomids are a very important component of drift (Waters, 1969; Williams and Hynes, 1976). Other important taxa in the drift are Ephemoptera (Waters, 1969; Williams and Hynes, 1976; Stoneburner and Smock, 1979), Coleoptera (Williams and Hynes, 1976; Stoneburner and Smock, 1979), Plecoptera and other Diptera (Stoneburner and Smock, 1979). Elliott (1967) observed that cased Trichoptera, Ancylus fluviatilis and triclads rarely drifted.

Colonisation of artificial substrates by drifting invertebrates has been remarked upon by Elliott (1967), Wise and Mollis (1979) and Girton (1980). Elliott (1967) observed that the more frequent members of the drift settled on trays immersed in deep pools. Girton (1980) found that many colonisers of S.Auf.U. downstream of nearby riffles were riffle species which he presumed had drifted downstream to them. He observed many of the species colonising S.Auf.U. as far as 1.13 km downstream of a riffle. Wise and Mollis (1979) collected fewer individuals on downstream baskets in a blocked experiment and suggested that this was because drift was a major source of insect colonisers and that this declined over the study area.

2.2 Gastropod Biology and Ecology

2.2.1 Classification

Members of the class Gastropoda belong to the phylum Mollusca. Morton and Yonge (1964) describe gastropods as asymmetrical with a well developed and, at least primitively, a broad flattened foot. The shell is of one piece and coiled in a helical spiral at least in the young stages. The visceropallium has undergone a torsion of 180^{o}. There are three subclasses within the class namely the Prosobranchia, the Opisthobranchia and the Pulmonata.

The Prosobranchia are generally aquatic. The visceral mass retains a pronounced torsion. The spiral shell is closed by an operculum and the mantle cavity primitively contains two ctendia (or gills) but this is usually reduced to one. The Opisthobranchia are marine and hermaphrodite, the shell is reduced becoming internal and finally disappearing with an accompanying tendency towards detorsion. The Pulmonata are also hermaphrodite. They have no ctendia but obtain oxygen via the walls of the mantle cavity which is vascularised as a lung. It has a small contractile pallial aperture. The shell and visceral mass is primitively spiral but may assume a slug-like from. There is no operculum (Morton and Yonge, 1964). The prosobranchs and the pulmonates are the two groups to be found in freshwater. Prosobranchs are believed to have colonised fresh-water from an ancestral littoral home (Fretter and Graham, 1962) while pulmonates probably recolonised water from land (Hunter, 1964). The freshwater Pulmonata are primarily air-breathing and show varying degrees of adaptation to aquatic life. (Hunter 1953, 1957).

2.2.2 Life-Cycles, Reproduction and Growth

In temperate regions most of the smaller prosobranchs have an annual life-cyle and a single breeding season (Hunter, 1964). However, several larger species have been shown to live longer. Boycott (1936), Lilly (1953) and Dussart (1979) all remark that *Bithynia tentaculata* live for more than one year and Van Cleave and Leaderer (1932) state that *Viviparus contectoides* females live for 3 years. Dussart (1979) found maximum production of *B. tentaculata* offspring in August, the young snails grew slowly through

the winter and spring until they reached 5mm in length in the following August. They continued growing for a second year, reaching 10mm. In May there were 3 overlapping generations. Schafer (1953) states that B. tentaculata lives for more than 2 years.

In contrast to B. tentaculata, Viviparus spp. and Potamopyrgus jenkinsi bear live young. These are retained in a "marsupial brood pouch" (Gillespie, 1969). Van Cleave and Leaderer(1932) found that these "marsupial" young were present in Viviparis contectoides in New York in late Summer and that these were born between March and June the following year over a period of time. There was a rapid initial increase in height which slowed during later life. De Bernadi et al (1976) observed a slow demographic turnover in V. ater in Northern Italy so that the population was dominated by adults throughout the year. Fecundity reached a maximum in April. Young were produced principally from March to July. Growth was continuous and higher in the warmer months.

P. jenkinsi is an annual species (Boycott, 1936). It exhibits parthenogenesis (Boycott, 1919). Gametogenesis is ameiotic with a single maturation division (Fretter and Graham, 1964). Females dominate the populations (Hubendick, 1950).

All British freshwater pulmonates are annuals (Boycott, 1936). Oviposition and hatching of young is particularly evident in the spring and early summer months (McCraw, 1970). Growth is most rapid from spring to late fall. During winter, months may pass with little or no change (except possibly for deaths) in population structure (Duncan, 1959; McCraw, 1961). After the rise in temperature following winter, growth resumes, often resulting in a quickly changing demographic structure and sometimes even an almost complete population turnover (Hunter, 1953; DeWitt, 1955; Geldiay, 1956; McCraw, 1961).

Dussart (1979) found the life cycle of Lymnaea peregra to differ with water chemistry. In hard waters offspring were produced in early spring and early summer. Before the onset of winter, the snails produced in summer grew rapidly to 8 mm in height, but growth was slower over winter. In the following spring growth was resumed and a few of this generation might survive a second winter so that

in May 3 generations are present. In contrast, in soft waters there was little overlap in generations. Young produced in July and August remained relatively small before being joined by more offspring in November. This overwintering population grew rapidly over the March-August period and produced young in summer and early autumn. The adults did not appear to survive the winter.

Growth and reproduction in both Physa gyrina and P. integra were found to be greatest in spring by Clampitt (1970). DeWitt (1955) found that a few individuals born in spring became sexually mature by late summer and oviposited as long as the temperature remained above a critical point. Clampitt (1970) observed high mortality during the summer among certain groups of snails.

As mentioned in Section 2.2.1the majority of prosobranchs are unisexual and these populations are often dominated by females. In contrast, all pulmonates are hermaphrodite and it is usually said that this has been secondarily derived from the unisexual condition but this may not be true since there is some evidence for regarding the hermaphrodite state as the primitive one, particularly in the Mollusca (Fretter and Graham, 1964).

The curve of growth as a function of age is commonly, but not invariably, sigmoid. However the plateau in wild populations may be lost because of death (Wilbur and Owen, 1964). The decreased growth rate in older individuals may be a function of size as well as age.

2.2.3 Molluscan Habitats/"Natural" Distribution

Boycott (1936) stated that there were 62 freshwater species of molluscs incorporating 26 bivalves and 36 gastropods of which 10 were operculates and 26 were pulmonates. In addition he said there were 4 operculates and 2 pulmonates occurring in estuarine habitats. He defined a good molluscan habitat as one which is large, has a slow flow of clean water, is warm, has a fair but not excessive growth of rooted plants, and contains hard water. Similarly, Hubendick (1958) deduced that a rich gastropod fauna was, on average, associated with deciduous forest, cultivated land, clay soils, calcareous areas abundant vegetation and eutrophic conditions. He said that the

optimum conditions for different species were roughly similar but that the tolerable extremes often differed slightly.

The British distribution of the gastropods studied most closely in this thesis roughly conform to the following according to the "Atlas of the Non-Marine Mollusca of the British Isles" (Kerney, 1976):-

(a) Lymnaea peregra is found over the whole of Britain.

(b) Physa fontinalis is found over all of Britain except for the north of Scotland and it is less widely distributed in the north, the south-west and Wales than elsewhere.

(c) Bithynia tentaculata is widely distributed south of Cumbria except for Wales and the south-west. According to Lilly (1953) it is not found north of Stirling.

(d) Potamopyrgus jenkinsi is found over all of Britain but is less widely distributed in Scotland.

(e) Theodoxus fluviatilis is found south of Cumbria except for Wales and the south-west.

(f) Viviparus viviparus is similarly distributed to T. fluviatilis but there are fewer records of its occurrence in the south.

The distribution of P. jenkinsi is particularly interesting. It has spread to brackish waters and later freshwaters in recent times in many north-west European countries (Bondensen and Kaiser, 1949). The first reliable find in Europe was made in 1859 in brackish water in the Thames estuary (Hubendick, 1950). In the 1880's it suddenly appeared in several brackish water localities along the British south and east coasts and in Ireland (Hubendick, 1950). This sudden appearance in new localities is quite characteristic of the species (Bondensen and Kaiser, 1949). Considering all occurrences of the species in Britain there can hardly be any doubt that it has immigrated several times from brackish to fresh water (Hubendick, 1950). Despite its brackish origins in Europe freshwater individuals cannot tolerate high salinities (Johansen, 1918; Adam, 1942; Bondensen and Kaiser, 1949).

The following "natural" factors have been said to affect the distribution of gastropods:-

2.2.3.1 Hardness/Alkalinity - 20mgl^{-1} of calcium is the critical figure below which a number of mollusc species do not occur (Boycott, 1936). Other species can tolerate lower calcium levels but Boycott is doubtful whether there are any true calcifuges. Species found where there are particularly low levels of calcium include Lymnaea glabra (Boycott, 1936), L. peregra found in <1mgl^{-1} by Boycott et al. (1932) and in <3mgl^{-1} by Macan (1950), Ancylus fluviatilis found in 1-2mgl^{-1} (Boycott, 1936) and Bulinus globosus, Lymnaea natalensis and Gyraulus spp. all found in ca. 2mgl^{-1} by Williams (1970a). In contrast, Biomphalaria pfefferi (Williams, 1970a) and B. tentaculata (Dussart, 1976) are restricted to medium and hard waters and Macan (1977) lists 15 British species as hard water ones including T. fluviatilis and V. viviparus. Young (1975) found that caged individuals of the latter did not survive in the calcium poor Llyn Nantille.

The results of laboratory studies on hard-water snails are somewhat conflicting. Harrison et al. (1970) working with B. pfefferi and Williams (1970b) working with the same species and B. globosus obtained greater population increases in medium waters than in soft or hard ones. Harrison et al. (1970) found poor survivorship in soft waters. Williams (1970b) found that the r_m values obtained for B. pfefferi were directly proportional to the relative density of this species at the different hardnesses in the field. Young (1975), on the other hand, found that hard-water species were tolerant of soft water in the laboratory. Five out of 6 species, Segmentina complanata being the exception, completed a life-cycle in the laboratory at 3-7mg Ca l^{-1}.

2.2.3.2 Substratum and Sediment - gastropod distribution appears to be greatly affected by substratum. Okland (1969) found that more gastropod species in Norway were found on a substratum of gyttja than on clay or stones. Harman (1972) obtained a good correlation ($r = 0.79$) between mollusc diversity and substrate diversity. Among the species he studied he found Ferrisia rivularis and Spirodon carinata exclusively on clear cobbles while Lymnaea columella,

Gyraulus parvus and Amnicola limosa were usually found on autochthonous organic matter, Lymnaea humilis on eulittoral silt and detritus and Campeloma decisum on littoral silt and detritus. Dussart (1979) found that the distributions of B. tentaculata and G. albus were correlated with stone and mud substrata respectively. In laboratory experiments Vaidya (1979) discovered that both Melania scabra and Viviparus bengalensis preferred sand to stone even when food was supplied only with the latter. In conclusion it can be said that different species appear to prefer or occur on different substrata.

2.2.3.3 Vegetation - This is connected with the above section in that vegetation offers a stable substratum to organisms. Macrophytes also influence the chemical microclimate through their metabolism, provide shade and provide protection from running water (Hubendick, 1958). Boycott (1936) states that a good supply of vegetation is favourable to molluscs whereas a thick growth is harmful while Okland (1969) found more gastropod species where the vegetation was rich both quantitatively and qualitatively than elsewhere. Alsterberg (1930) only found snails in shallow areas where there was enough light for vegetation.

2.2.3.4 Water Movement - The primary ecological effects of water movement are both positive (aeration) and negative (mechanical function) (Hubendick, 1958). Okland (1969) found most species of snail on average where both small and medium sized waves were present and the smallest number of species where there was heavy wave action.

2.2.3.5 Other factors - Okland (1969) found in his study of snail habitats in Norwegian lakes that the number of species increased with decreasing elevation above sea level and increasing pH up to 8.8, and also that more species were found where the surrounding land was cultivated and where the water was turbid than elsewhere. In contrast, Boycott (1936) stated that clear water was best for molluscs. Hubendick (1958) said that insulation was important since light was required for the production of algae which provide a food source for many species. He also thought temperature to be an important factor limiting snail distribution. He said that exceptionally the temperature in small ponds might rise to such a degree at times that snails could not survive. However, he thought long periods of low temperature retarding reproduction, egg development and growth to be more important. Physa gyrina requires

at least 10-12°C for oviposition (DeWitt, 1955). Effects of temperature under laboratory conditions are discussed in Section 2.2.7.6.

2.2.4 The Effects of Pollution on Gastropod Distribution

2.2.4.1 Metals - Molluscs are widely regarded as being intolerant of metals (Wurtz and Bridges, 1961; Patrick et al., 1969; Dickson et al., 1974: Canton and Slooff, 1977; Murphy, 1978). Indeed Wurtz (1962) regarded them as the least tolerant animal group in freshwater. High levels of metals occur naturally in thermal springs but are more often associated with industrial effluents of which mining is a very important source (Whitton and Say, 1975). Pollution from mines in Wales have had a particularly severe effect on the distribution of molluscs. They were absent from the Lower Rheidol during 1919-21 when filterable lead concentrations of 0.2-0.5 mgl^{-1} were recorded (Laurie and Jones, 1938) and had not returned to the R. Ystwyth forty years after mining operations causing zinc pollution had ceased (Jones, 1940). Zinc levels of 0.9-1.2 mgl^{-1} were recorded at the Ystwyth sites. Similarly, pollution from a base metal mine into the Northwest Miramichi River eliminated molluscs for 12 miles (Wurtz, 1962). Total zinc, lead and copper values reached a maximum of 0.57 mgl^{-1} 9 miles downstream and molluscs had still not returned 4 months later when the metals were present at <0.2 mgl^{-1}. In the R. Churnet molluscs were eliminated when copper works effluent raised the copper level of the river to 1 mgl^{-1}. They were not found in the next 11 miles of river to the confluence with the Dove, where the copper content had fallen to 0.6 mgl^{-1} (Pentelow and Butcher, 1938; Butcher, 1946, 1955). Extence (1978a) and Brown (1980) have both accounted for the absence of P. jenkinsi from sites on the R. Roding, Essex and R. Holme, Yorkshire respectively to heavy metal levels. Extence (1978a) found that it was eliminated from 3 sites after the drought summer of 1976. Levels of copper, lead, zinc and particularly nickel in the water rose drastically at this time reaching maxima of 0.36 mgl^{-1}, 0.58mgl^{-1}, 0.93mgl^{-1}, and 2.78 mgl^{-1} respectively, P. jenkinsi remained present at a cleaner upstream site during this period. Brown (1980) observed that caged P. jenkinsi were killed in the R. Holme when levels of chromium and copper as low as 0.05 mgl^{-1} and 0.01 mgl^{-1} respectively and 0.033 mgl^{-1} and 0.02 mgl^{-1} respectively were present. Levels of

other metals were similar at sites where caged P. jenkinsi survived.

2.2.4.2 Oxygen - In complete contrast to their susceptibility to metals, molluscs are widely regarded as being tolerant of low dissolved oxygen (D.O.) levels. The lung breathing pulmonates are regarded as more tolerant than the prosobranchs by Hawkes (1977). However, the latter have been frequently collected from very low oxygen tensions. Viviparus georgianus, Amnicola limosa and Valvata tricarinata were found in <2 mgl^{-1} D.O. by Harman and Berg (1971). Horst (1971) found the same three species in 0.4 mgl^{-1} D.O., Richardson (1925) found Campeloma decisum in 0.5 mgl^{-1} D.O. and Sutter and Moore (1972) found C. decisum and Goniobasis virginica in anaerobic waters. Sulphite depresses D.O. levels as well as sewage; Bartsch and Churchill (1949) found Campeloma integrum to resist high concentrations of waste sulphite liquor in the Flambeau River, Wisconsin. Low D.O. values should not be a problem for pulmonates where they can gain access to the water surface since Chaetum (1934) observed them to consistently surface for atmospheric oxygen.

Hynes (1959) noted that P. jenkinsi was usually the first mollusc to be affected by organic pollution and, despite the examples of prosobranchs being recovered from water with very low D.O's, attributed this to an intolerance of low D.O. There are quite a few examples of organic pollution eliminating this species. It disappeared from the R. Ivel below the junction with the sewage contaminated R. Hiz and the species was also eliminated from the R. Tees on the entry of sewage effluent (Butcher et al., 1937). Extence (1978a) found it to be absent from 3 sites below organic input from Brockhouse Brook into the R. Roding in late 1976 and 1977 while it was present above the brook.

2.2.4.3 Suspended Solids - As gastropods "natural" distribution is affected by substratum (see Section 2.2.3.2) it is not surprising that suspended solid discharges can have a severe effect on their distribution since their sedimentation will alter the nature of the substratum. Greenfield and Ireland (1978) found that deposits of coal-waste eliminated molluscs in the Burnley area. Extence (1978b) reported that Ancylus fluviatilis was eliminated from a site on the R. Roding by sediment originating from motorway roadworks.

2.2.4.4 Temperature - Hawkes (1979) says that molluscs generally appear to be favoured by elevated temperatures up to 30°C. Elevated temperatures can increase reproductive capacity (Shiff and Garnett, 1967; Mattice, 1975). Harman (1974) reported that Ferrissia spp. and Gyraulus spp. were eliminated from the Delaware River where cooling water from a generating station elevated the August 1959 temperatures from 80°F to >105°F. Physa spp. were not eliminated. This effect was purely due to temperature as physical oxygenation of the water occurred. Temperature can have indirect effects by lowering the D.O. content while increasing oxygen consumption and by lowering resistance to toxicants (Harman, 1974).

2.2.4.5 pH - Morrison (1932) reported that molluscs were found in natural waters of pH 5.6-8.3. In agreement with this Scwartz and Meredith (1962) said that a pH <5.5. was deleterious to most benthic organisms. Harman (1974) stated that molluscs do not occur where the pH exceeds 9.0. He found the majority of gastropods in and around New York to occur at pH 7.0-8.4. Both acid and alkaline pollution can be detrimental to molluscs. This is well illustrated by two discharges into the Clinch River, Virginia. In 1967 a fly-ash pond collapsed at Carbo releasing 130×10^6 gallons of mainly calcium hydroxide slurry of pH 12.0-12.7 into the river making up 40% of the flow (Cairns et al., 1971). This eliminated snails for 11.7 miles below the outfall. There was no recovery in the following 2 years. In 1970 sulphuric acid from the Appalachian Power Plant was spilt into the river with the result that molluscs were eliminated for 11.7 miles (Cairns et al., 1971).

2.2.4.6 Pesticides - In general, pesticides impinging on rivers only make a periodic impact, producing high concentrations for a short period of time (Muirhead-Thomson, 1971). Tolerance varies greatly with the pesticide - organotins and organoleads are very toxic to snails and their eggs whereas they are relatively resistant to DDT (Muirhead-Thomson, 1971). Crossland (1967) eliminated Biomphalaria pfefferi from experimental canals in Tanzania with as little as 0.01 mgl^{-1} n-tritylmorpholine. On the other hand Hanson (1952) found that treating 15 acres of lentic water with chlordane at 1 lb $acre^{-1}$ had no apparent effect on the snail populations.

2.2.5 "Natural" Factors affecting Gastropod Populations and Communities

A multitude of biotic and abiotic environmental factors affect populations and in consequence the community. One factor of importance to freshwater gastropod populations appears to be competition. Competition for food has been cited as an important factor in intraspecific competition. In a field study Eisenberg (1966) concluded that population density in Lymnaea elodes was regulated through the adjustment of adult fecundity. In a further study Eisenberg (1969) found a significant negative relationship between snail density and mean size, total numbers of eggs, and numbers of eggs in a mass in unfed pens in a pool while this relationship was overcome by feeding. Similarly, Turner (1927) and Lagrange (1957) respectively concluded that stunting in to Lymnaea species and fecundity in Australorbis glabratus were due to intense food competition. In a laboratory study Wright (1960) concluded that pheromones were primarily responsible for increased mortality and reduced fecundity in L. elodes since water from tanks overcrowded with snails exerted similar effects to direct overcrowding. However, as growth of grouped individuals was lower and infant mortality higher among grouped snails, even when the water was regularly changed, he also proposed a direct crowding effect.

Food also appears to be an important factor in interspecific competition. Underwood (1978) proposed, on the basis of results from field experiments using cages, that the supply of benthic, microalgal food was the limiting resource for which three species of intertidal prosobranchs competed. Madsen and Frandsen (1979) and Madsen (1979) found that, in the laboratory, competition with Helisoma duryi clearly inhibited the growth and reproduction of Biomphalaria camerunensis. Madsen (1979) concluded that competition for food was at least partly responsible because partitioning of the experimental aquaria reduced the effects. In contrast, competition for ions has been proposed as the interaction between Helisoma spp. and Biomphalaria alexandrina and Bulinus truncatus (El-Hassan, 1974). Field evidence from naturally occurring gastropods of interspecific competition has been gained by Fenchel (1975a, b) who found that co-existing Hydrobia ulvae and H. ventrosa had different reproductive periods and average shell lengths whereas in allopatric populations these were similar.

Gillespie (1969) found that mortality rates in four species of molluscs showed a general correlation with temperature but he concluded that the principal temperature-correlated cause was probably predation. Many species of fish feed on gastropods, and so do some leeches (Elliott and Macan, 1979).

Vegetated areas were found to yield more snails than other areas in the English Lake District by Macan (1950). Pip and Stewart (1976) found that t-tests revealed a significant tendency for snails of 13 species out of 13 to occur in vegetated areas. Physa gyrina and Lymnaea stagnalis were associated specifically with Potamogeton pectinatus and P. richardsonii while other species showed no specific association. Heywood and Edwards (1962) observed that the population of P. jenkinsi was much higher in the summer of 1959 when much weed was present than in the following year. However only 30% of the snails were present on plants.

2.2.6 The Effects of Pollution on Gastropod Populations and Communities

Organic pollution tends to result in Lymnaea spp. and Physa spp. replacing a more diverse gastropod community (Hawkes, 1979). Gaufin and Tarzwell (1956) discovered that Physa integra was several hundred times as abundant in polluted stretches of Lytte Creek, Ohio. Extence (1978a) noted that prosobranch populations and, in particular, P. jenkinsi decreased downstream of an input of organic effluent into the R. Roding. Lymnaea peregra dominated the mollusc community at two of these downstream riffles. In Nigeria it was found that Bulinus globusus tended to replace other gastropods in polluted pools (Hira and Muller, 1966). Harman (1968a) discovered that a similar replacement of one gastropod species by another in the Oswego River basin, New York was due to competition. He found that pleurocerids were able to withstand moderately polluted conditions but that they could not compete successfully with Bithynia tentaculata under such conditions while the two taxa co-existed with stable populations in unpolluted areas. He concluded (Harman, 1968b) that the ability of B. tentaculata to filter-feed, thereby utilising suspended organic matter gave it a competitive advantage over pleurocerids in enriched waters. Extence (1978b) found that suspended solid matter had almost an opposite effect on L. peregra populations which were reduced downstream of a discharge

of sand from a motorway building site in the R. Roding, presumably because of the resulting change in substratum.

2.2.7 Toxicity and Some Other Tolerance Tests on Gastropods

The purpose of a toxicity test is to determine whether a potential toxicant is harmful to life and, if so, to find the relationship between toxicant concentration and its effect on organisms (Hunter, 1978). Most toxicity tests on freshwater gastropods have been in static conditions and of 96h or less in duration (Murphy, 1978). Partial or full life-cycle tests have been described for Campeloma decisum and Physa integra (Arthur, 1970; Arthur and Leonard, 1970), Helisoma trivolis (Flannagan, 1974), Lymnaea stagnalis (Canton and Slooff, 1977) and Lymnaea palustris (Borgmann et al., 1978). The predominance of acute lethal tests applies to a much wider group of taxa (Buikeima and Benfield, 1979). The authors also discovered that over 50% of the studies in the preceding 15 yrs. incorporated neither life history nor life-cycle information in the experimental design. They state that this information is essential so that the sensitivity of the organism to toxicants can be maximised. According to them one of the best examples of a toxicity test is that of Fremling (1975) who included in his design organisms of definite age, appropriate light conditions, a proper substrate which allowed the Hexagenia nymphs to burrow, and a water current.

2.2.7.1 Heavy Metals - Toxicity tests on metals should preferably be carried out under flow-through conditions as metals tend to adsorb to the surfaces of test vessels and are also accumulated by the animals themselves, causing a marked reduction in the nominal concentrations during the course of a static test (Warnick and Bell, 1969). Toxicity of the metal depends on the form it is present as. Andrew et al. (1977) found that copper toxicity to Daphnia magna was clearly related to the concentrations of the ionic species Cu^{2+}, $CuOH^{+}$ and $Cu_2(OH)_2^{2+}$. Copper in cationic form has also been found to be the toxic form to fish (Pagenkopf et al., 1974; Waiwood and Beamish, 1978). Only a very small part of the total soluble copper is in toxic form (Stiff, 1971). Burrows (1977) also states that only some forms of aluminium are toxic.

A factor which influences concentrations of ionic species is hardness; Tabata (1969), Stiff (1971) and Pagenkopf et al. (1974)

have indicated that the bicarbonate alkalinity usually associated with hard waters may reduce toxicity through the formation of non-toxic carbonate complexes or precipitates. Cairns and Scheier (1958) found that the 96h LC50 for P. heterostropha was 0.79-1.27 mgl^{-1} zinc at 20°C in soft water and 2.66-5.57 mgl^{-1} in hard water. Wurtz and Bridges (1961) and Wurtz (1962) noted similar effects with zinc on the same species and Wurtz (1962) found that increasing hardness from 20 to 100 mgl^{-1} $CaCO_3$ increased the 96h LC50 for Helisoma campanulatum from 3.85 to 13.4 mgl^{-1} zinc at 55°F.

Cairns et al. (1978) discovered that increasing the temperature increased the toxicity of copper, chromium and zinc to Nitocris sp. Similarly, Gupta et al. (1981) found the 96h LC50's for Viviparus bengalensis to be decreased from 0.39 to 0.06 mgl^{-1} copper by raising the temperature from 20.3 to 32.5°C. In contrast, Wurtz (1962) obtained a reduction in zinc toxicity to P. heterostropha and H. campanulatum with increasing temperature. More different results were obtained by Cairns and Scheier (1958) who found that increasing the temperature from 20 to 30°C had little effect on toxicity of zinc to P. heterostropha.

Using 48h and 96h LC50's as the criteria, a review of Murphy (1978) seems to indicate that toxicity to gastropods decreases copper>mercury> cadmium>zinc>chromium>nickel. Work by Borgmann et al. (1978) and Spehar et al. (1978) indicate that lead is highly toxic.

96h LC50's for gastropods as low as 0.013 mgl^{-1} copper have been reported (Wurtz, 1962). This value was obtained for young individuals of P. heterostropha whereas adults gave the higher value of 0.069 mgl^{-1}. Values of a similar order to this have been obtained for various species by Howard et al. (1964), Arthur and Leonard (1970), Extence (1978a) and Gupta et al. (1981). On the other hand, 96h LC50's as high as 1.7 mgl^{-1} for Campeloma decisum and 0.9 mgl^{-1} for Amnicola sp. have been recorded by Arthur and Leonard (1970) and Rehwoldt et al. (1973) respectively. Ravera (1977) found embryos of Biomphalara glabrata to be more resistant than adults. Cheng and Sullivan (1977) concluded that exposure to copper results in a disruption of osmoregulation in B. glabrata and that it is quite possible that this disruption is responsible for the molluscicidal effect of copper.

Very little work has been carried out on the toxicity of mercury to freshwater macroinvertebrates. Rehwoldt et al. (1973) found the 96h LC50 for Amnicola sp. to be 0.08 mgl^{-1} inorganic mercury. The same authors obtained a 96h LC50 of 3.8 mgl^{-1} for cadmium. Wier and Walter (1976) and Ravera (1977) found rather lower levels of cadmium to be toxic and so did Spehar et al. (1978) who obtained a 28d LC50 of 0.0104 mgl^{-1} for P. integra. This system differed from all those above in being of flow-through design. It emphasises the need for toxicity tests of longer duration requested by Buikema and Benfield (1979) in that the 7d LC50 of 0.114 mgl^{-1} cadmium was much higher than the 28d figure. A sublethal effect, reproductive impairment, was demonstrated by Wier and Walter (1976) who found that 48h exposure to 1.8 mgl^{-1} had such an effect.

Patrick et al. (1969) and Rehwoldt et al. (1973) obtained strikingly different 96h LC50's for P. heterostropha and Amnicola sp. respectively in waters of similar hardness spiked with zinc. The latter obtained a value of 14.0 mgl^{-1} and the former 0.79-1.27 mgl^{-1}. Values obtained by Cairns and Scheier (1958), Wurtz and Bridges (1961) and Wurtz (1962) for P. heterostropha and H. campanulatum are towards the lower end of this range. Patrick et al. (1969) also obtained a comparatively high 96h LC50 of 17.3 mgl^{-1} chromium for P. heterostropha. In contrast, Cairns et al. (1978) calculated a 48h LC50 of 0.80 mgl^{-1} for Nitrocris sp. at 25°C. The value at 5°C was much higher. Sublethal effects of chromium have been demonstrated by Dowden and Bennett (1965), who found that 24 or 48h exposure to 0.17-0.22 mgl^{-1} chromium caused a 50% reduction in hatching of Lymnaea spp. eggs, and Ravera (1977) who found that 1.4 mgl^{-1} chromium reduced fertility of B. glabrata to about 1/3 that of the controls and that development time increased with increasing chromium concentration.

Tests on the toxicity of nickel and lead to gastropods are limited. Rehwoldt et al. (1973) obtained a 96h LC50 of 14.3 mgl^{-1} nickel for adult Amnicola sp. and Extence (1978a) obtained a value of 4.4 mgl^{-1} for P. jenkinsi. The latter also found that concentrations of nickel >0.1 mgl^{-1} reduced growth and inhibited reproduction.

Using a flow-through system Borgmann et al. (1978) demonstrated that 0.019-0.036 mgl^{-1} lead reduced the long-term survival of

Lymnaea palustris. In contrast, another flow-through study by Spehar et al. (1978) showed that 0.565 mgl^{-1} lead did not significantly reduce the survival of P. gyrina over 28d. Borgmann et al. (1978) also found that 0.036 mgl^{-1} lead halved the biomass production rate in L. palustris.

2.2.7.2 Ammonia - The toxicity of ammonia to aquatic organisms has been attributed to the NH_3 species (Chipman, 1934; Wuhrmann et al., 1947; Wuhrmann and Woker, 1948); the NH_4^+ species is considered nontoxic, or significantly less toxic (Tabata, 1962). These two forms exist in equilibrium with one another thus:

$$NH_2 + nH_2O \rightleftharpoons NH_3\ nH_2O \rightleftharpoons NH_4^+ + OH^- + (n-1)H_2O.$$

The concentration of NH_3 is dependent on a number of factors of which pH and temperature are the most important (Emerson et al., 1975). The proportion of NH_3 increases with both increasing pH and temperature. Very little work has been done on the toxicity of ammonia to invertebrates except for Daphnia magna. Patrick et al. (1969) obtained a 96h LC50 of 90 mgl^{-1} total ammonia for P. heterostropha Dowden and Bennett (1965) found 96h exposure to 70 mgl^{-1} to reduce hatching of Lymnaea spp. eggs by 50%. Thomas et al. (1976) found that growth enhancement of B. glabrata occurred up to 50 mgl^{-1} total ammonia but that inhibition occurred once optimum levels were exceeded; inhibition was found to occur above 0.0435 and 2.455 mgl^{-1} free NH_3 in the two culture waters used.

2.2.7.3 Synthetic Organic Pollutants - A review of Murphy (1978) reveals that invertebrate toxicity tests on insecticides have been largely restricted to the Arthropoda which is not surprising since this is the group they were designed to control. Bluzat and Seuge (1979) showed that L. stagnalis was considerably more tolerant to three insecticides, namely lindane, fenthion and carbaryl than Gammarus pulex and two insect species. Lindane affected fertility and embryogenesis at sublethal levels (2 mgl^{-1}). In contrast, Canton and Slooff (1977) found L. stagnalis to be the most sensitive organism to α-HCH, another insecticide, of 5 species, including Daphnia, tested. An inverse relationship between egg production and concentration was obtained and the EC50 estimated as 0.065 mgl^{-1} by combining inhibition of egg production and embryo mortality.

However, in view of their involvement in the transmission of bilharziasis, other pesticides have been developed as molluscicides. The major molluscicide is N-tritylmorpholine or frescon according to Muirhead-Thomson (1971) who states that molluscicidal concentrations range from 0.1-0.5 mgl^{-1} for 1h exposure to 0.01-0.05 mgl^{-1} for 24h exposure.

Little work has been carried out on the effects of detergents; Murphy (1978) reports lethal values ranging from a 48h LC50 of <4.6 mgl^{-1} for Goniobasis sp. (Dolan and Hendricks, 1976) to a 96h LC50 of 27.0 mgl^{-1} for Campeloma decisum (Arthur, 1970). Gastropods appear to be tolerant of phenols 96h LC50's typically being >300 mgl^{-1} (Murphy, 1978). Alekseyev and Antipin (1976) concluded that tolerance to phenols increased fish<crustaceans<tolerant insects< worms<molluscs<highly tolerant insects<arachnids.

2.2.7.4 pH - This can affect the biota directly, through altering the equilibria of pollutants or by reducing the bicarbonate buffering capacity of the water (Murphy, 1978). Bryant (1939) found that L. peregra tolerated pH 5.9-8.6, L. stagnalis pH 6.0-8.0, L. truncatula 6.4-ca. 8.0 and L. palustris ca. 6.2-ca. 8.0. However the borate buffer he used has been found to be toxic by Thomas et al. (1976) and this probably depressed the upper limits. Bell and Nebeker (1969), Bell (1971)and Gaufin (1973) report rather lower pH tolerances for other invertebrates.

2.2.7.5 Dissolved Oxygen (D.O.) - Surber and Bessey (1974) found molluscs to be considerably more tolerant of low D.O. values than other taxa. Pleurocerids survived 12h at 0.5 mgl^{-1}. Munro Fox and Taylor (1954) discovered that in 29d experiments at 18-21^{o}C 4% oxygen saturation (equivalent to 0.5 mgl^{-1} D.O.) was detrimental to the survival of adult L. stagnalis and young Planorbis corneus but not to adult P. corneus. Extence (1978a) observed that 20% saturation at 18^{o}C (equivalent to 1.9 mgl^{-1} D.O.) resulted in adverse sublethal effects in P. jenkinsi. Periodic low D.O. greatly reduces the 96h LC50's for P. heterostropha towards naphthenic acid and potassium cyanide using animals obtained from a high D.O. environment (Cairns and Scheier, 1957). This is not so, however, for snails from deep ponds with a low D.O.

2.2.7.6 Temperature - Testing 7 species of gastropod Van der Schalie and Berry (1973) found that none could be cultivated at temperatures much below 12°C and none reproduced above 30°C. P. gyrina tolerated the widest temperature range, surviving sometimes at >30°C. Lymnaeids and Amnicola sp. reproduced and thrived best at 19-22°C while planorbids preferred warmer water (22-25°). Mattice (1975) discovered that L. obrussa died within 3 weeks at 30°C. Even mortality of the tropical B. pfefferi increases at 27°C (Shiff and Garnett, 1967). Increasing temperature up to the deleterious level increases reproduction (Shiff and Garnett, 1967; Mattice, 1975).

3. FACTORS AFFECTING COLONISATION OF THE STANDARD AUFWUCHS UNIT (S.AUF.U.)

3.0.1. Introduction

Since colonisation samplers such as the S.Auf.U. are not part of the natural substratum, colonisation has to occur before removal in a sampling programme. Colonisation is affected by a multitude of factors including immersion period, drift, migration, natural substratum and topography. A review of the relevant literature on these topics was included in the previous chapter. It is likely that some of these factors have a profound effect on the use of S.Auf.U. in biological surveillance, the purpose for which it was developed, by influencing the numbers of taxa and individuals colonising the sampler. Three potentially important factors affecting the use of S.Auf.U. were investigated:-

(1) the influence of immersion period,
(2) the location of S.Auf.U. - whether it was preferable to locate the unit on the river bed or suspend it above it, and
(3) the proximity of riffles as a source of potential drift.

In previous work on S.Auf.U. Girton (Dept. of Env., 1979) concluded that a four week immersion period was optimal on grounds of effectiveness and practicability. These experiments were performed on depositing stretches of rhithron zones. However, as Girton and Hawkes (1979) concluded that the S.Auf.U. was of greatest value in lowland rivers with no nearby riffles, this work was repeated on potamon rivers.

All previous work on S.Auf.U. has involved anchoring them to the river bed. However, many workers with other colonisation samplers, e.g. Arthur and Horning (1970), Dickson and Cairns (1972), Nilsen and Larimore (1973), have suspended them above the river bed. Indeed EPA (1973) recommends that in deeper rivers colonisation samplers are suspended 1-2m below the surface. A problem with samplers anchored to the river bed is silting up. Roby et al. (1978) found that accumulated detritus was the major factor influencing the

number of colonisers of a sampler consisting of porcelain balls. On the other hand, suspension could preclude access to the sampler of some non-swimming invertebrates. In order to assess the relative value of benthic and suspended S.Auf.U. a comparison of sampling using these two methods was carried out on rhithron and potamon zones.

Riffles tend to be richer in macrofauna than depositing stretches so drift or migration from nearby riffles could affect the composition of the S.Auf.U. colonisers. Girton (1980) found evidence of this in previous work on S.Auf.U. In biological surveillance such colonisation could affect comparisons between sites masking the effects of water quality. Therefore a detailed study on S.Auf.U. colonisation in the rhithron-potamon transition zone was carried out.

3.1 THE INFLUENCE OF IMMERSION PERIOD ON S.AUF.U. COLONISATION

3.1.1 Site Description

Immersion period experiments were carried out at two sites - Saxons Lode on the R. Severn and Great Comberton on the R. Avon (Grid. Refs. SO 864391 and SO 953426 respectively)(Fig. 5.2). Saxons Lode was 40 km below the lowermost riffle in the R. Severn at Ribbesford. Several large tributaries with riffles input below this but there were no major inputs within 14 km upstream of Saxons Lode. The substratum was fine, being composed of heavy clay and mud for most of the year (STWA, 1979a). No permanent macrophytes were present although drifting Myriophyllum sp. was collected from time to time. In contrast, the R. Avon at Great Comberton was rich in vegetation - this site being chosen to see if the presence of macrophytes affected colonisation. The macrophytes present were Phragmites communis, Sparganium erectum, S. emersum, Potamogeton pectinatus, Nuphar lutea and Schoenoplectus lacustris. The substratum here was slightly coarser being composed of a silt-sand mixture. The river was not a true potamon river having regular weirs until it joined the Severn at Tewkesbury. No true riffles, however, were present below Stratford and the nearest upstream weir to Great Comberton was 7 km away at Pershore. No major stream inputs into the Avon occurred within 8 km of the site.

3.1.2 Methods

Two runs were made at Saxons Lode and one at Great Comberton. The two runs at the former took place between 9th August and 18th October 1979 and 24th April and June 1980 to take account of seasonal variation. The single run at Great Comberton occurred between 24th April and 22nd May after which the experiment was prematurely terminated owing to loss from vandalism.

At Saxons Lode, S.Auf.U. were anchored 3m to 4m offshore in 1 to 1.5m of water whereas at Great Comberton they were 2m to 3m offshore and in 2 to 2.5m of water. At least 2m separated each S.Auf.U.

At both sites, S.Auf.U. were anchored by house bricks in three groups of 10 within which samplers were located so as not to interfere with direct drift to other samplers. Polystyrene floats were used to mark the samplers. After each immersion period one S.Auf.U. from each block was removed, the choice being made by using random numbers. Hence there was a randomised block design. On the first run at Saxons Lode, S.Auf.U. were removed after 7, 14, 28, 42, 56 and 70 days while on the second run they were removed weekly for 7 weeks. At Great Comberton S.Auf.U. were lifted weekly for 4 weeks.

Immediately on removal S.Auf.U. were separated from their anchors and placed in separate bowls. Animals were removed in the field and taken back to the laboratory in plastic jars where most samples were studied while fresh although a few were first preserved in 4%. formalin. All macroinvertebrates were counted except for Hydracarina and Naididae which were lost in preservation. Sub-sampling was only necessary for Corophium curvispinum where 1/4 subsamples were sometimes taken by counting the number of animals in four diagonal squares of a 16-square counting tray.

Physicochemical sampling of both sites was carried out at four-week intervals. Variables measured were:-

temperature
dissolved oxygen (Winkler Method)
5-day B.O.D. (unsuppressed)
chloride
pH
alkalinity
total, calcium and magnesium hardnesses (Schwarzenbach Method)
ammoniacal nitrogen ($N\text{-}NH_3$)
nitrogenous nitrate ($N\text{-}NO_3$)) by Technicon auto-analyser
orthophosphate (as $P\text{-}PO_4$)

Shannon-Weaver (1947) and Simpson's (1949) diversity indexes were calculated using totals for 3 S.Auf.U. for each immersion period. So too were two coefficients of variation, s^2 and $s^2/\bar{x}$, for the numbers of taxa and individuals of all species.

Differences in the total numbers of taxa and individuals at Saxons Lode between different immersion periods were tested for statistical significance using two-way parametric analyses of variance (anovar) incorporating breakdown of the treatment sums of squares into linear, quadratic and cubic components by the method of orthogonal polynomial analysis. This method is described in Ridgman (1975) p. 101-108. Differences between the three blocks of S.Auf.U. were also taken into account.

A problem that often arises with studies of benthic invertebrates is that their contagious distribution results in the variance being dependent on the mean and consequently, parametric significance tests tend to give too many significant results (Elliott, 1972). In this study the distribution of taxa between S.Auf.U. was not contagious ($s^2 < \bar{x}$) and, although the distribution of total individuals was, the variance was largely independent of the mean. The latter was indicated by a low value of r^2, the amount of variation accounted for by the regression line, for the plot of log s^2 on log $\bar{x}$. In contrast, the distribution of individuals of most taxa between S.Auf.U. was contagious and the variance was dependent on the mean. Therefore differences in the abundance of the more frequently recorded taxa between different immersion periods were tested for significance using the non-parametric Kruskal-Wallis anovar. This method is described in Siegel (1956) p.**184 - 192**.

During the second run at Saxons Lode anovar was also applied to three four-week S.Auf.U. immersions which overlapped with the main immersion period experiment to see if there were any significant seasonal changes in taxa or individuals. A one-way parametric anovar was carried out on the total numbers of taxa and individuals whereas, as before, the Kruskal-Wallis anovar was applied to the abundances of specific taxa.

Finally colonisation and extinction rates in terms of taxa per day were calculated for individual S.Auf.U. for each immersion interval. Colonising taxa were defined as the sum of previously unrecorded and recolonising taxa. A two-way parametric anovar with breakdown of the treatments into polynomials was applied to see if and how colonisation and extinction rates varied significantly with immersion time.

Hence the fit to the MacArthur-Wilson equilibrium model (1963) (see Section 2.1.1) was tested.

3.1.3 Results and Discussion

Physicochemical data is displayed in Appendix Table 9.1, raw biological data in Appendix Tables 8.1 to 8.4 and anovar tables in Appendix Tables 10.1 and 10.2. Physicochemical variables remained relatively stable for the duration of the experiments.

Both the numbers of taxa and individuals of all species excluding worms at Saxons Lode changed significantly with immersion period while there were no significant seasonal changes to wholly account for them (Table 3.1.1). During the first run the lines best fit were linear increases in the numbers of both taxa and individuals whereas in the second run quadratic curves provided the best fit (Figure 3.1.1). There were no significant differences between blocks (Table 3.1.1).

The number of taxa on 3 S.Auf.U. at Saxons Lode peaked after 21-28 days, after which there was a slight fall (Fig. 3.1.2, Table 3.1.2). Similarly, the mean number of taxa per S.Auf.U. tended to reach an asymptote after ca. 28 days (Table 3.1.2). However, the lines of best fit produced a different impression: during the first run no maxima was achieved whereas in the second run a peak was achieved after 35-42 days (Fig. 3.1.1). Girton (1980) also obtained peak numbers of taxa of 3 S.Auf.U. after 28 days in one of his runs at Bewdley (R. Severn) but in another run numbers continued to increase throughout the study period which is similar to many previous studies on other colonisation samplers (Mason et al., 1973; Meier et al., 1979; Shaw and Minshall, 1980). The location of the latter two of these studies in riffles, where the number of taxa available for colonisation is greater, may be important here. In contrast, Wise and Mollis (1979) found the number of taxa colonising stone baskets to peak within 19 days.

The number of taxa in the early weeks was greater at Gt. Comberton than Saxons Lode (Table 3.1.2); the presence of nearby macrophytes as a source of colonisation may have been responsible.

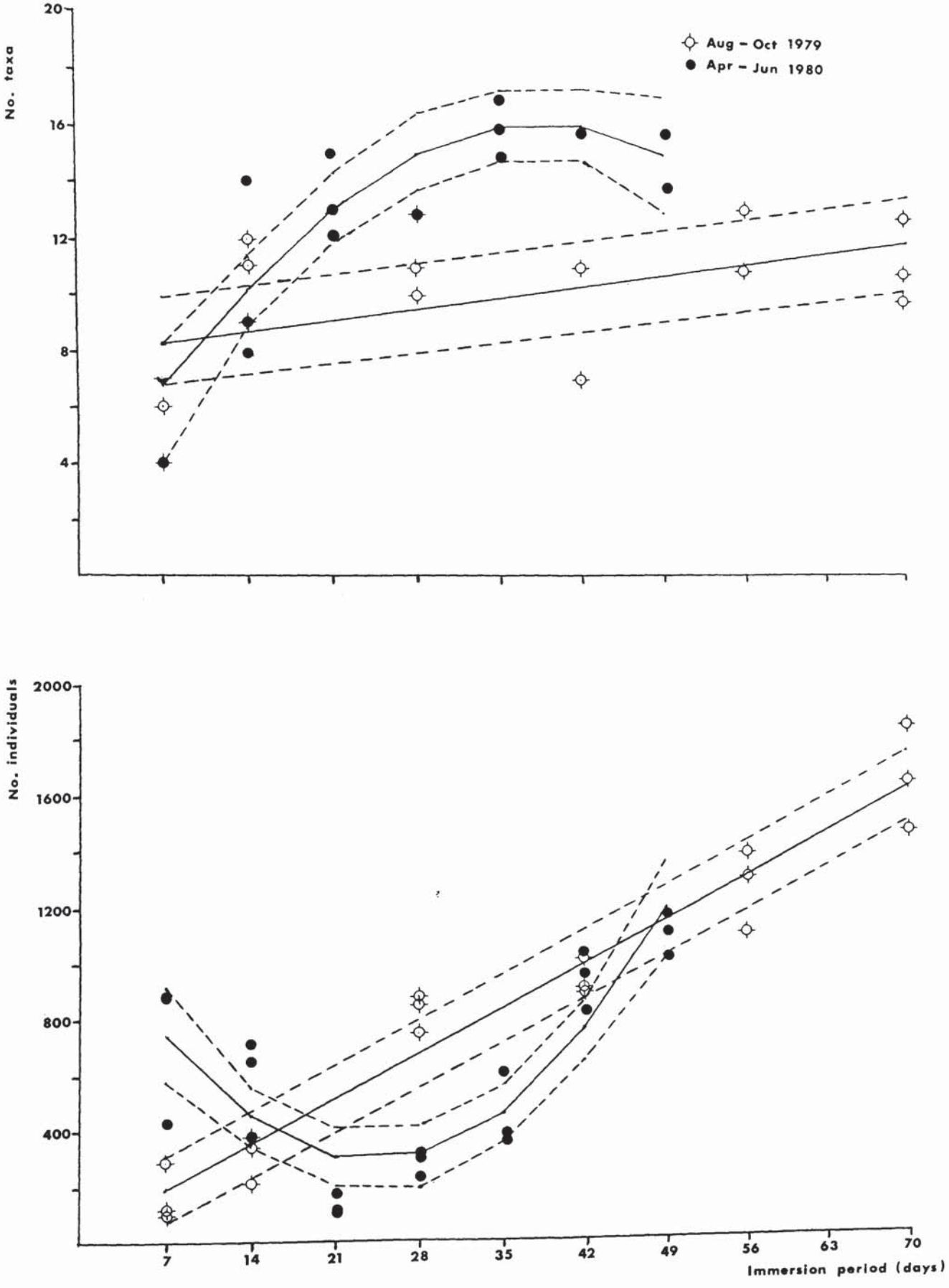


FIGURE 3.1.1 : LINES OF BEST FIT FOR THE INFLUENCE OF IMMERSION PERIOD ON THE NUMBERS OF TAXA AND INDIVIDUALS COLONISING SINGLE S.AUF.U. AT SAXONS LODE

SOURCE OF VARIATION → / TREATMENT EFFECT →	F			
	Immersion Period			Blocks
	Linear	Quadratic	Cubic	
Taxa				
Run 1	9.85*	3.64	4.58	1.27
Run 2	54.00***	17.43**	0.14	0.37
Seasonal Effects	3.49	0.48	-	-
Individuals				
Run 1	256.21***	0.95	2.47	0.01
Run 2	19.90**	58.36***	1.91	0.25
Seasonal Effects	0.52	0.32	-	-

TABLE **3.1.1** : ANOVAR INCORPORATING BREAKDOWN INTO ORTHOGONAL POLYNOMIALS (WITH SIGNIFICANCE LEVELS) ON THE EFFECT OF IMMERSION PERIOD ON THE TOTAL NUMBERS OF TAXA AND INDIVIDUALS COLLECTED ON KAUFU AT ALL SCALE.

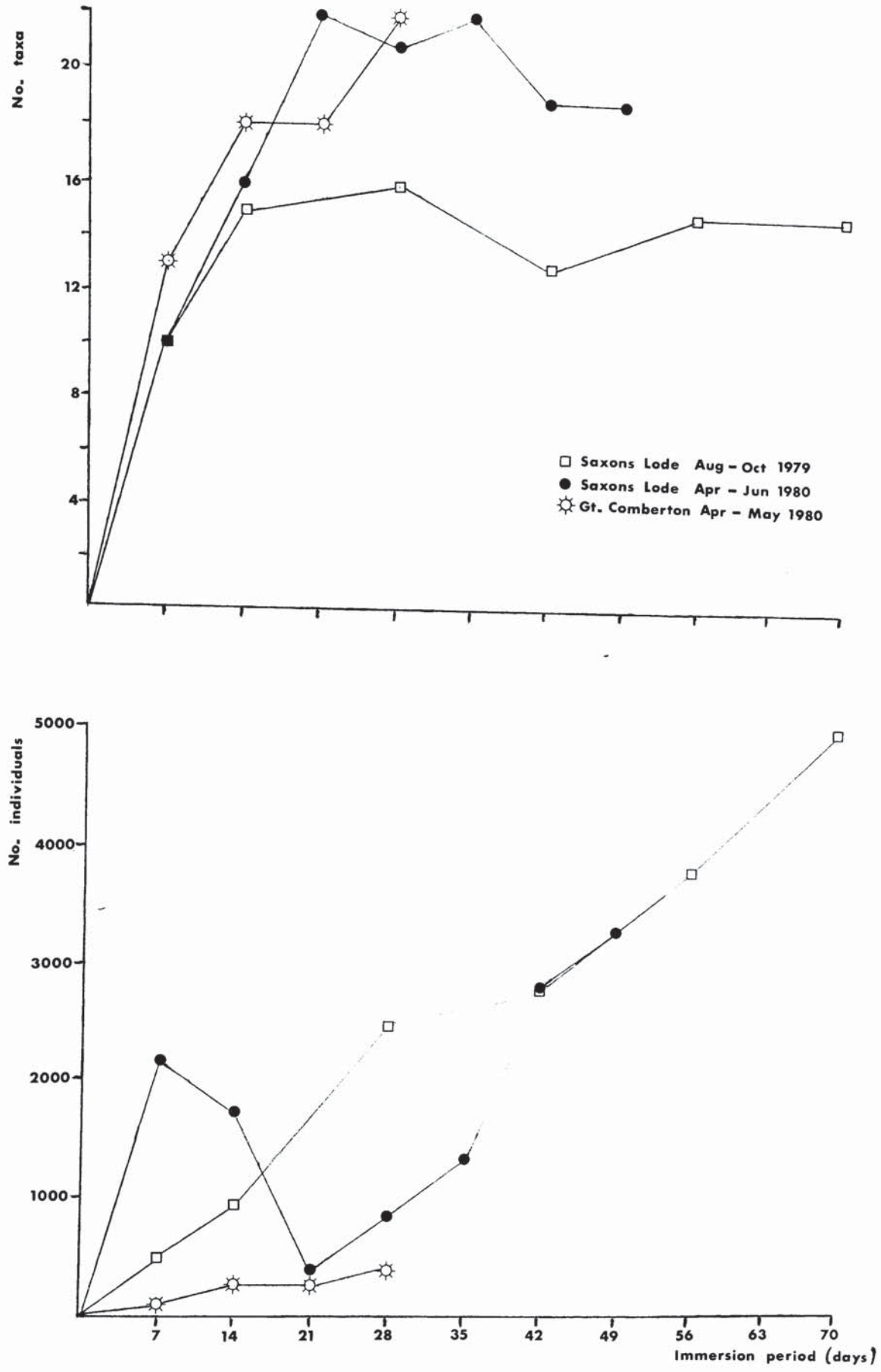


FIGURE **3.1.2** : INFLUENCE OF IMMERSION PERIOD ON THE NUMBERS OF TAXA AND INDIVIDUALS COLONISING 3 S.AUF.U.

Immersion Period (days)	Total Taxa on 3 S.Auf.U	Total Inds. on 3 S.Auf.U	No. of Taxa/S.Auf.U			No. of Indvs./S.Auf.U.			Diversity	
			$\bar{x}$	s^2	$s^2/\bar{x}$	$\bar{x}$	s^2	$s^2/\bar{x}$	Shannon Weaver	Simpson's
(a)										
7	10	500	5.67	2.34	0.41	166.67	11777	70.66	0.3230	0.1085
14	15	936	10.67	2.34	0.22	312.00	7732	24.78	0.8027	0.3425
28	16	2463	11.33	2.34	0.21	821.00	5161	6.29	0.5527	0.2036
42	13	2774	9.67	5.34	0.55	924.67	4356	4.71	0.4333	0.1567
56	15	3787	11.67	1.32	0.11	1263.33	22389	17.72	0.6070	0.2341
70	15	4974	11.33	2.34	0.21	1658.00	36100	21.77	0.4183	0.1457
(b)										
7	10	2184	6.00	2.99	0.50	728.00	67506	92.73	0.1063	0.0309
14	16	1738	10.33	10.30	1.00	579.33	31492	54.36	0.2482	0.0772
21	22	393	13.33	2.34	0.18	131.00	1033	7.89	1.3385	0.5091
28	21	844	15.00	2.99	0.20	281.33	2304	8.19	1.4239	0.6464
35	22	1330	16.00	1.00	0.06	443.33	22234	50.15	1.7140	0.7616
42	19	2796	16.00	0.00	0.00	932.00	12873	13.81	1.6810	0.7225
49	19	3272	15.33	1.32	0.09	1090.67	5752	5.27	1.3442	0.5563
(c)										
7	13	114	7.67	4.33	0.56	38.00	7	0.18	1.6531	0.6847
14	18	255	10.33	4.33	0.42	85.00	981	11.54	1.6793	0.6859
21	18	252	14.33	0.34	0.02	84.00	307	3.65	2.1698	0.8467
28	22	381	14.33	3.84	0.27	127.00	192	1.51	2.0049	0.7944

TABLE **3.1.2** :

VARIATION IN THE NUMBERS OF TAXA AND INDIVIDUALS, TWO COEFFICIENTS OF VARIATION (s^2 and $s^2/\bar{x}$) AND DIVERSITY WITH IMMERSION PERIOD AT (a) SAXONS LODE AUGUST - OCTOBER 1979, (b) SAXONS LODE APRIL - JUNE 1980 and (c) GT. COMBERTON APRIL - MAY 1980

The total number of individuals tended to increase throughout all the experiments (Figures 3.1.1 and 3.1.2, Table 3.1.2) although seasonal fluctuations of chironomid larvae (Table 3.1.4) affected the results in the second run at Saxons Lode. This is in contrast to the vast majority of similar studies on other colonisation samplers where peaks were achieved usually within 6 weeks, e.g. Dickson and Cairns (1972) with conservation webbing, Nilsen and Larimore (1973) with logs, Pearson and Jones (1975) with ground boxes, Roby et al. (1978) with porcelain balls and Shaw and Minshall (1980) with trays. Increases in the numbers of Corophium curvispinum throughout the experiments at Saxons Lode were primarily responsible (Tables 3.1.3 and 3.1.4).

Changes in the abundance of the separate taxa with immersion time are displayed in Tables 3.1.3 to 3.1.5. The abundance of many taxa changed significantly with immersion period (Table 3.1.6). Numbers of Corophium curvispinum, Caenis moesta, Agrion spendens, Tanytarsini and most gastropods increased while Gammarus pulex significantly decreased. The abundance of Ephemerella ignita, Chironomini and Orthocladiinae also significantly changed but these were accompanied by large seasonal fluctuations giving rise to significant seasonal changes in abundance (Table 3.1.6). C. curvispinum also showed a seasonal increase from 156 to 450 over the period 8.5.80 to 2.7.80 (Table 5.4c) but the increase from 4 to 2104 during run 2 at Saxons Lode (Table 3.1.4) by far outweighed this. Without doubt S.Auf.U. became more suitable to some of these taxa with time; many of the taxa increasing in abundance are detritus feeders and many of the colonising snails feed on algae (Graham, 1955) which increasingly colonised the S.Auf.U. with time.

Neither the variance s^2 nor $s^2/\bar{x}$ showed any clear pattern with increasing immersion time for the distribution of either taxa or individuals of all species between replicate S.Auf.U. except that $s^2/\bar{x}$ tended to decline with increasing immersion time during the second run at Saxons Lode (Table 3.1.2). A similar lack of pattern was observed by Dickson and Cairns (1972), Pearson and Jones (1975) and Meier et al. (1979).

↓ TAXON	IMMERSION PERIOD (days)					
	7	14	28	42	56	70
Corophium curvispinum	472	756	2184	2544	3316	4604
Crangonyx pseudogracilis					1	
Gammarus pulex	4	6	13		2	
G. tigrinus						2
Baetis rhodani		1				
Caenis moesta		1	1			
Hydropsyche pellucidula	1					
Leptoceridae		1				
Polycentropus flavomaculatus			1	1		2
Agrion splendens			1	3	3	8
Chironomini (excl. *(C.rip.)*(L)	7	34	27	32	32	71
Orthocladiinae (L)	7	12	14	8	15	11
Tanypodinae (L)	4	12	6	2	9	3
Chironomidae (P)		1	2	2		
Simulium spp.			1			
Lymnaea peregra		2	13	37	45	23
Bithynia tentaculata		4	33	32	103	96
Potamopyrgus jenkinsi	1	63	108	49	160	53
Theodoxus fluviatilis	2	6	29	45	85	74
Viviparus viviparus		9	4	1	9	3
Pisidium spp.	1	11	14	11	10	30
Piscicola geometra	1					2
Oligochaeta		17	2	7	6	2
Polycelis tenuis					1	

TABLE 3.1.3: NUMBERS OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED ON THREE S.AUF.U. AT SAXONS LODE DURING THE FIRST RUN OF THE IMMERSION PERIOD EXPERIMENT (9TH AUGUST - 18TH OCTOBER 1979).

↓ TAXON	IMMERSION PERIOD (days)						
	7	14	21	28	35	42	49
Asellus aquaticus				2	1		1
Corophium curvispinum	4	9	12	27	285	1312	2104
Crangonyx pseudogracilis			1				
Gammarus pulex	1	3		9	11	5	2
G. tigrinus	15	15	24	23	51	32	30
Isoperla grammatica						1	
Baetis rhodani	3	12	8	5	4	3	
Caenis moesta				1	1	14	16
Ephemerella ignita			17	308	337	223	134
Heptagenia sulphurea		1	1		2		
Leptoceridae					4	2	
Polycentropus flavomaculatus	1	3	2	1	2		
Agrion splendens		1	4	2	2	5	2
Brychius elevatus			1				
Haliplus spp.			1				
Chironomini (excl. *C. rip.*) (L)		1		6	4	454	480
Tanytarsini (L)		1	5	19	458	308	107
Diamesinae (L)						23	
Orthocladiinae (L)	2148	1632	256	388	104	300	121
Tanypodinae (L)	1	2	1	18	15	8	25
Chironomidae (P)	2	39	24	8	4	7	12
Simulium spp.	7	8	18				
Lymnaea auricularia							1
L. peregra			1	4	1	5	92
Physa fontinalis							
Bithynia tentaculta		4	2	9	10	20	33
Potamopyrgus jenkinsi	1	4	3	4	6	32	53
Theodoxus fluviatilis	1		1	5	20	36	46
Valvata macrostoma		1					
Viviparus viviparus			4		3	10	9
Pisidium spp.				1	2		
Piscicola geometra			2	2	1		1
Oligochaeta		2	3	1			
Polycelis tenuis				2	1		3

TABLE **3.1.4**: NUMBERS OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED ON THREE S.AUF.U. AT SAXONS LODE DURING THE SECOND RUN OF THE IMMERSION PERIOD EXPERIMENT

(24TH APRIL - 12TH JUNE 1980).

TAXON	IMMERSION PERIOD (Days)			
	7	14	21	28
Asellus aquaticus	3	4	21	8
Corophium curvispinum	60	133	69	149
Crangonyx pseudogracilis	4	4	4	7
Gammarus pulex		1	3	
Baetis rhodani	1	5		
Caenis moesta	12	17	47	30
Limnephilidae	2	1	3	9
Polycentropus flavomaculatus	3	2	18	19
Ischnura elegans	3	13	7	15
Potamonectes depresus elegans				2
Tanytarsini (L)	17	22	29	42
Diamesinae (L)				1
Orthocladiinae (L)	1	35	19	53
Tanypodinae (L)		5	6	2
Chironomidae (P)		4	8	9
Lymnaea peregra				2
Physa fontinalis	2			1
Bithynia tentaculata	4	2	6	4
Potamopyrgus jenkinsi		1	1	1
Theodoxus fluviatilis			1	3
Viviparus viviparus				1
Pisidium spp.	1	1		3
Erpobdella ococulata			2	
Helobdella stagnalis		1		
Piscicola geometra			1	3
Oligochaeta		2	1	15
Polycelis tenuis		2	3	2

TABLE 3.1.5 : NUMBERS OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED ON THREE S.AUF.U AT GT. COMBERTON DURING THE IMMERSION PERIOD EXPERIMENT (24TH APRIL - 22ND MAY 1980).

↓ Taxon	K		
	Run 1	Run 2	Seasonal Variation
Corophium curvispinum	16.39**	19.23**	5.96*
Gammarus pulex	18.74**	-	-
G. tigrinus	-	2.97	0.70
Baetis rhodoni	-	8.25	4.24
Caenis moesta	-	16.87**	4.50
Ephemerella ignita	-	17.96**	7.45**
Polycentropus flavomaculatus	3.42	2.27	-
Agrion splendens	11.18*	7.07	5.33
Chironomini (excl. *C. rip*) (L)	11.60*	18.44**	7.32**
Tanytarsini (L)	-	14.03*	2.09
Orthocladiinae (L)	2.17	16.31*	5.65*
Tanypodinae (L)	7.04	11.63	2.25
All chironomids (L)	10.92	15.57*	2.76
Lymnaea peregra	15.53**	11.11	4.50
Bithynia tentaculata	14.83*	14.11*	5.50
Potamopyrgus jenkinsi	15.25**	12.16	5.65*
Theodoxus fluviatilis	15.00**	17.80**	3.85
Viviparus viviparus	8.45	12.99**	7.62**
All gastropods	14.77*	18.44**	5.42
Pisidium spp.	6.48	-	-
Piscicola geometra	-	3.56	1.00
Oligochaeta	5.05	-	-

TABLE 3.1.6: K-VALUES (WITH SIGNIFICANCE LEVELS) FOR KRUSKAL-WALLIS ANOVAR ON THE EFFECT OF IMMERSION PERIOD ON THE ABUNDANCE OF DIFFERENT TAXA AT SAXONS LODE TOGETHER WITH THE EFFECT OF SEASONALITY ON ABUNDANCE

Diversity peaked after 14 days in run 1 and at 35 days in run 2 at Saxons Lode (Table 3.1.2). No clear increase or decrease throughout the period was observable in the first run but there was a steady increase over the first 5 weeks during the second run. Diversity in both experiments was distinctly affected by the numbers of C. curvispinum which, by the end of the periods, made up the vast majority of the individuals. Furthermore, seasonal fluctuations in the numbers of chironomids greatly affected diversity in the spring run at Saxons Lode. Patterns in diversity found by other workers differ considerably. Mason et al. (1973) and Stauffer et al. (1976) found it to decrease throughout their experiments whereas Meier et al. (1979) observed a linear increase, Roby et al. (1978) a peak after 2-4 weeks followed by fluctuations and Dickson and Cairns (1972) no clear trend.

Colonisation and extinction rates are displayed in Appendix Table 8.5. The colonisation rate varied significiantly with time during the first run at Saxons Lode whereas the extinction rate varied significantly during the second run the lines of best fit being linear and quadratic respectively (Table 3.1.7). Therefore, only the curve of extinction rate against time during the second run conformed to the MacArthur-Wilson model (1963) which states that the colonisation rate decreases with time while the extinction rate increases the lines of rate against time being simple concave curves. Cairns et al. (1969), Dickson and Cairns (1972) and Stauffer et al. (1976) found that the MacArthur-Wilson model adequately described colonisation of colonisation samplers.

3.1.4 Conclusions

There is no real evidence to suggest a need to change the 28 day immersion period recommended by Girton (Dept. of Environment, 1979). This conclusion is based on the following criteria:-

1. The number of taxa on three S.Auf.U., the sampling unit, peaked after 21-28 days. Consequently, after this period the maximum number of taxa should be available to monitor any pollution.
2. Large numbers of individuals of the more abundant taxa were already present after 28 days. This could be important if relative abundances are required.

SOURCE OF VARIATION → / TREATMENT EFFECT →	F				
	Immersion Period				Blocks
	Linear	Quadratic	Cubic	Log	
Colonisation Rate					
Run 1	9.09*	4.07	0.78	3.24	0.35
Run 2	3.80	0.69	0.32	1.46	1.63
Extinction Rate					
Run 1	4.26	1.56	2.14	2.10	0.83
Run 2	12.13**	9.17*	0.23	4.70*	0.66

TABLE **3.1.7** : ANOVA INCORPORATING BREAKDOWN INTO ORTHOGONAL POLYNOMIALS (WITH SIGNIFICANCE LEVELS) ON COLONISATION AND EXTINCTION RATES OF TAXA ON LEAF LITTER SUBSTRATES IN LOCH LOMOND.

3. No stable community was achieved within 10 weeks so it is best to remove S.Auf.U. as soon as possible to reduce the risk of loss by vandalism and/or accident.

3.2 COLONISATION OF BENTHIC AND SUSPENDED S.AUF.U. IN DEPOSITING STRETCHES OF RIVER

3.2.1 Site Description

S.Auf.U. were immersed at three sites: Checkley, upstream of Blithe Valley Sewage Works, on the R. Tean (Grid ref. SK 030375) in the metarhithron zone with regular alternating riffle and pool sections, Bewdley on the R. Severn (Grid. ref. SO 782762) a hyporhithron stretch with widely spaced riffles, and Saxons Lode on the R. Severn (Grid ref. SO 86439) in the potamon zone. S.Auf.U. were located ca. 20-40m downstream of a riffle at Checkley and ca. 100m downstream of one at Bewdley. Submerged and emergent vegetation was present at Bewdley but almost completely absent from the other two sites. All sites were DoE chemical class 1 (S.T.W.A., 1979b).

3.2.2 Methods

Four pairs of benthic and suspended S.Auf.U. were anchored at each site. House bricks were used to anchor all S.Auf.U. at the two R. Severn sites, suspended ones were trailed just below the surface from large polystyrene floats. All S.Auf.U. at Checkley on the R. Tean were anchored using 7 mm. diameter steel rods with the S.Auf.U. either in contact with the river bed or just below the water surface. Three benthic and three suspended S.Auf.U. were recovered from Saxons Lode after a four weeks immersion period from 2.7.80 to 31.7.80 whereas three benthic and two suspended S.Auf.U. were recovered from the other two sites. These had been immersed for four weeks from 17.4.79 to 15.5.79 at Checkley and 9.8.79 to 6.9.79 at Bewdley. The other S.Auf.U. immersed were lost.

Surface drift in the pool where the S.Auf.U. were located was collected over a 24h period during the immersion at Checkley (R. Tean) while both 24h surface drift and drift 2-23cm above the river bed was collected at Saxons Lode (R. Severn) on 5.6.80 and 2.7.80. In addition surface drift alone was collected on 31.7.80. Drift nets 18cm in height and 40 cm wide with meshes of 0.25 mm were used. Drift was not measured at Bewdley (R. Severn) because the site was widely open to public access. Flow at the mouths of the drift nets was measured at the beginning and end of each 24h using an OTT current meter (No. 47964, type "10.002").

The riffles upstream of the Checkley (R. Tean) and Bewdley (R. Severn) sites were sampled with three $0.05m^2$ Aston cylinder (plate 3.2.1) samples during the S.Auf.U. immersion period.

Animals were separated from S.Auf.U. in the field and preserved in ca. 4% formalin before identification. Cylinder samples were also preserved but drift samples were sorted while fresh.

Differences in the numbers of taxa and individuals of all species between benthic and suspended S.Auf.U. were tested for statistical significance using parametric t-tests whereas differences in the abundances of separate taxa were tested using non-parametric χ^2-tests. The reason for this distinction has been explained in section 3.1.2. The totals for three S.Auf.U. were used for χ^2-tests at Saxons Lode (R. Severn) whereas pairs of benthic and suspended S.Auf.U. from the same blocks were compared at the other two sites. Only taxa with an expected abundance greater than one were subjected to χ^2-tests.

Finally Shannon-Weaver diversity values were calculated for groups of three S.Auf.U. at each site. Worms were excluded from these calculations since their abundance often appeared to be primarily dependent on the amount of silting up of the S.Auf.U.

3.2.3 Results and Discussion

Significantly more taxa were recorded on benthic S.Auf.U. at Saxons Lode (R. Severn) whereas significant differences were not recorded at the other two sites (Table 3.2.1). Twenty-two taxa were collected on benthic S.Auf.U. at Saxons Lode compared to 15 on suspended ones. More taxa were also recorded on benthic S.Auf.U. at the other two sites where 23 and 12 taxa at Bewdley (R. Severn) and 14 and 10 taxa at Checkley (R. Tean) were collected on benthic and suspended S.Auf.U. respectively. No significant differences between the numbers of individuals of all species recovered on benthic S.Auf.U. were recorded at any site (Table 3.2.1) However more individuals were recovered from benthic S.Auf.U. at all sites. At Saxons Lode 3202 were collected on 3 benthic S.Auf.U. compared to 2009 on suspended ones. Bewdley had 216 and 155 and Checkley 320 and 101

PLATE **3.2.1**: THE "ASTON" CYLINDER SAMPLER (sampling area $0.05m^2$)

SITE →	t		
	Checkley	Bewdley	Saxons Ld
Total taxa	1.25	2.49	5.29**
Total individuals	1.10	0.96	1.53

TABLE **3.2.1** : VALUES OF STUDENTS-t (WITH SIGNIFICANCE LEVELS) FOR DIFFERENCES IN THE NUMBERS OF TAXA AND INDIVIDUALS BETWEEN BENTHIC AND SUSPENDED S.AUF.U.

individuals on S.Auf.U. from blocks where both benthic and suspended S.Auf.U. were recovered on benthic and suspended S.Auf.U. respectively. The lack of statistically significant differences was presumably due to the small sample sizes. This was not remedied because this work was an offshoot of the main project. Nilsen and Larimore (1973) also found that more individuals colonised logs at the bottom of a pool section than just below the water surface but, as above, this difference was not statistically significant. In contrast Roby et al. (1978) found that depth accounted for only 2% of the variation in numbers on samplers of porcelain balls.

There were significant differences in the species-abundance lists between benthic and suspended S.Auf.U. at all sites (Table 3.2.2). The raw species-abundance lists are displayed in Table 3.2.3.

At Checkley (R. Tean) significantly more Limnephilidae, Chironomini, and consequently all chironomid larvae, and oligochaetes were recovered from benthic S.Auf.U. (Table 3.2.2). Limnephilids cannot swim and live in quite heavy cases and are therefore unlikely to drift as are the mud-dwelling Tubificidae and Lumbriculidae. Nearly all the worms recovered from suspended S.Auf.U. were Naididae which were very abundant in the drift (Table 3.2.4). Chironomid larvae were also well represented in the drift and this is perhaps reflected in there being more Orthocladiinae and Tanypodinae on suspended S.Auf.U. (Table 3.2.3).

Bewdley (R. Severn) had significantly more Corophium curvispinum Viviparus viviparus, total numbers of gastropods and flatworms on benthic S.Auf.U. (Table 3.2.2). This is not on the whole surprising as the last three groups are all non-swimming and either heavy or well-equipped for holding on to the bottom. Gastropods were exclusive to the benthic S.Auf.U. with 5 species being recorded there. Significantly more Baetis rhodani, Heptagenia sulphurea, Orthocladiinae and consequently all chironomid larvae were collected on suspended S.Auf.U. (Table 3.2.2). Mason et al. (1973) also found mayflies to be more abundant on colonisation samplers located near the surface. Mayflies and chironomids often make up a major part of the drift (Waters, 1969; Williams and Hynes, 1976; Stoneburner and Smock, 1979) which is probably a major source of colonisation of suspended S.Auf.U.

↓TAXON SITE →	χ^2		
	Checkley	Dewdley	Saxons Lde
SELECTED LIST	108.81***	213.98***	845.54***
Corophium curvispinum		99.20***	438.01***
Gammarus pulex	(0.07)		
G.tigrinus			(1.78)
Baetis rhodani	0.00	(28.26)***	
Ephemerella ignita		(3.13)	(1.33)
Heptagenia sulphurea		(5.14)*	
Hydropsyche pellucidula		(1.62)	
Limnephilidae	6.13*		
Electrocnemia geniculata			(1.33)
Polycentropus flavomaculatus		0.44	
Agrion splendens		2.25	
Aphelocheirus Montandoni		1.33	
Chironomidae (L)	43.76***	(22.75)***	(49.32)***
Chironomini (L)	79.28***	3.20	21.00***
Tanytarsini (L)		1.78	(17.45)***
Orthocladiinae (L)	(1.11)	(39.05)***	(209.88)***
Tanypodinae (L)	0.00	0.80	0.00
Chironomidae (P)		0.00	0.05
Gastropoda		18.05***	5.63*
Lymnaea peregra		3.20	27.80***
Physa fontinalis			16.69***
Bithynia tentaculata			(143.32)***
Potamopyrgus jenkinsi			121.01***
Theodoxus fluviatilis			24.04***
Viviparus viviparus		9.09**	11.08***
Pisidium spp.	3.20		14.06***
Piscicola geometra			1.33
Oligochaeta	91.77***	(1.33)	0.00
Polycelis tenuis		9.09**	

All taxa with $E(x)>1$ included in analysis. Figures in parentheses indicate abundance on suspended S.Auf.U. greater, otherwise abundance on benthic S.Auf.U. greater.

TABLE **3.2.2** : χ^2 VALUES (WITH SIGNIFICANCE LEVELS) DEMONSTRATING DIFFERENCES IN THE ABUNDANCE OF DIFFERENT TAXA BETWEEN BENTHIC AND SUSPENDED S.Auf.U.

SITE →	CHECKLEY (TEAN 1)								BEWDLEY								SAXONS LODE							
S.AUP.U. →	Benthic				Suspended				Benthic				Suspended				Benthic				Suspended			
↓TAXON REPLICATE →	1	2	3	Tot	1	2	3	Tot	1	2	3	Tot	1	2	3	Tot	1	2	3	Tot	1	2	3	Tot
Asellus aquaticus						1	L	1.5		1		1		L										
Corophium curvispinum							0		77	42	47	166	7	0	3	15	1272	828	504	2604	608	392	296	1296
Gammarus pulex	16	12	2	30	25	6	S	46.5						S									1	1
G. tigrinus							T							T			1	1		2	4	3		7
Baetis rhodani	2	1		3		2		3			1	1	4		29	49.5	2			2				
Ephemerella ignita										1	1	2	3		4	10.5						1	2	3
Heptagenia sulphurea													2		5	10.5								
Hydropsyche angustipennis		1		1																				
H. pellucidula									8	6	12	26	7		23	45								
Leptoceridae																		2		2				
Limnephilidae	2	6	4	12																				
Plectrocnemia geniculata																						1		2	3
Polycentropus flavomaculatus									4	4	2	10	2		1	4.5								
Agrion splendens											4	4												
Brychius elevatus (L)										1		1												
Aphelocheirus montandoni									2	1	1	4												
Sialis fuluginosa										3	1	4												
Chironomini (excl C.rip) (L)	87		23	110	2			3	4	1	1	6					125	50	31	206	52	45	25	122
Tanytarsini (L)									5	1	2	8	1		1	3	3		1	4	17	8	4	29
Diamesinae (L)	3		2	5	1			1.5																
Orthocladiinae (L)	6	12		18	19	7		39	3	7	2	12	19		35	81	10	5	5	20	70	119	67	266
Tanypodinae (L)	6	5		11	12			18		1	4	5			1	1.5	6	5	1	12	5	6	2	13
Chironomidae (P)		1		1					1	1	1	3	2		1	4.5	7	4	1	12	7	2	1	10
Dicranota sp.	1			1																				
Simulium sp.															2	3								
Ancylus fluviatilis	1		1	2																				
Lymnaea auricularia																	1			1				
L. peregra	2			2		1		1.5	3	2	2	7					20	52	18	90	2	16	13	31
Physa fontinalis																	5	15	6	26		2	1	3
Segmentina complanata									2			2												
Bithynia tentaculata										1	1	2					3	13	12	28	21	87	108	216
Potamopyrgus jenkinsi						2		3		1	1	2					54	14	55	123				
Theodoxus fluviatilis																	4	10	12	26				
Viviparus viviparus									3	2	8	13					5	6	2	13				
Pisidium spp.	5		2	7													1	11	4	16				
Erpobdella octoculata											1	1							1	1				
Glossiphonia complanata																					1			1
G. heteroclita																		1		1				
Helobdella stagnalis									1	1		2												
Piscicola geometra																	2	1		3				
Theromyzon tessulatum		1		1																				
Oligochaeta	84	66	14	164	16	7		34.5					3			4.5		6	2	8	6	1		7
Dugesia polychros																			1	1	1			1
Polycelis tenuis									6	9	5	20							1	1				

TABLE 3.2.3: ABUNDANCE OF DIFFERENT TAXA COLLECTED ON BENTHIC AND SUSPENDED S.AUP.U. AT THREE SITES

	24h DRIFT					
SITE →	CHECK-[illegible]	SAXONS LODE				
DATE →	17.4-[illegible].4.79	5.6-6.6.80		2.7-3.7.80		31.7-1.8.80
TIME →	10.00-10.00	12.45-12.45		11.45-11.45		11.45-11.45
LOCATION OF DRIFT NET →	Surface	Surface	Bottom	Surface	Bottom	Surface
DEPTH/FLOW RATE						
Total Depth (cm)	56	56	36	86	65	72
Depth of Flow Measurement (cm)	5	5	15	5	45	5
Velocity ($m\ s^{-1}$)	0.37	0.11	0.10	0.17	0.15	0.12
TAXA						
Asellus aquaticus				1		
Corophium curvispinum		2	1	4		
Gammarus pseudogracilis		2		1		
Gammarus pulex	6			1		
Baetis rhodani			4			
Caenis moesta			1		4	
Ephemerella ignita		2	2			
Limnephilidae	1					
Oulimnius tuberculatus					1	
Chironomini (excl C.rip) (L)	11			40	7	18
Tanytarsini (L)		352	221			1
Diamesinae (L)	2					
Orthocladiinae (L)	13			2		34
Tanypodinae (L)	7			1		
Chironomidae (P)	12	2	5	4	3	1
Empididae	2					
Simulium spp.	1			1		
Piscicola geometra		1		1		
Tubificidae/Lumbriculidae					1	
Dendrocoelum sp.				1		1
Oligochaeta (predom. Naididae)	169					

TABLE **3.2.4** : 24h DRIFT

in rhithron rivers.

The abundance of mayflies and chironomid larvae in the riffles upstream of Bewdley (R. Severn) and Checkley (R. Tean)(Table 3.2.5) implies that these were a very important source of the drift and ultimately the colonisation of suspended S.Auf.U. They were presumably a less important source of colonisation for benthic S.Auf.U. which at Bewdley had Polycentropus flavomaculatus, Agrion splendens, Aphelocheirus montandoni, Sialis fuluginosa and several gastropod species (Table 3.2.3) absent from the upstream riffle samples.

Saxons Lode (R. Severn) had significantly more C. curvispinum, Chironomini and all molluscan taxa except for Bithynia tentaculata on benthic S.Auf.U. (Table 3.2.2). This was similar to the situation at Bewdley and Checkley but on a larger scale. Significantly more Tanytarsini, Orthocladiinae and B. tentaculata were collected from suspended S.Auf.U. Vast numbers of Tanytarsini were collected in drift on 5.6.80 and quite a few orthoclads on 31.7.80 (Table 3.2.4) so drift was probably the major source of colonisers of these taxa. Quite a few Chironomini were also recorded in the drift. The large numbers of B. tentaculata on suspended S.Auf.U. was due entirely to very young individuals which probably hatched out of egg masses laid by the occasional drifting adult.

Diversity was similar on benthic and suspended S.Auf.U. (Table 3.2.6). The large numbers of Chironomini at Checkley and C. curvispinum at Bewdley and Saxons Lode on benthic S.Auf.U. compared to suspended ones (Table 3.2.3) would counteract the effects of more taxa on the former.

3.2.4 Conclusions

1. More taxa and individuals were collected on benthic S.Auf.U. than suspended ones. This effect was greatest in the large R. Severn.
2. Suspended S.Auf.U. appeared to be largely colonised by drifting animals whereas benthic S.Auf.U. were also readily available to animals crawling along the river bed. Since many of the

↓TAXON REPLICATE →	1	2	3	Tot
Gammarus pulex	1			1
[illegible] phaeani	2	13	13	28
Chironomini (excl. [illegible])(L)		3	17	20
Orthocladiinae (L)	38	29	12	79
Chironomidae (P)	1	1		2
Empididae			1	1
Ancylus fluviatilis		2	3	5
Potamopyrgus jenkinsi	1	1		2
Oligochaeta	200	40	64	304

TABLE **3.2.5** : NUMBERS OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED IN 0.05m^2 CYLINDER SAMPLES FROM CHEDDLEY RIFFLE ON 15.5.79 (BENTHIC v. SUSPENDED [illegible] LABERIUS).

SITE	DIVERSITY	
	Benthic	Suspended
Checkley	1.5938	1.4703
Bewdley	1.8517	1.7210
Saxons Lode	0.8316	1.1403

TABLE **3.2.6** : A COMPARISON OF SHANNON-WEAVER DIVERSITIES ON BENTHIC AND SUSPENDED F.A.U.P.U.

colonisers of S.Auf.U. in lowland rivers belong to the latter, e.g. gastropods, flatworms and oligochaetes, and as C. curvispinum and leeches were more abundant on benthic S.Auf.U., it is recommended that benthic S.Auf.U. be used in preference to suspended ones.

3.3 THE INFLUENCE OF RIFFLES ON S.AUF.U. COLONISATION

3.3.1. Site Description

This study was carried out on the R. Severn over the last four riffles, which lay between Bewdley and Ribbesford, and downstream of them. The main study area is shown in Figure 3.3.1, but S.Auf.U. were also immersed at Saxons Lode (Grid ref. SO864391) approximately 55 km downstream of the final riffle and ca. 15 km. downstream of the nearest major tributary, the Teme.

The upper three of the last four riffles, named the Upper, Middle and Lower Bewdley riffles, all had a stony substratum whereas the final riffle at Ribbesford had a solid rock base with scattered large stones lying on it. The substratum downstream of all the riffles and at Saxons Lode was of an unstable depositing nature. Emergent macrophytes were present in the depositing stretches downstream of each riffle but not at Stourport (Grid ref. SO792724) or at Saxons Lode. The river was DoE chemical class 1B throughout the study area (S.T.W.A., 1979b).

3.3.2 Methods

3.3.2.1 Colonisation of S.Auf.U. in the Rhithron-Potamon Transition Area and the Potamon Zone

The last four riffles were sampled during the S.Auf.U. immersion period with three 0.05m^2 "Aston" cylinder samples (Plate 3.2.1) and three 30-second heel-kicks. Because of the depth of the riffles in midstream samples were confined to the west bank. S.Auf.U. were immersed ca. 100m below each riffle. Those below the Upper and Middle Bewdley riffles were located on the east side of the river and those below the other two riffles on the west side. In addition, S.Auf.U. were located at Stourport ca. 3km below the final riffle and at Saxons Lode. Six S.Auf.U. were immersed at each site to allow for losses and after a period of 4 weeks three were removed and sorted except below the Lower Bewdley riffle where all samplers were lost. All data from this site was subsequently discarded. All S.Auf.U. were anchored using house bricks and the removal date was 13.9.79,

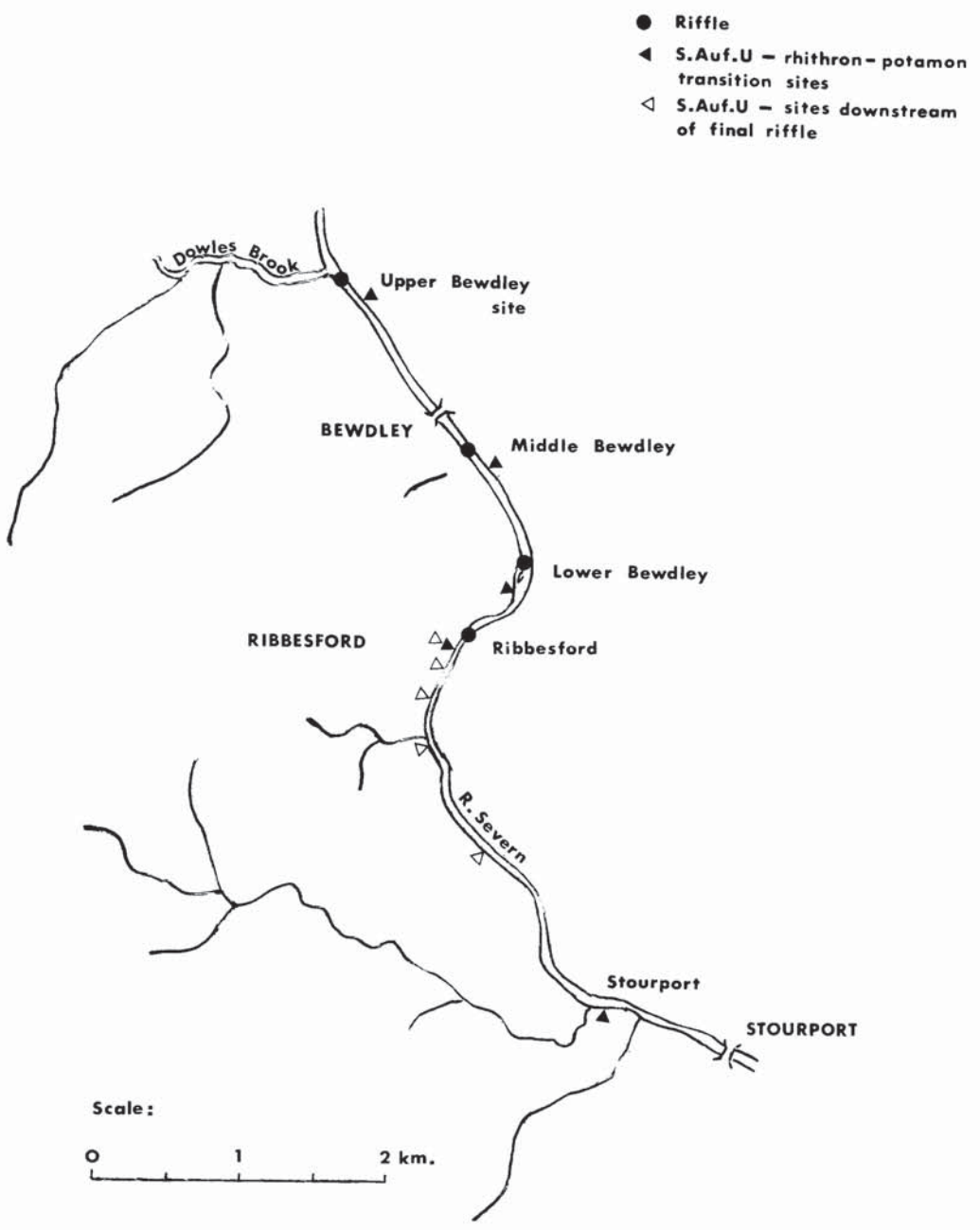


FIGURE **3.3.1** : SAMPLING SITES USED FOR STUDYING THE INFLUENCE OF RIFFLES ON S.AUF.U. COLONISATION

except at Saxons Lode where it was one week earlier. Animals were removed from S.Auf.U. in the field and preserved in 4% formalin before identification.

The same physicochemical variables as in Section 3.1.2 were measured at each S.Auf.U. sampling site at the beginning of the immersion period.

The Trent Biotic Index (TBI), Chandler Score and B.M.W.P. Score were calculated for each group of three S.Auf.U., cylinder and heel-kick samples along with the Shannon-Weaver diversity index (natural logs).

Variations in the numbers of taxa and individuals and the abundance of certain taxa of S.Auf.U. over the Bewdley to Stourport stretch were assessed for statistical significance using one-way analyses of variance (anovars) incorporating breakdown of the treatments into polynomials by the method of orthogonal polynomial analysis. Lines of best fit were estimated from these. Anovars without transformations were applied to numbers of taxa and total numbers of individuals for reasons given before (Section 3.1.2). With respect to the abundance of specific taxa or species the need for transformations was assessed by plotting log s^2 on log $\bar{x}$ and calculating r^2 to see how dependent the variance was on the value of the mean. When the r^2 value was low no transformation was carried out as this indicated that the criterion of independent means and variances required in parametric tests was fulfilled. However when the variance was largely dependent on the mean the appropriate transformation to make them independent was estimated using Taylor's Power Law:

$$\sigma^2 = a\mu^b$$

where σ^2 is the population variance, μ the population mean and a and b are population parameters. Log transformations were by far the most common appropriate ones so for reasons of simplicity in plotting lines of best fit, these were applied to all data requiring transformations. Changing data back from log form produced derived means. This rather complicated procedure was adopted rather than the Kruskal-Wallis anovar used in Section 3.1

because it was necessary to know how the numbers of different species changed downstream.

t-tests using the same transformations as above, if necessary, were used to see if there were any significant differences in taxa or individuals between the potamon sites. The Saxons Lode site was not included in the above anovar because its location nearly 50km downstream of the Stourport site would have grossly distorted the lines of best fit.

3.3.2.2 Colonisation of S.Auf.U. at Different Distances Downstream of a Riffle

The final riffle of the R. Severn at Ribbesford was sampled using three $0.05m^2$ Aston cylinder samples and three 30-second heel-kicks near the west bank on 23.5.80. S.Auf.U. were immersed near the same bank at geometrically increasing intervals of ca.100m, 200m, 400m, 800m and 1600m below this riffle for six weeks from 23.5.80 to 8.7.80. A six week immersion period was used because spate conditions prevented earlier removal of S.Auf.U. Six S.Auf.U. were anchored with house-bricks at each site and three were removed and sorted except at the 400m site where only two were recovered. As before animals were separated from S.Auf.U. in the field and preserved in 4% formalin before identification. Numbers of animals of each taxon on the missing S.Auf.U. from the 400m site were estimated using the formula:

$$X = \frac{aT + bB - S}{(a-1)\,(b-1)}$$ (Snedecor and Cochran, 1967, p. 318)

where a = number of treatments

b = number of blocks

T = sum of items with same treatment as missing item

B = sum of items in same block as missing item

S = sum of all observed items.

The same physicochemical variables as in Section 3.1.2 were measured at each S.Auf.U. sampling site at the beginning of the immersion period.

The Shannon-Weaver diversity index (natural logs) was calculated for each group of three samples.

Anovar of S.Auf.U. samples was carried out as in Section 3.3.2.1. The 100m site produced some unusual results implying that it was not completely exposed to drift from the upstream riffle so this site was excluded from anovar.

3.3.3 Results and Discussion

3.3.3.1 Colonisation of S.Auf.U. in the Rhithron-Potamon Transition Area and the Potamon Zone

Physicochemical data is displayed in Appendix Table 9.2. Samples taken on 16.8.79 had lower values for chloride, pH, alkalinity and hardness than those taken one week earlier. Heavy rain in the intervening week was probably responsible. Low BOD's and ammonia values indicate that there was negligible organic input over the study area.

Raw invertebrate data from the riffles and S.Auf.U. samples are shown in Appendix Tables 8.6 to 8.8 while analysis of variance (anovar) tables are shown in Appendix Table 10.3. Anovar revealed that both the numbers of taxa and individuals of all species on S.Auf.U. between Bewdley and Stourport changed significantly (Table 3.3.1). Lines of best fit showed that taxa declined linearly whereas individuals increased linearly. t-tests revealed no significant differences between the two potamon sites (Stourport and Saxons Lode) (Table 3.3.1).

Graphs of numbers of taxa collected on 3 S.Auf.U. and on individual S.Auf.U. also reflect a steady decline over the study area (Fig. 3.3.2); numbers on 3 S.Auf.U. declined from 30 at Upper Bewdley to 16 at Saxons Lode (Table 3.3.2). On the whole riffle samples from both heel-kicks and cylinders showed a slight downstream decline as well (Fig. 3.3.2, Table 3.3.2). In contrast the number of individuals of all species on 3 S.Auf.U. remained relatively constant at 400-500 below the riffles and then rose sharply to over 2000 in the potamon zone (Fig. 3.3.2, Table 3.3.2). Numbers of individuals in the riffles showed a slight downstream decline like the taxa (Fig. 3.3.2, Table 3.3.2).

TAXON	Trans-formation	P			+	t
		Linear	Quadratic	Cubic		
TOTAL TAXA	None	7.18*	2.35	0.42	a	-0.15
TOTAL INDIVIDUALS	None	14.65**	3.06	0.21	b	0.08
Corophium curvispinum	None	20.19**	7.09*	0.37	c	-0.11
Gammarus pulex	ln(x+1)	0.60	2.47	5.39*	d	-0.64
Ephemeroptera	ln(x+1)	0.71	0.65	0.17		0.00
Hydropsychidae	ln(x+1)	2.68	0.87	0.41		0.00
Cased Trichoptera	ln(x+1)	0.74	0.61	0.43		-0.45
Coleoptera	ln(x+1)	1.75	0.59	0.15		0.00
Chironomidae (L)	ln(x+1)	2.24	2.24	0.71		2.80*
Chironomini (L)	ln(x+1)	1.21	3.44	0.16		1.89
Tanytarsini (L)	ln(x+1)	1.23	1.12	3.02		-1.00
Orthocladiinae (L)	ln(x+1)	3.17	0.72	0.32		3.54*
Tanypodinae (L)	None	3.65	0.14	1.80		1.31
Gastropoda	None	0.41	1.61	0.75		11.11***
Lymnaea peregra	None	0.30	1.30	1.03		2.71
Bithynia tentaculata	ln(x+1)	2.61	0.74	2.69		6.63**
Potamopyrgus jenkinsi	None	0.16	3.74	0.34		8.09**
Theodoxus fluviatilis	None	40.00***	11.22*	0.63	e	0.59
Viviparus viviparus	None	0.08	2.62	0.10		-1.21
Bivalvia	ln(x+1)	1.99	2.72	0.61		1.26
Hirudinea	ln(x+1)	1.23	0.31	1.05		-1.86
Oligochaeta	ln(x+1)	2.12	1.22	0.39		0.31
Tricladida	ln(x+1)	0.10	1.08	0.86		-1.85

\+ DOWNSTREAM PATTERN OF ABUNDANCE

a linear decrease

b linear increase

c concave with increase in potamon

d cubic effect

e increase in potamon

For details see table **10.3** in appendix.

Significant positive values for t indicate that numbers are significantly higher in the metapotamon zone than in the epipotamon.

TABLE **3.3.1** : ANOVAR INCORPORATING BRANDON'S OF THE TRANSFORMS INTO POLYNOMIALS (WITH SIGNIFICANCE LEVELS) AND t-TESTS ON THE EFFECT OF TRANSITION FROM EPITHRON ZONE TO POTAMON ZONE ON THE NUMBERS OF TAXA AND INDIVIDUALS OF DIFFERENT TAXA OCCURRING D.AUF.U.

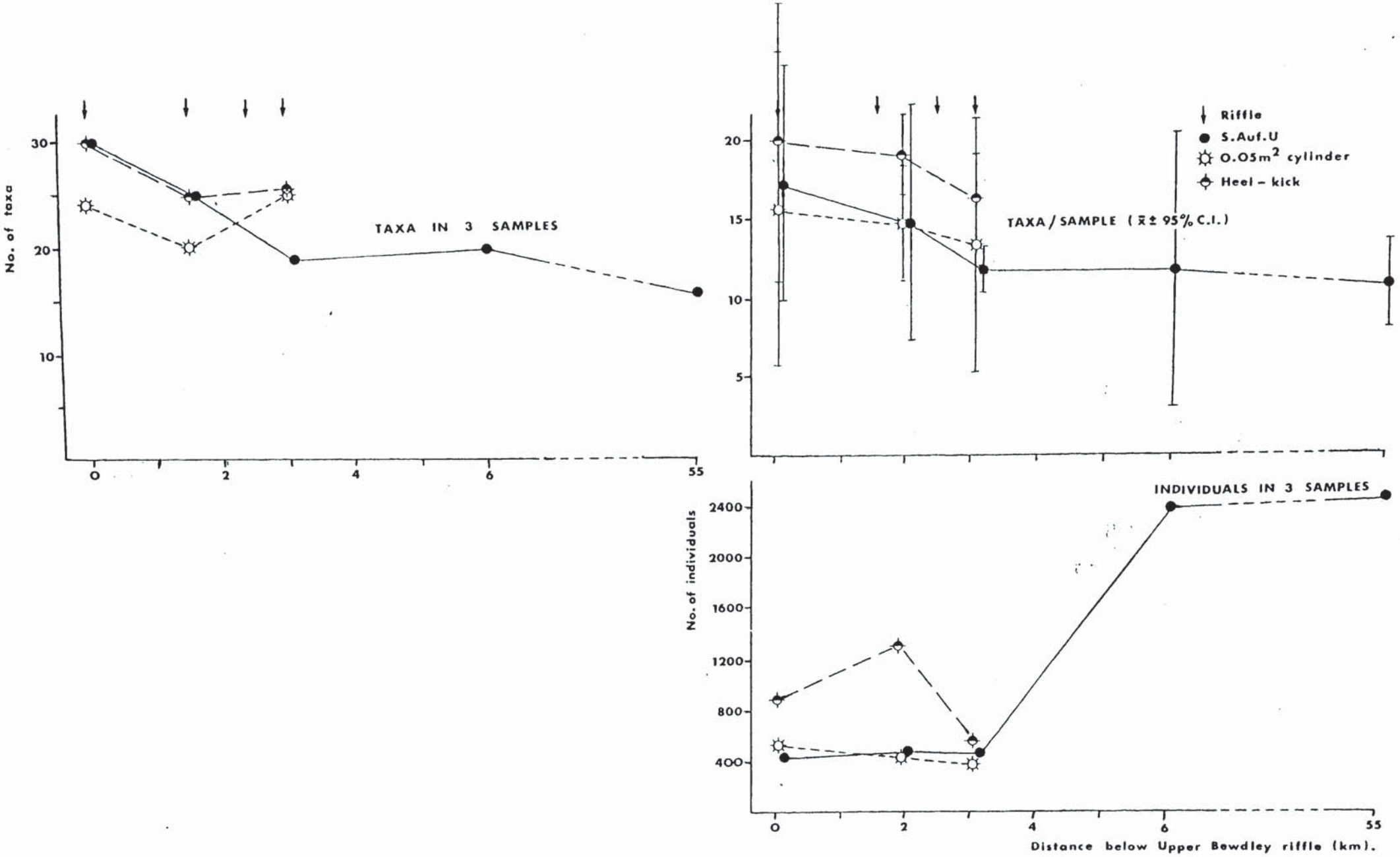


FIGURE 3.3.2 : NUMBERS OF TAXA AND INDIVIDUALS IN SAMPLES COLLECTED IN THE RHITHRON-POTAMON ZONE OF R. SEVERN

SITE		Taxa/ sample ($\bar{x} \pm 95\%$ C.L.)	Taxa in 3 samples	Indiv in 3 samples	TBI	Chandler Score	LWP Score	Diversity
Riffles								
Upper Bewdley	cyl	15.67±10.03	24	529	IX	723	96	1.5813
	net	20.00±8.95	30	893	IX	1117	127	2.3679
Middle Bewdley	cyl	14.67±3.79	20	418	VIII	570	75	1.8038
	net	19.00±2.50	25	1307	IX	945	105	1.4105
Ribbesford	cyl	13.33±7.96	25	366	IX	868	104	1.6348
	net	16.33±2.88	26	573	IX	838	102	2.2623
Pools								
Upper Bewdley		17.33±7.62	30	438	IX	763	110	2.0431
Middle Bewdley		14.67±7.62	25	489	VIII	649	95	1.9902
Ribbesford		11.67±1.46	19	472	VIII	601	78	1.2362
Stourport		11.67±8.74	20	2392	VIII	494	82	0.3370
Saxons Lode		10.67±2.84	16	2463	VII	402	58	0.5496

TABLE **3.3.2** : VARIATION IN THE NUMBERS OF TAXA AND INDIVIDUALS, POLLUTION INDICES AND DIVERSITY IN AND BELOW THE FINAL RIFFLES OF THE R. SEVERN AUGUST/SEPTEMBER 1979.

The abrupt increase in individuals in the potamon zone was principally due to a rise in the numbers of Corophium curvispinum which rose from 90 at Ribbesford to 2259 at Stourport (Fig. 3.3.3). Anovar revealed numbers of C. curvispinum together with Gammarus pulex and Theodoxus fluviatilis to change significantly over the rhithron-potamon transition area (Table 3.3.1). Lines of best fit showed that both C. curvispinum and T. fluviatilis increased in numbers in the potamon zone whereas the cubic polynomial for G. pulex (Table 3.3.1) gave no clear underlying trend. As both C. curvispinum and T. fluviatilis are purely lowland river species these results are not unexpected.

t-tests showed that numbers of chironomid larvae and gastropods were significantly greater at Saxons Lode in the metapotamon than Stourport in the epipotamon (Table 3.3.1). Increases in Chironomini and Orthocladiinae the latter of which also gave a significant t value, were mainly responsible for the increase in chironomids whereas significantly more Bithynia tentaculata and Potamopyrgus jenkinsi at Saxons Lode were mainly responsible for the increase in gastropods. Overall, however, fewer chironomid larvae were present at Saxons Lode that at Upper Bewdley in the rhithron zone (Fig. 3.3.3). On the other hand, numbers of gastropods clearly increased in the potamon zone (Fig. 3.3.3); 17 were collected from Ribbesford, 50 from Stourport and 187 from Saxons Lode.

Although anovar revealed no significant decreases in the numbers of specific taxa over the transititon area numbers of Hydropsychidae, cased caddises, beetles and leeches on S.Auf.U. declined over the study area (Fig. 3.3.3). The uneven distribution of individuals between replicates was largely responsible for the lack of significant values. Numbers of beetles and leeches on S.Auf.U. reflected numbers in riffle samples taken by heel-kicks and cylinders respectively (Fig. 3.3.3).

Mayflies and Atherix sp. were abundant in riffles but rarely collected on S.Auf.U. (Fig.3.3.3). Over 200 mayflies were found in heel-kicks from Upper Bewdley but only 3 were recorded on the down-stream S.Auf.U. Hydropsychidae, beetles, chironomid larvae and bivalves were also clearly more abundant in riffles than on

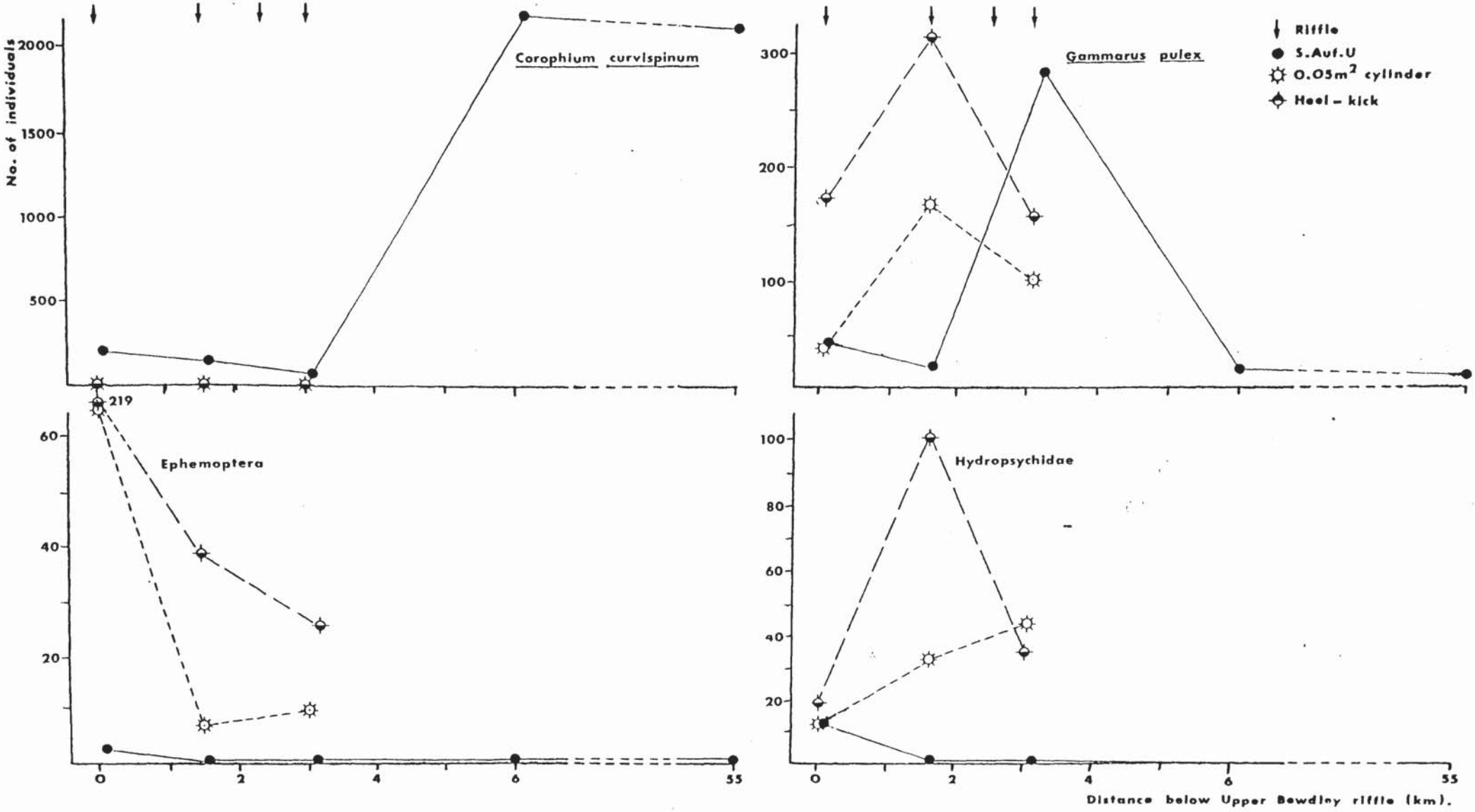


FIGURE 3.3.3 : ABUNDANCE OF DIFFERENT TAXA IN GROUPS OF THREE REPLICATE SAMPLES COLLECTED IN THE RHITHRON-POTAMON ZONE OF THE R. SEVERN

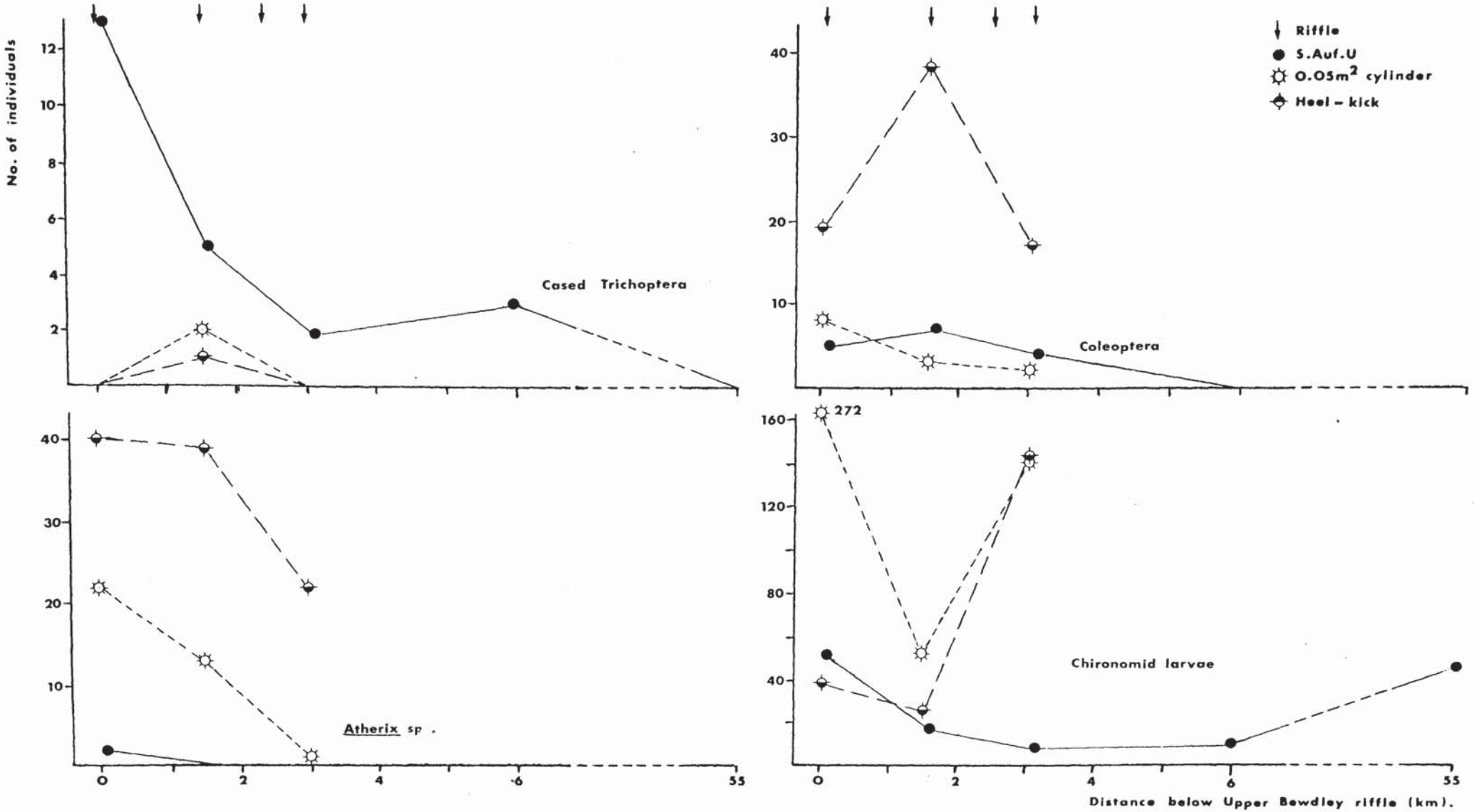


FIG. 3.3.3 continued

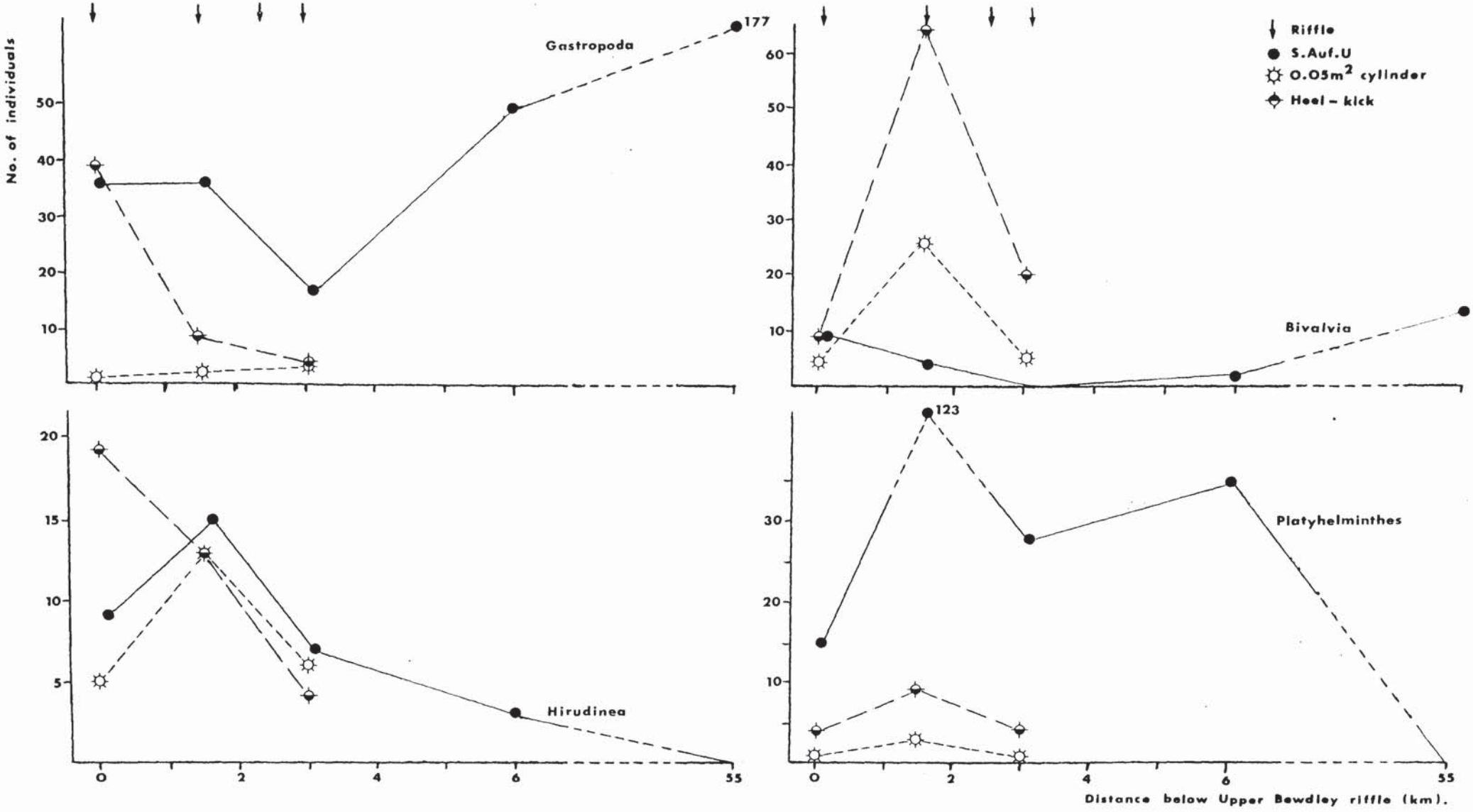


FIGURE 3.3.3 continued.

corresponding S.Auf.U. whereas C. curvispinum, cased caddises, gastropods and flatworms were much more abundant on S.Auf.U. (Fig. 3.3.3). Girton (1980) also found that more mayflies were collected from riffles and more gastropods from S.Auf.U. in the R. Tean at Checkley. In contrast he found more gastropods in riffles in the R. Mease and numbers of Hydropsychidae in riffles and on S.Auf.U. in the R. Weaver were similar.

The decline in the numbers of taxa on S.Auf.U. over the study area is reflected in declines in all three pollution indexes (Fig. 3.3.4); the TBI declined from IX to VII, the Chandler Score from 763 to 402 and the B.M.W.P. Score from 110 to 58. The absence particularly of high scoring taxa such as mayflies from the potamon zone accentuated this effect. Girton (1980) also found much lower B.M.W.P. Scores at sites not associated with nearby riffles. These results emphasise the unreliability of applying the same indexes to rhithron and potamon zones even when only depositing substrata are compared. An index for potamon zones should have a very different species composition to one for rhithron zones so that less weight is given to insect species such as stoneflies and mayflies which are of restricted distribution in potamon zones and more weight is given to crustaceans and gastropods which the results above revealed greatly increased in numbers in the potamon zone.

Pollution index values for S.Auf.U. below riffles mirrored the trend in values for heel-kick samples but, on the whole, the scores were lower (Fig. 3.3.4); the Chandler Score for heel-kicks at Upper Bewdley was 1117 while that for downstream S.Auf.U. was 763. As above, the presence of fewer high scoring riffle taxa on S.Auf.U. was responsible. Cylinder samples in general gave lower scores than the heel-kicks (Fig. 3.3.4).

Diversity for S.Auf.U. samples declined sharply over the study area reaching a low of 0.3370 at Stourport crashing from 1.2362 3km upstream (Fig. 3.3.4). The decline in numbers of taxa and increases in the abundance of certain species, principally C. curvispinum, to very high levels was responsible. Therefore, as with pollution indexes, values from rhithron and potamon zones cannot realistically be compared.

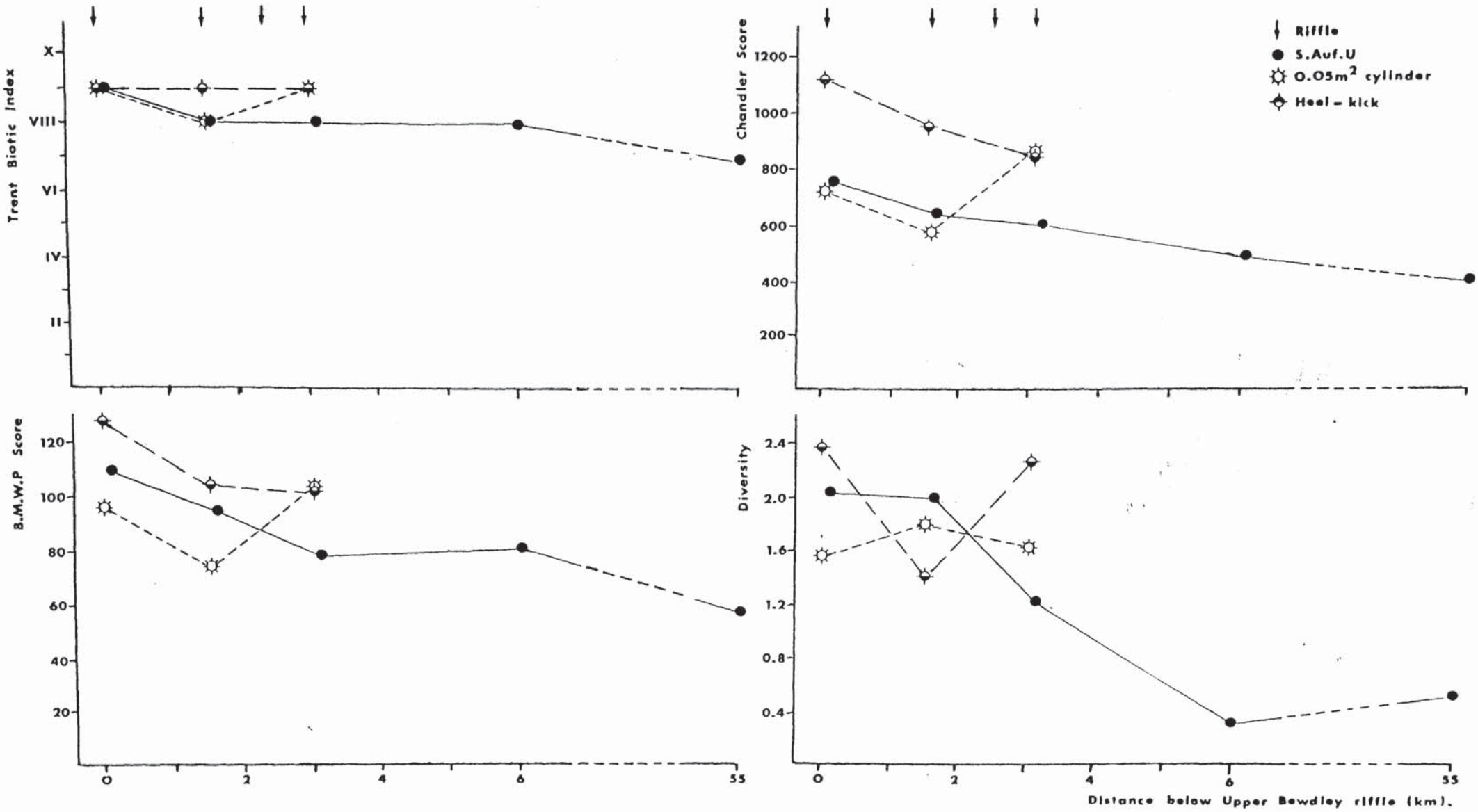


FIGURE 3.3.4 : POLLUTION INDEXES AND DIVERSITY IN THE RHITHRON-POTAMON ZONE OF THE R. SEVERN

3.3.3.2 Colonisation of S.Auf.U. at Different Distances Downstream of a Riffle

Physicochemical data is displayed in Appendix Table 9.3. Values for all variables measured were relatively constant throughout the study area.

Raw invertebrate data from the final riffle and S.Auf.U. below it are shown in Appendix Tables 8.9 and 8.10 while anovar tables are shown in Appendix Table 10.4. Anovar revealed that the numbers of taxa collected on S.Auf.U. did not significantly change downstream of the final riffle (Table 3.3.3). The raw data indicated a slight decline between 800 and 1600m downstream on both individual and groups of 3 S.Auf.U. (Table 3.3.4, Fig. 3.3.5); the number of taxa collected on 3 S.Auf.U. declined from 32 to 28. Total numbers of individuals did, however, change significantly downstream of the final riffle the line of best fit producing a clear peak 400m below the riffle (Fig. 3.3.6). Girton (1980) collected fewer individuals beyond 800m below a riffle in the R. Blythe.

Changes in the number of individuals were again principally due to changes in the number of C. curvispinum which had a similar significant cubic polynomial (Table 3.3.3) and line of best fit (Fig. 3.3.6). Numbers of Ephemoptera, Ephemerella ignita, Coleoptera, chironomid larvae, Tanytarsini and Tanypodinae declined significantly below the final riffle (Table 3.3.3, Fig. 3.3.6). Numbers of Ephemoptera, mainly due to declining numbers of E. ignita, Coleoptera and chironomid larvae declined fairly continuously over the stretch 200m to 1600m below the riffle (Figs. 3.3.6 and 3.3.7) whereas the Tanytarsini and Tanypodinae declined in numbers beyond the 200m point. Girton (1980) observed similar declines in the abundance of mayflies and Tanytarsini on S.Auf.U. below a riffle in the R. Blythe. Declining numbers of mayflies were in this case due to fewer Caenis moesta. Since many mayflies, beetles and chironomid larvae are primarily riffle species these significant declines are not surprising.

Declines in the abundance of Hydropsyche spp., principally over 200-800m below the riffle, and G. pulex 1600m below the riffle were also observed (Fig. 3.3.7). As above this is not unexpected because

TAXON	Trans-formation	F		
		Linear	Quadratic	Cubic
TOTAL TAXA	None	4.50	1.10	0.17
TOTAL INDIVIDUALS	None	0.96	3.36	8.16*
Asellus aquaticus	ln(x+1)	0.66	0.40	0.12
Corophium curvispinum	None	1.09	3.71	10.62*
Gammarus pulex	ln(x+1)	1.45	2.23	0.15
Ephemeroptera	ln x	5.80*	0.16	0.35
Caenis moesta	ln(x+1)	1.75	0.47	0.30
Ephemerella ignita	ln x	10.70*	0.18	0.77
Hydropsyche spp.	ln(x+1)	2.23	2.57	0.20
Polycentropus flavomaculatus	None	0.20	3,52	0.23
Cased Trichoptera	None	0.41	4.56	0.98
Coleoptera	None	9.02*	4.25	4.33
Agrion splendens	ln(x+1)	0.44	1.22	9.82*
Chironomidae (L)	ln x	19.47**	1.07	0.99
Chironomini (L)	ln(x+1)	4.95	0.46	9.22*
Tanytarsini (L)	ln(x+1)	5.32*	6.40*	36.48***
Orthocladiinae (L)	ln(x+1)	5.23	0.81	0.05
Tanypodinae (L)	None	26.35***	18.77**	19.72**
Gastropoda	ln x	5.08	0.05	2.14
Lymnaea peregra	ln(x+1)	26.18***	1.75	0.33
Bithynia tentaculata	ln(x+1)	2.27	0.24	2.16
Potamopyrgus jenkinsi	None	0.38	0.30	0.37
Theodoxus fluviatilis	ln(x+1)	9.09*	49.07***	11.13*
Viviparus viviparus	ln x	0.62	0.37	0.56
Sphaeriidae	ln(x+1)	2.23	1.01	0.65
Hirudinea	None	3,51	5.82*	1.33
Erpobdella octoculata	None	4.14	0.20	1.54
Glossiphonia complanata	None	3.22	2.30	1.49
Helobdella stagnalis	ln(x+1)	0.71	2.24	0.08
Oligochaeta	ln(x+1)	0.19	2.74	0.33
Tricladida	None	0.01	0.68	1.99
Dendrocoelum lacteum	None	1.22	0.61	2.26
Dugesia polychroa	ln(x+1)	0.22	0.92	1.07
Polycelis tenuis	None	0.05	0.38	2.66

TABLE **3.3.3** : ANOVAR INCORPORATING BREAKDOWN OF THE TREATMENTS INTO POLYNOMIALS (WITH SIGNIFICANCE LEVELS) OF THE EFFECT OF DISTANCE DOWNSTREAM OF A RIFFLE ON NUMBERS OF TAXA AND INDIVIDUALS OF DIFFERENT TAXA COLONIZING S.AUF.U.

DISTANCE BELOW FINAL RIFFLE	Taxa/sample ($\bar{x} \pm 95\%$ C.L.)	Taxa in 3 samples	Indiv in 3 samples	Diversity
Riffle (cyl)	20.67 ± 9.40	30	732	2.0723
Riffle (net)	15.33 ± 9.40	25	890	1.5503
100m	23.00 ± 6.57	29	2226	1.1766
200m	23.33 ± 12.25	33	1517	1.9533
400m	24.00 ± 7.03	31	3918	0.6194
800m	23.67 ± 3.79	32	3002	1.1361
1600m	19.33 ± 3.79	28	1888	1.4641

TABLE **3.3.4** : NUMBERS OF TAXA AND INDIVIDUALS AND DIVERSITY IN AND BELOW THE FINAL RIFFLE OF THE R. NIVE IN JUNE/JULY 1980.

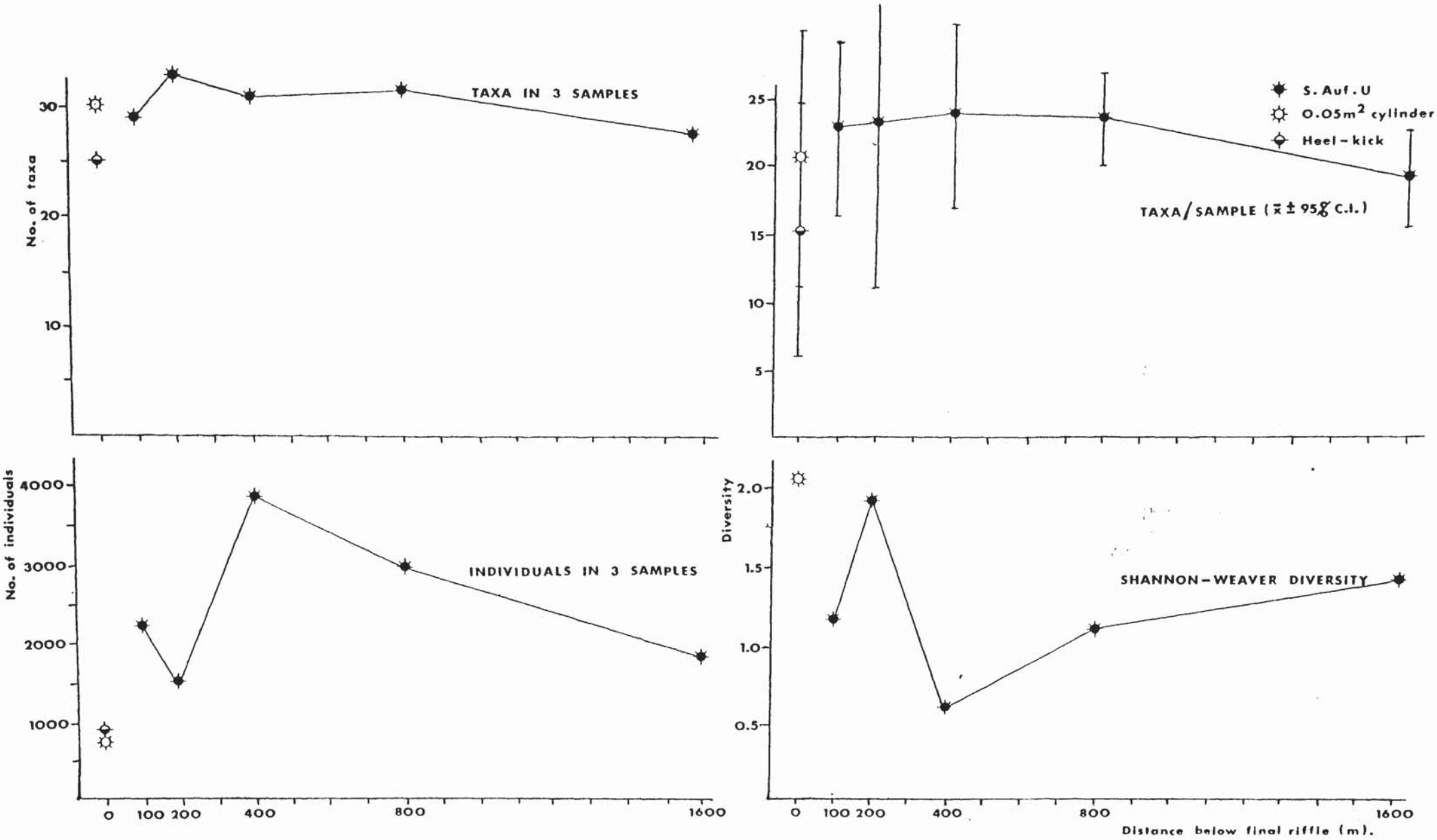


FIGURE 3.3.5 : NUMBERS OF TAXA AND INDIVIDUALS AND DIVERSITY IN SAMPLES COLLECTED IN AND BELOW THE LOWERMOST RIFFLE OF THE R. SEVERN

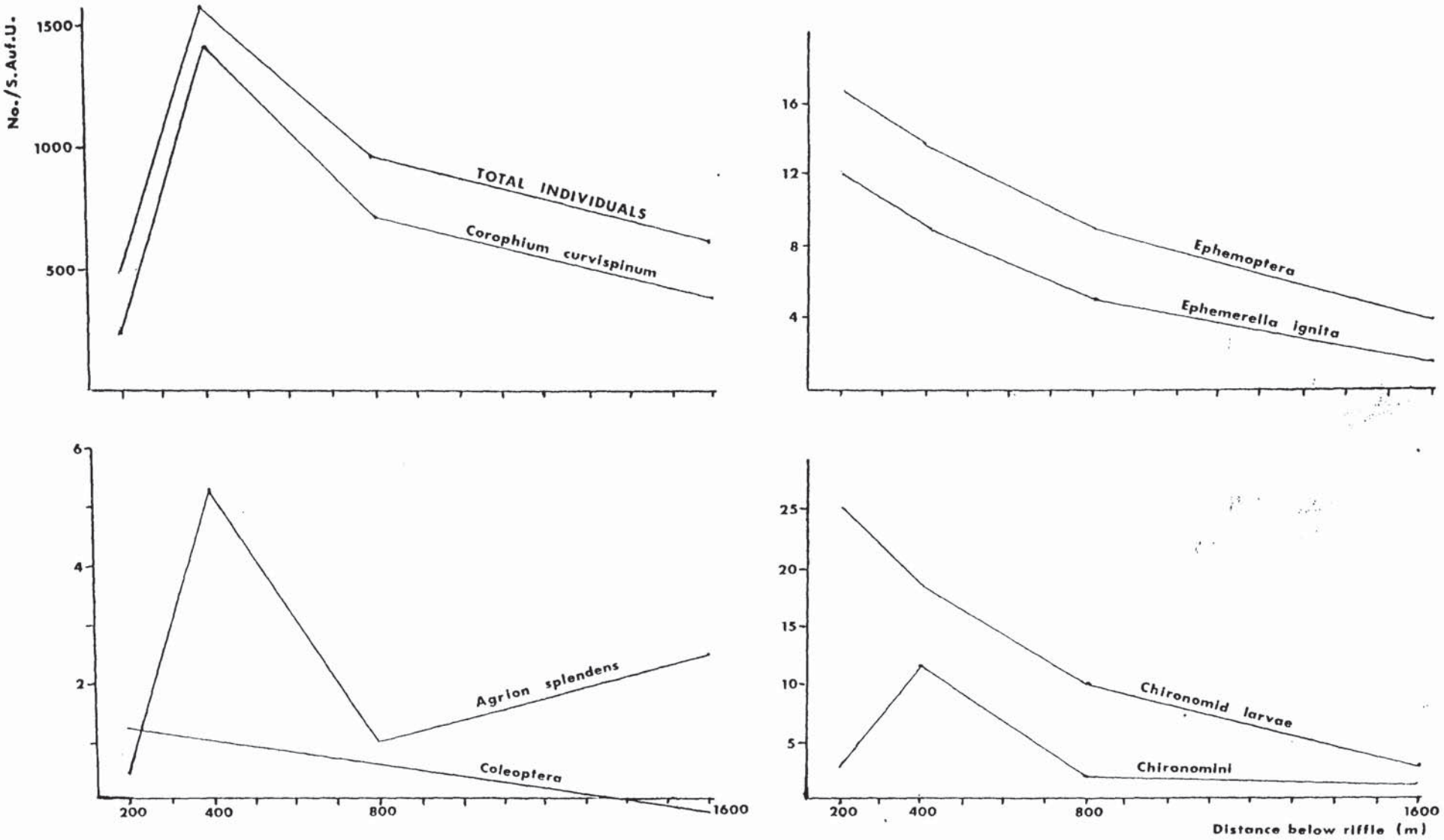
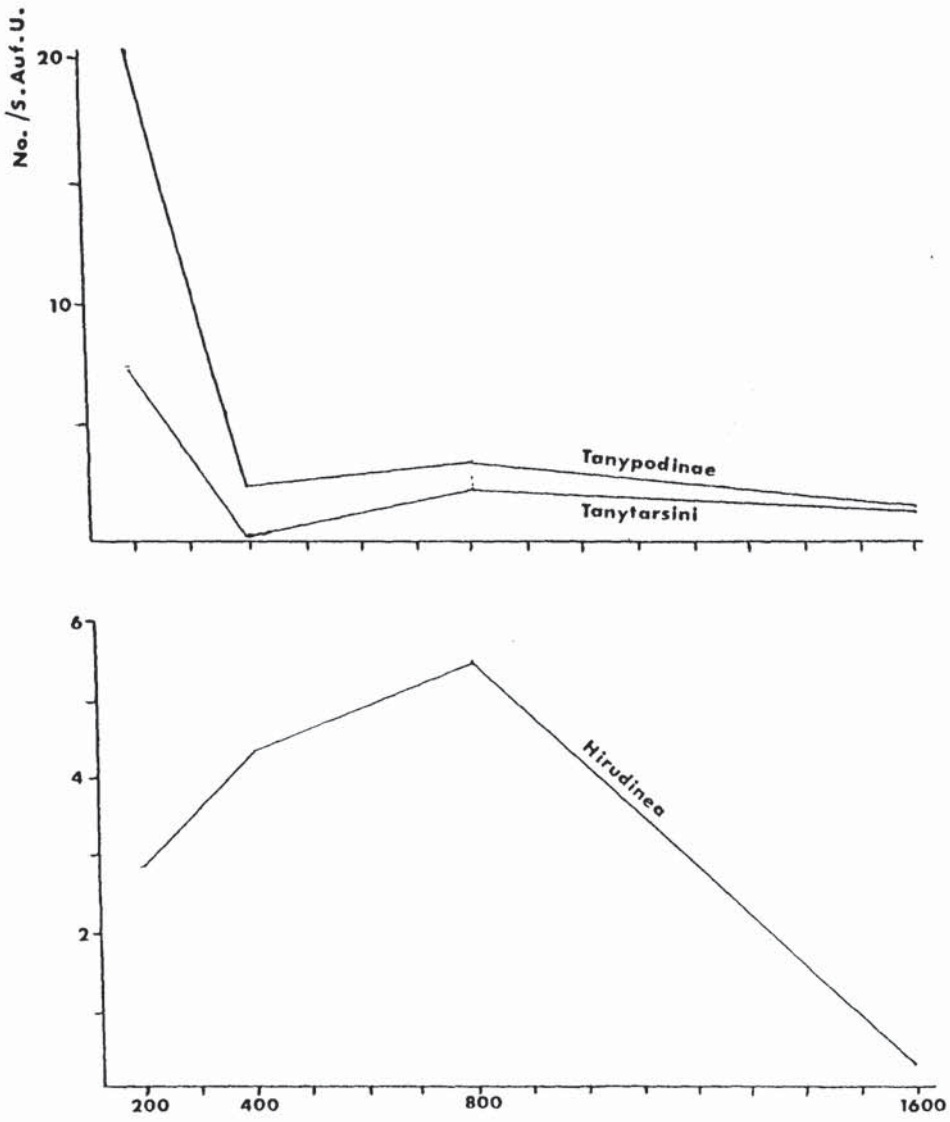


FIGURE 3.3.6 : LINES OF BEST FIT ESTIMATED BY ORTHOGONAL POLYNOMIAL ANALYSIS FOR NUMBERS OF INDIVIDUALS AND THE ABUNDANCE OF DIFFERENT TAXA ON SINGLE S.AUF.U. 200-1600m BELOW THE LOWERMOST RIFFLE OF THE R. SEVERN



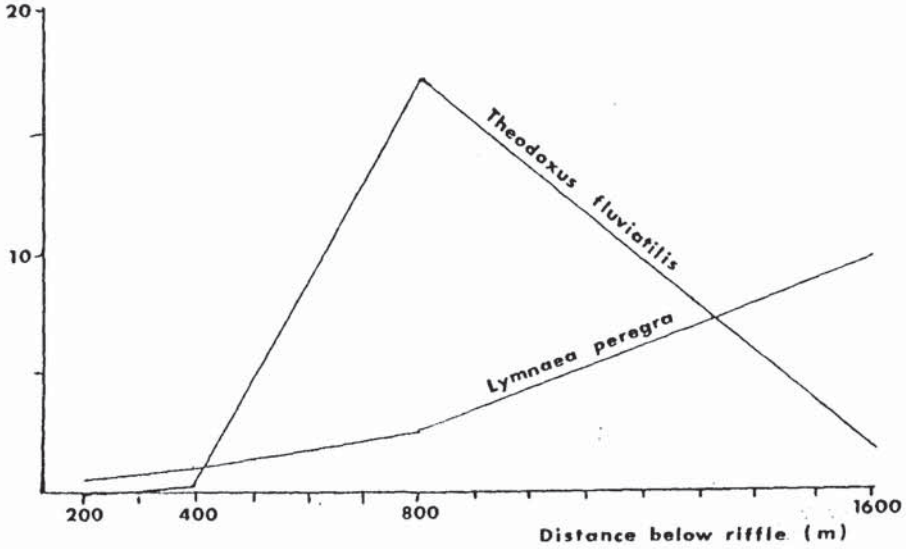


FIGURE 3.3.6 continued

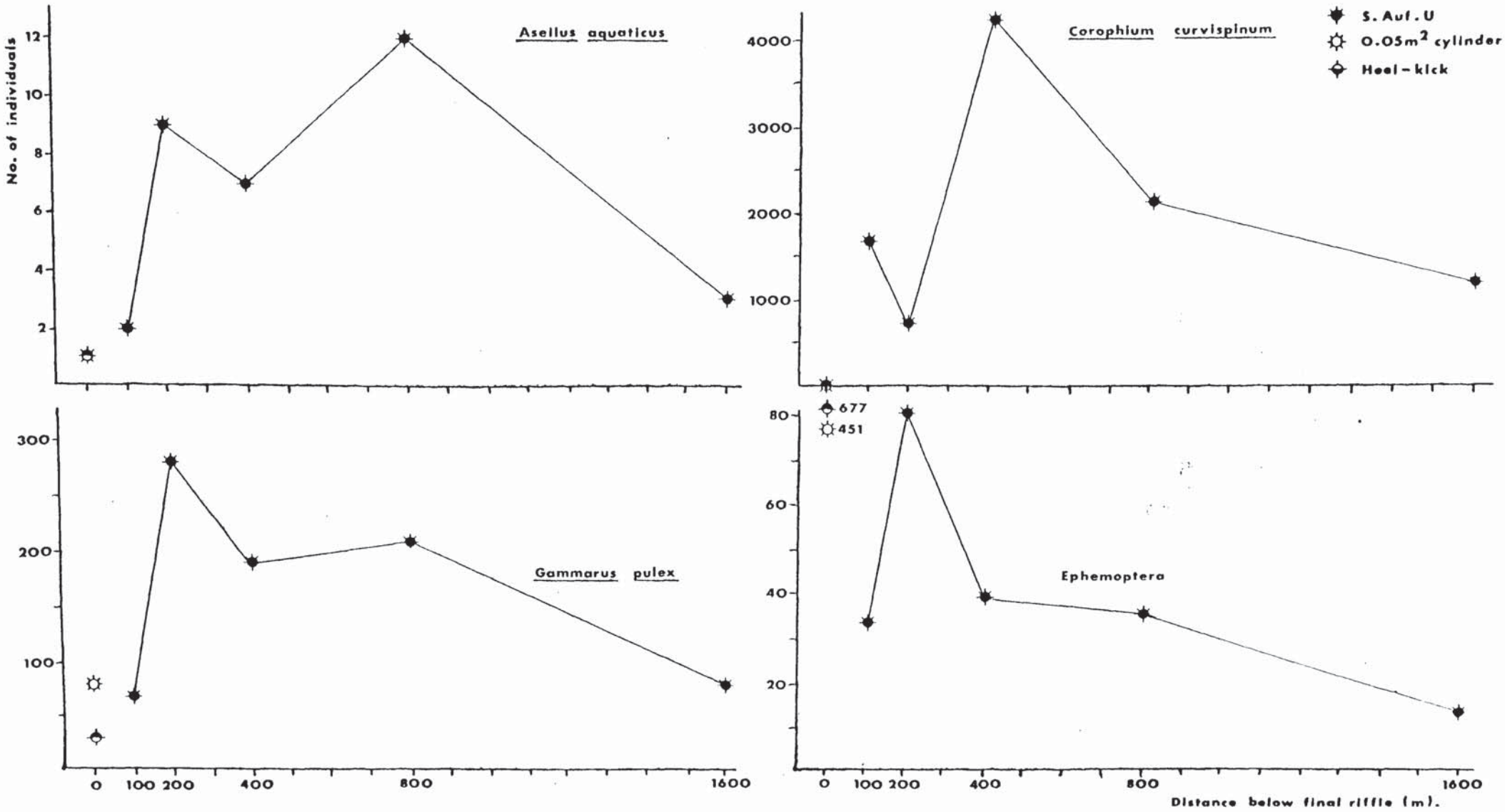


FIGURE 3.3.7 : ABUNDANCE OF DIFFERENT TAXA IN GROUPS OF THREE REPLICATE SAMPLES COLLECTED IN AND BELOW THE LOWERMOST RIFFLE OF THE R. SEVERN

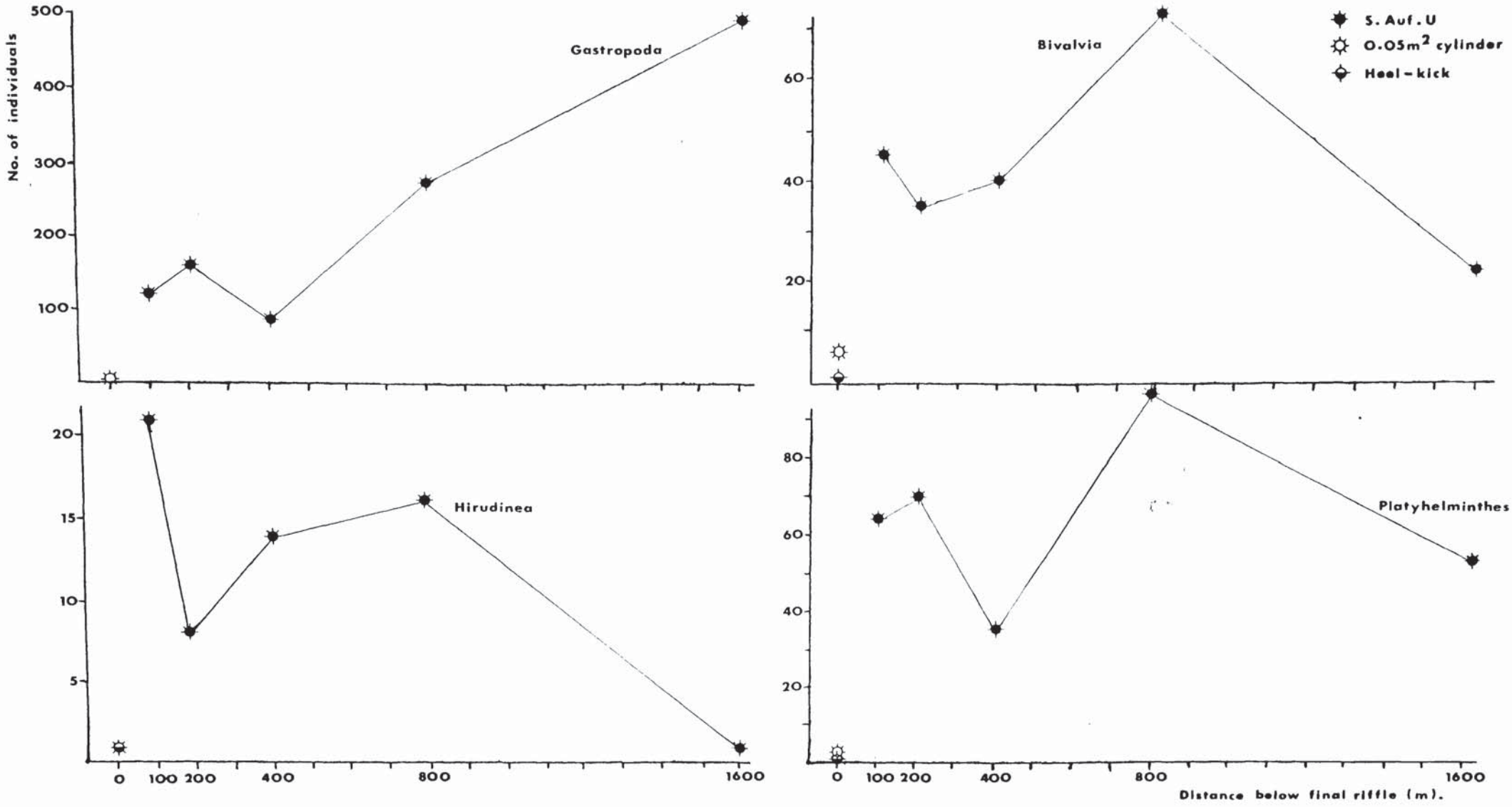


FIGURE 3.3.7 continued

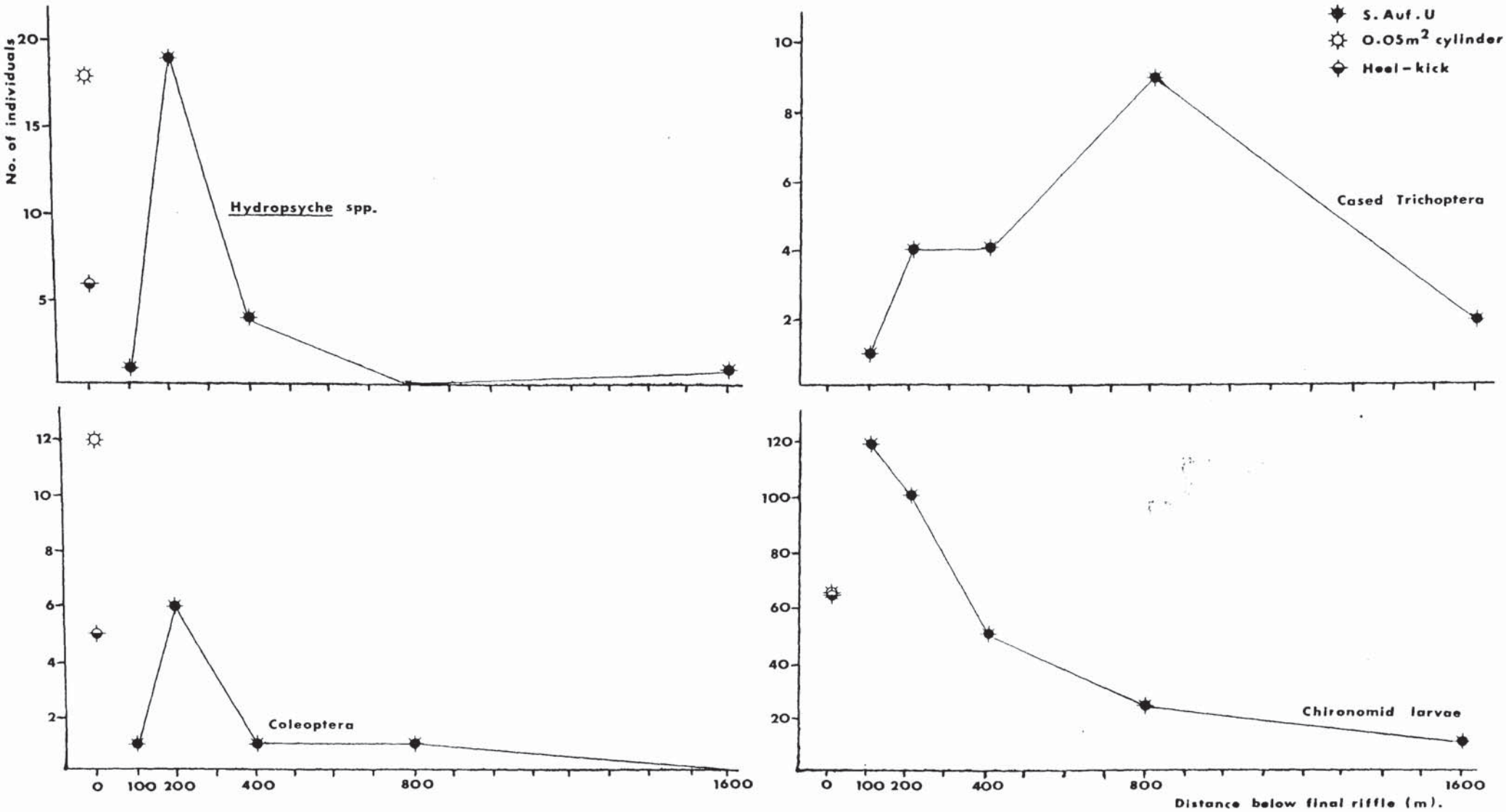


FIGURE 3.3.7 continued

both taxa are primarily riffle species. Girton (1980) obtained a similar decline in the abundance of Hydropsyche spp. up to 440m below a riffle in the R. Blythe but found that G. pulex on the whole increased in abundance downstream of the studied riffle. The presence of marginal vegetation as a source of colonisers may have been responsible for the latter.

The abundance of L. peregra significantly increased over the stretch 200-1600m below the riffle while T. fluviatilis and Hirudinea also changed significantly in numbers over the study area the lines of best fit indicating an increase up to 800m. below the riffle followed by a decline (Table 3.3.3). T. fluviatilis is exclusively a lowland river species so its sudden appearance in abundance 800m below the final riffle is no surprise. L. peregra and Hirudinea have also been found widely on S.Auf.U. in lowland rivers by Girton (1980) and in work for this thesis (See Section 5.4.2.1). Numbers of gastropods in general increased downstream of the final riffle (Fig. 3.3.7). They were observed to be one of the major taxa colonising S.Auf.U. in lowland rivers by Girton (1980) and this is emphasised by the results in Chapter 5.

Significant changes in abundance downstream of the riffle were also recorded for Chironomini which were most abundant at the 100m and 400m sites and Agrion splendens for which no clear pattern in abundance was recognisable from the lines of best fit (Fig. 3.3.6).

Shannon-Weaver diversity dropped abruptly from 1.9533 200m below the riffle to 0.6194 400m below and then gradually recovered to 1.4641 1600m below (Table 3.3.4, Fig. 3.3.5).

3.3.4 Conclusions

1. Fewer taxa but more individuals colonised S.Auf.U. in the potamon zone than in the rhithron zone pools.
2. C. curvispinum and gastropods were distinctly more abundant on S.Auf.U. in the potamon zone whereas Hydropsychidae were much less abundant. Mayflies and Atherix sp. were largely restricted to the riffles.

3. The decline in the number of taxa over the rhithron-potamon zone was reflected in depressions in the values of pollution and diversity indexes. The much greater abundance of certain species also depressed the latter in the potamon zone. Values for pollution indexes calculated using S.Auf.U. were, on the whole, lower than those obtained from comparable riffles. It can be concluded that index values obtained from potamon zones are not comparable with rhithron zones and that corresponding riffles and pools cannot realistically be so compared. Completely different pollution indexes are necessary for the potamon zone as most of the high scoring riffle taxa are absent.

4. No clear increase or decrease in either the number of taxa or the number of individuals on S.Auf.U. was apparent downstream from the final riffle.

5. Numbers of Ephemoptera mainly due to E. ignita, Coleoptera and chironomid larvae largely due to Tanytarsini and Tanypodinae clearly declined beyond the final riffle. To a lesser extent declines in the abundance of G. pulex and Hydropsyche spp. were also observed. On the other hand the abundance of L. peregra significantly increased downstream.

6. No clear pattern in diversity was observed below the final riffle.

4. THE EFFECTS OF WATER QUALITY ON S.AUF.U. COLONISATION AND GASTROPOD ECOLOGY IN SIMULATED STREAMS

4.1 Introduction

The simulated streams in question were located at the Aston University Applied Hydrobiology Field Station at Checkley, Staffs. The artificial earth channels at Checkley provided an ideal opportunity to study the effect of water quality on S.Auf.U. colonisation as each channel had a different water quality while they were hydrologically very similar and also similar in hardness and alkalinity. In so far as they were artificial and built specifically for pollution studies these channels cannot be considered synonymous with a natural river. Instead they really represent an intermediate situation between laboratory studies on pollution and field studies on rivers though possibly leaning strongly toward the latter. In an attempt to reflect how well they represented the situation in a natural river the R. Tean, from which water for the channels was taken and into which the same effluent supplying the channels falls, was sampled at three stations chemically similar to the three channels.

One particularly important aspect of the project was the recording of the presence or absence and relative abundance of gastropods in relation to the type and degree of pollution (see Chapter 5). However, effluents can exert detrimental or even beneficial effects on animal species by affecting mortality, competition, reproduction and/or growth. Indeed, the way in which it affects a particular species can change with the concentration of pollutant. Many workers have found chemicals to significantly raise mortality above a certain threshold while principally affecting reproduction and/or growth at lower concentrations. Much of this work has been done on Daphnia spp., e.g. Biesinger and Christensen (1972), while Flannagan (1974) and Canton and Slooff (1977) have obtained such results with snails. For this reason it was deemed necessary to not only monitor a wide range of different sites for presence or absence of gastropods but at selected sites to monitor population dynamics so that biomass, size class distribution, growth and reproduction were assessed at different times of the year. Once again the Checkley channels were considered worthy of detailed study for the reasons mentioned above.

4.2 Site Description

The effects of an oxidised sewage effluent were investigated at the University of Aston Applied Hydrobiology Field Station at Checkley, Staffs. (Grid. ref. SK035373) (Fig. 4.1). Three artificial stream channels had been excavated in marl soil adjacent to the R. Tean (Fig. 4.2). Each channel was 300m long comprising two 90m x 1m (width) x 20cm (depth) riffle sections alternating with two 60m x 1.25m x 40 cm pool sections. The riffle sections contained gravel and pebbles of 1.0 cm to 4.0 cm diameter while the pools contained silt that had accumulated naturally. A gradient of $5^{o}/oo$ producing a flow of 43 cms^{-1} existed in the riffle sections whereas $0^{o}/oo$ gradient and flow of 10 cms^{-1} was present in the pool sections.

River water from the R. Tean, a chemical class 1A river (S.T.W.A., 1979b), and effluent from the adjacent Blithe Valley Sewage treatment works were used to supply the channels. The central channel A carried 100% river water while the lateral channels B and C carried 25% effluent / 75% river water and 50% effluent / 50% river water respectively.

Owing to the similarities of the channels in parameters other than pollution, differences in the biota could largely be attributed to pollution. However, possible interfering factors had developed during colonisation of the channels; macrophytes had grown in channels A and B and large amounts of filamentous green algae, mainly *Cladophora* spp., had developed in channels B and C. *Potamogeton crispus* was very abundant in the pools of channel A, so much so that it had to be cleared from time to time to prevent flooding. In contrast, channel B had much *Elodea canadensis*. *Callitriche stagnalis* was also present in channel A, while channels B and C had some *Leptodictyon* sp.; quantities of these were, however, small. It is conceivable that the macrophytes and algae could affect the distribution and abundance of snails in the channels. Hubendick (1958) states that macrophytes can provide snails with a firm substratum and shelter from the current, and Pip and Stewart (1976) found *Physa gyrina* and *Lymnaea stagnalis* to significantly occur in vegetated areas as opposed to bare areas in Lake Manitoba. Meanwhile, Calow (1970) has shown that *L. peregra* primarily feeds on filamentous green algae.

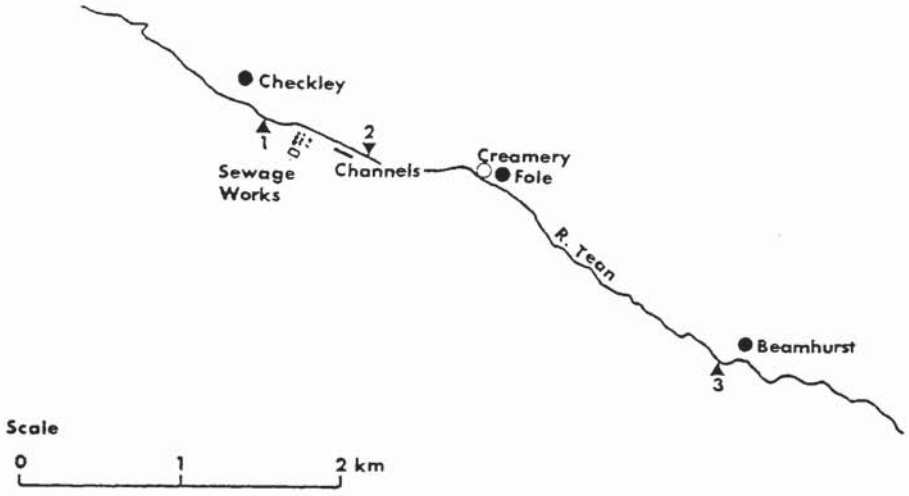


FIGURE 4.1 : R. TEAN SAMPLING SITES AND LOCATION OF THE CHECKLEY CHANNELS.

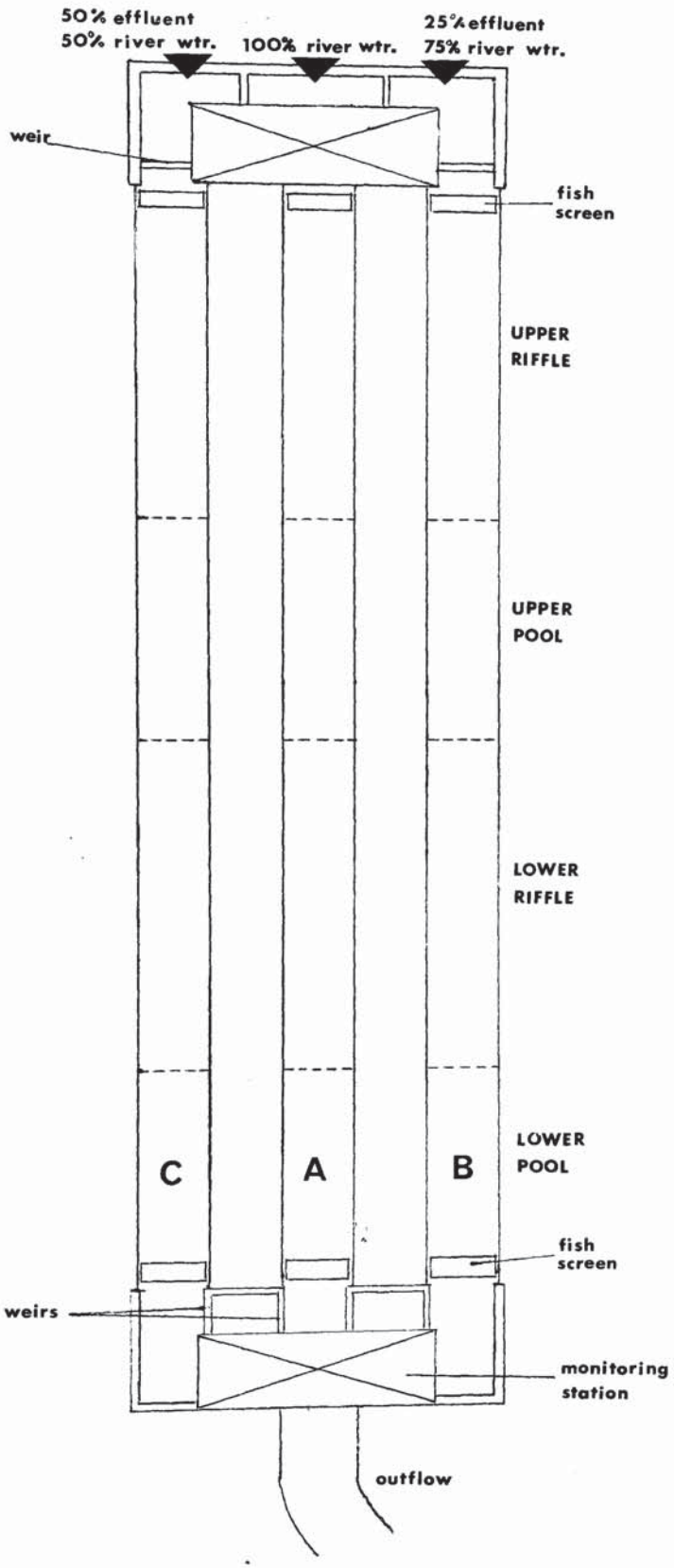


FIGURE 4.2 : DIAGRAM OF THE CHECKLEY CHANNELS (not to scale).

For this reason, it was deemed necessary to sample macrophytes and algae in conjunction with snails.

To compare the artificial channels with natural conditions the adjacent R. Tean was sampled upstream and downstream of the effluent at points 1, 2 and 3 (Figure 4.1) (Grid refs. SK 030375, SK 036373 and SK 059361 respectively). Site 3 received dairy effluent from Fole in addition to effluent from the Blithe Valley Sewage Works. The river consisted of regularly alternating riffle and pool sections in a strongly meandering course.

4.3 Methods

4.3.1 Physicochemical Sampling

Water samples were taken from the channels regularly (several times a week) over 3-month periods. Variables measured were the same as in section 3.1.2 with the exception of BOD_5. In addition suspended solids were monitored along with total and filtrable cadmium, chromium, copper, lead, nickel and zinc by atomic absorption spectrophotometry. Five, 50- and 95- percentiles were calculated for the data over each 3 month period. This data was supplied by courtesy of the research team at Checkley Applied Hydrobiology Field Station.

Water samples from the R. Tean were taken monthly at Tean 1 and Tean 3 over the period August 1979 to July 1980 (courtesy of H. Hirst). Samples were also taken from Tean 2 on the S.Auf.U. immersion date. Variables measured were as in section 3.1.2.

4.3.2 S.Auf.U. Sampling

Each channel was sampled monthly using 28-day* immersion periods with two S.Auf.U. for one year (March 1979 to March 1980). One sampler was anchored to the bottom in the central 20m of the upper and lower pools. A 7mm diameter steel rod pushed through one end of the S.Auf.U. with red rubber rings, located immediately above and below the unit, was used to anchor each one. In addition to sampling the channels, pool sections of the R. Tean were sampled with three

* except over Christmas 1979.

S.Auf.U. at stations 1, 2 and 3. (Fig. 4.1). Stations 1 and 3 were sampled on three occasions while station 2 was sampled once. In both channels and river S.Auf.U. were immersed for four weeks. Following this, macroinvertebrates were removed from the S.Auf.U. in the field, put in containers and transported back to the laboratory where they were preserved in 4% formalin when necessary. All macroinvertebrates were recorded except Hydracarina and Naididae which were lost in preservation.

Subsampling was necessary with several taxa. The largest subsamples taken were 1/64 for Asellus aquaticus and 1/16 for Potamopyrgus jenkinsi and oligochaetes. One-quarter subsamples were taken by counting the number of individuals in four diagonal squares of a 16-square tray. Larger subsamples were taken by first sucking the sample through a divided filter paper using a vacuum pump. Three different pollution indexes - the Trent Biotic Index (Woodiwiss, 1964), the Chandler Score (1970) and the B.M.W.P. Score (Department of the Environment, 1980) - and two diversity indexes - Simpson's (1949) and the Shannon-Weaver (1947)(natural logs) were calculated for pairs of S.Auf.U. for each immersion period.

4.3.3 Gastropod Populations and Biomass

Gastropod populations of the natural benthos were estimated by taking three "Aston" cylinder samples from the lower riffle and upper pool of each channel. Samples were taken from the middle and both sides of each channel of each occasion. Samples were taken monthly from January 1979 to June 1980 in the lower riffles using a $0.1m^2$ cylinder up to May 1979 inclusive and thence a $0.05m^2$ cylinder. Sampling of the upper pool was less frequent; samples were taken with a $0.1m^2$ cylinder every two months from October 1979 to September 1980. Only areas of pool free from macrophytes were used in this set of samples. S.Auf.U. sampling also gave some idea of the relative populations in the three channels but the regular fluctuations showed this method to be rather inaccurate. No subsampling was required for Lymnaea peregra but in some months 1/4 or 1/16 subsamples of P. jenkinsi were taken in the same manner as in the S.Auf.U. sampling above.

Biomass was estimated by taking the dry weights of all those snails counted directly except for the first three months of S.Auf.U. sampling when dry weights were estimated by log weight - length regression lines for each channel (Table 8.11). Snails to be weighed were washed thoroughly under a running tap and then dried in an oven at 105^{o}F for at least 36h.

Again, most of the samples were preserved in formalin. Invertebrates, in general, tend to lose about 2 - 4% of their weight in formalin after four months (Borutski, 1934). However, comparisons of preserved snails with fresh ones showed there to be no clearly detectable weight loss during the first three months of preservation, after which weight loss increased rapidly. Consequently, all biomasses were estimated within three months of sampling.

Wherever possible both populations and biomass of snails were divided into separate cohorts. A cohort here is taken to mean a group of individuals born to a particular generation.

4.3.3.1 Division into Separate Cohorts

Snail populations were divided into separate cohorts principally on evidence derived from size class - frequency distributions (see later). Indeed, this method was used entirely for L. peregra. However the large degree of overlap between successive generations of P. jenkinsi precluded this. Similarly, in the past it has been found difficult to separate cohorts of continuously reproducing populations (Winberg et al., 1971). In this case, however, the combination of a relatively stable non-reproducing population of P.jenkinsi in mid-1979 and subsidiary evidence mainly from studies on reproduction enabled cohorts to be distinguished for the riffle and S.Auf.U. samples.

4.3.4 Macrophytes and Algae

In addition to sampling the upper pools in areas free of macrophytes, samples were also taken from within the vegetated areas during the late summer and autumn of 1979. Three 0.1m^{2} cylinder samples were taken from the left, centre and right of the pool section on three occasions in channel A and on one occasion in channel B.

Macrophytes were removed by hand and the dry weight of the shoots and leaves estimated after removal of the roots followed by thorough washing and drying for at least 36h at 105°F. Snails from both the macrophyte and the upper layers of the sediment were collected, counted and weighed as above.

For each date when sampling of bare and vegetated areas coincided, differences in the abundance of each species of snail between these two areas were assessed using t-tests. When channels A and B were sampled simultaneously, values of r^2 were calculated for the relationship between snail abundance and macrophyte dry weight for the two channels together. Log(x + 1) transformations were used to stabilise the variances as distributions of both snails and macrophytes were contagious ($s^2 > \bar{x}$). The need for transformations was explained in Section 3.1.2 .

The effect of the quantity of filamentous green algae present on snail abundance was investigated during June 1978 when six $0.1m^2$ riffle cylinder samples were taken from each riffle in each channel. In addition to the snails, algae was collected from within each cylinder sample and its dry weight estimated after washing and drying as above. Values of r^2 for the relationship between snail abundance and algae dry weight, were calculated for each riffle in each channel separately and then for the three channels together. Once again log (x + 1) transformations were used for both parameters since distributions were contagious.

4.3.5 Size Classes and Growth

All snails counted in the monthly riffle samples over the period June 1979 - 1980 and bimonthly cylinder pool samples were divided into

1mm size classes and size class - frequency histograms constructed. Snails were divided into particular size classes by measuring them against a background of millimetre graph paper - this enabled large numbers to be measured in a reasonable time. Size class - frequency distributions were divided into separate cohorts wherever possible.

Growth rates were calculated for cylinder riffle and pool sampling and S.Auf.U. sampling where separate cohorts could be distinguished, and where it could be established that there was no recruitment of new individuals from births or any large die off of adults, both of which would suppress any calculated rate. This meant that, while growth rates were calculated for most of the life cycle in L. peregra, growth rate calculations were restricted to May to September 1979 in P. jenkinsi. Too few individuals were collected to calculate growth outside channel A in the latter species.

Three growth rates were calculated:-

1. The absolute daily weight gain per statistical individual:

$$v = \frac{\overline{W}_{t_2} - \overline{W}_{t_1}}{t_2 - t_1}$$

where $\overline{W}_{t_2}$ is the average weight at time t_2 and $\overline{W}_{t_1}$ is the average weight at time t_1.

2. The relative daily weight gain rate:

$$v' = \frac{2\ (\overline{W}_{t_2} - \overline{W}_{t_1})}{(t_2 - t_1)\ (\overline{W}_{t_2} + \overline{W}_{t_1})}$$

This gives the growth rate per unit weight of an organism.

3. The instantaneous weight gain rate: this represents the weight increment during an infinitely short time interval and is expressed by the differential:

$$g = \frac{dw/dt}{w}$$

The instantaneous growth rate is calculated using:

$$g = \frac{\ln \overline{W}_{t_2} - \ln \overline{W}_{t_1}}{t_2 - t_1}$$

Growth rates were calculated using the actual mean individual weights for a specific cohort obtained from samples of P. jenkinsi from the riffle but in all other cases the mean weight-time relationships were smoothed using lines of best fit estimated by regression analysis. Linear lines were fitted to all data except for the L. peregra channel B riffle data, for which a cubic polynomial provided the best curve, as this was the only line to deviate significantly from linearity (Table 4.1). The method is described in Snedecor and Cochran (1967), p.455. Analysis of covariance was used to see whether the slopes of the regression lines for different channels were significantly different from one another. As these lines describe the change in weight with time significant differences in slope would indicate significant differences in growth rate. This significance test is described in Snedecor and Cochran (1967), p. 433-435.

Another aspect of growth that was investigated was the log weight - length relationship in L. peregra in the channels. The original regression lines constructed (Table 8.11) to estimate biomass suggested that the gradient might differ between channels, so regression lines for individual snail weights and lengths were constructed for an old cohort and a young cohort. On each occasion 30 snails were picked by hand from the sides of each channel, measured to the nearest 0.1mm length and weighed individually using the same technique as in the estimation of biomass.

Production was not estimated for any samples because of the inaccuracies in population sampling.

4.3.6 Reproduction

Reproduction was investigated in some detail as it has a direct effect on population levels. The study of reproduction in L. peregra was comparative between channels only. Between February and

↓ SAMPLING	CHANNEL →	F		
		A	B	C
Lower Riffle		-	10.71*	0.31
Upper Pool		0.87	0.17	0.03
S. Auf.U.		0.22	0.78	0.12

TABLE 4.1 : F-VALUES (WITH SIGNIFICANCE LEVELS) FOR DEVIATION FROM LINEARITY OF MEAN WEIGHT - TIME RELATIONSHIPS IN *L. peregra*.

September 1980 clean 50cm x 10cm polythene strips were pinned at their upstream end using 5in nails to the sides of the lower riffles and upper pools. A preliminary study had discovered that this was the best place to anchor them as ones on the bottom readily silted up and floating ones rapidly sank. Six were anchored to alternating sides of each riffle and pool throughout their length. They were recovered monthly and the number of egg masses on each counted. Egg masses were removed from each strip and carried in containers full of water to the laboratory where the number of eggs were counted. Where there were 20 or less masses on a strip the eggs in all masses were counted, when there were more than 20, the eggs in a subsample of 20 masses were counted. Differences in the number of egg masses and eggs per strip and the number of eggs/strip/adult/m^2 between channels were assessed for significance using the Kruskal-Wallis analyses of variance (anovar). This non-parametric test was used as distributions of both eggs and adult snails were contagious. A one-way parametric anovar was used to detect significance differences in the number of eggs/mass between channels. Riffles and pools were treated separately for all significance tests. Adult snails were classed as those at least 6mm long as this was the shortest length of snail observed breeding in the laboratory.

In contrast to L. peregra, P. jenkinsi is ovoviviparous, the young being retained in a "marsupial" brood pouch. This enabled an absolute study of reproduction in this species. Snails were collected by various means - from artificial substrates, macrophytes and heel-kicks. Wherever possible 30 individuals of each of the two largest size classes, 5.0 - 5.4mm and 4.0 - 4.9mm length, were collected from channels A and B monthly. However the small numbers of snails present in channel B meant that usually much fewer snails were collected from this channel despite using all the methods listed above. In fact, none could be collected at all during quite a few months. Regular monthly sampling concentrated on these two size classes as microscopic inspection revealed that they were usually the only size classes holding embryos that were near hatching. Embryos were defined as being near hatching on the following cirteria:-

1. They were differentiated into soft parts and shell.

2. The shell had acquired a spiral form with several whorls.
3. The embryo had burst free from its embryo sac or filled the whole of it.

Snails were crushed and the number of embryos in each adult counted. The number approaching hatching was estimated after taking a sub-sample of five embryos from up to fifteen snails and looking at them under a high power microscope. Where samples were obtained from both channels A and B, differences in the total number of embryos and the number near hatching were assessed for significance using t-tests separately for each size class.

The final aspect of P. jenkinsi reproduction that was investigated was embryo development. The proportion of snails in each size class with embryoid material and embryos in various states of development were compared in channels A and B on three occasions along with the proportion of embryos approaching hatching. The size class - frequency distributions of embryos in the two largest size classes of snail were also observed. Size class - frequency distributions of all distinguishable embryos and embryos near hatching were compared on three occasions at different stages in the age of a cohort while differentiated and undifferentiated embryos size distributions were compared once. Embryos were measured to the nearest 5μm under a high power microscope with fitted eyepiece micrometer. X^2-tests were carried out on the embryo size class - frequency distributions to see if there were any significant differences between channels. These tests were performed on the actual numbers of embryos not the percentages shown in the tables. All the data on embryo development were assembled by taking subsamples of five embryos from up to 30 snails of each size class and observing them under a high power microscope.

4.4. Results and Discussion

4.4.1 Physicochemical Data

Five, 50-and 95-percentiles of the physicochemical variables measured in the Checkley channels are shown in Appendix Table 9.4. The sewage effluent depressed the D.O. levels only slightly, the lowest 5-percentile

for channel C being 7.0mgl^{-1}. Levels of toxicants, both ammonia and filtrable metals, were raised along with the nutrients nitrate and phosphate. Ammonia reached quite high levels in channels B and C having 95-percentiles of 6.5 and 7.5mgl^{-1} N-NH_3 in these two channels respectively. Chromium was elevated the most among the metals, the 95-percentiles for channel C being over a factor of 10 greater than those for channel A. Copper and zinc were raised the most after chromium, 95-percentiales for channel C being on average a factor of 4 above those for channel A. pH, hardness and alkalinity were affected only a little by the addition of effluent.

Physicochemical data for the R. Tean is shown in Appendix Table 9.5. D.O. and P-PO_4 levels at Tean 1, 2 and 3 were similar to those in channels A, C and B respectively. pH levels at Tean 2 and 3 were also similar to those of the effluent containing channels. The pH at Tean 1, however, was clearly lower than that in channel A. Other differences from the channels were that the river was softer, it had a mean total hardness of 211 at Tean 1 whereas channel A had 50- percentiles of 320, 315 and 230, and that the maximum ammonia content of the river at Tean 3 (1.5mgl^{-1} N-NH_3) was much lower than the levels recorded in channels B and C, which had 95-percentiles reaching 6.5 and 7.5mgl^{-1} N-NH_3 respectively (Tables 9.4 and 9.5).

4.4.2 S.Auf.U. Sampling

The macroinvertebrates colonising S.Auf.U. in the channels during the sampling period are shown in Tables 4.2 a - f.

The macroinvertebrates colonising S.Auf.U. in the three Checkley channels reflected the differences in water quality between channels, there being a deterioration in species richness as the effluent concentration increased accompanied by vast numbers of Asellus aquaticus and worms colonising S.Auf.U. in the two effluent-containing channels. Twenty-nine taxa were recorded on S.Auf.U. in channel A compared with 26 and 18 in channels B and C. Seven taxa were unique to channel A - the mayflies Ecdyonurus dispar, Ephemerella ignita, Habrophlebia fusca and Rhithrogena semicolorata, the caddises Polycentropus flavomaculatus and Rhyacophila dorsalis and the flatworm Polycelis felina - most of which are widely regarded as intolerant of organic pollution. Three species - Baetis rhodani,

REMOVAL DATE → / ↓ TAXON	17.4	15.5	12.6	19 10.7	79 7.8	4.9	2.10	30.10	27.11	3.1*	29.1	19 26.2	80 25.3
Asellus aquaticus	3	12	3	12	18	3	1	4	6	93	85	2	12
Gammarus pulex	61	24	17	58	72	138	74	26	43	122	304	51	77
Baetis rhodani			1			2							1
Ephemerella ignita				14	6								
Habrophlebia fusca				1									
Limnephilidae				1		1		1	2	1	18	1	
Polycentropus flavomaculatus									1				
Rhyacophila dorsalis										1		1	
Brychius elevatus (L)					1			2					
B. elevatus (A)	3												
Dytiscinae (L)									1	2	3		
Sialis lutaria			1								1		
Chironomini (excl. *C. rip.*) (L)	11	19	5		1		8		51	65	2		1
Tanytarsini (L)				4		21	1	17	1		7	22	32
Diamesinae (L)	12	1	5		1			6	16	74	30	3	3
Orthocladiinae (L)	1		3	1	1	3	2	6		3		6	36
Tanypodinae (L)	1	5		7	8	6	2	1	10	15	13	3	3
Chironomidae (P)	7				1	1		2				1	2
Dicranota sp .				5	2					4	41	2	
Simulium spp.				1		8						1	1
Ancylus fluviatilis		1	1	3	8		49	19	2	3	5	3	
Lymnaea peregra	22	7	1	7	82	106	11	13	19	26	271	47	61
Potamopyrgus jenkinsi	33		1	38	176	444	71	49	1232	309	2280	864	172
Pisidium spp.	65	102	2	15	216	68	3	9	11	95	35	56	5
Erpobdella testacea		1	1			1							
Glossiphonia complanata	2	6			3	4	5	3				1	
Piscicola geometra					2		2		6	4	1		
Oligochaeta	270	372	149	40	18	6	5	21	136	137	70	1	42
Polycelis felina	1	20		5	3		1	4	83	2	65	15	72

* 5 week immersion period

TABLE **4.2 a** : CHANNEL A (Upper Pool)

TABLES **4.2** a - f: NUMBERS OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED ON SINGLE S.AUF.U IN THE CHECKLEY CHANNELS

↓ TAXON	REMOVAL DATE →			1979							1980		
	17.4	15.5	12.6	10.7	7.8	4.9	2.10	30.10	27.11	3.1*	29.1	26.2	25.3
Asellus aquaticus		5	4	7	19	37	6	1	16	9	304	38	86
Gammarus pulex	46	5	7	20	89	116	99	232	124	24	30	34	21
Baetis rhodani					6	11	12						
Ecdyonurus dispar					2								
Ephemerella ignita				6		2	1						
Habrophlebia fusca				1									
Rhithrogena semicolorata							1						
Limnephilidae	1	1	1	1				2	1	2	5	1	12
Rhyacophila dorsalis										1			
Brychius elevatus (L)				1									
Dytiscinae (L)										1	2		
Sialis lutaria	1												
Chronomini (L)	7	14	17					9	2	21	6	6	1
Tanytarsini (L)			1		8		32					22	24
Diamesinae (L)	24	1	2			1		18	22	73	105	51	21
Orthocladiinae (L)	7		1	3	1	1	9	4			1	7	4
Tanypodinae (L)		1			1		1	7	3	5		18	5
Chironomidae (P)			4										1
Dicranota sp .				1						1			
Simulium spp.									2				
Ancylus fluviatilis						20		17				1	
Lymnaea peregra	2			1	2	3	1	2	5	6	3	4	1
Potamopyrgus jenkinsi	1			29	1842	152	308	56	312	286	111	52	34
Pisidium spp.		6	4	15	3	81	1	5	29	43	19	7	22
Erpobdella testacea								4					
Glossiphonia complanata	8	6	1	1			2	1	2	3	3	2	
Piscicola geometra										1		1	
Oligochaeta	90	528	185	414				296	272	376	168	260	336
Polycelis felina	24						1	3	13	1	33	10	10

TABLE **4.2b**: CHANNEL A (Lower Pool)

↓ TAXON Removal date →	17.4	15.5	12.6	10.7	1979 7.8	4.9	2.10	30 .10	27.11	3.1*	1980 29.1	26.2	25.3
Asellus aquaticus	196	212	1232	2	800	716	1808	576	8064	44656	5280	3744	2368
Gammarus pulex			1		1	3		2	6	5	1	19	7
Baetis rhodani					1								
Limnephilidae									13			3	1
Brychius elevatus (A)							1						
Dytiscinae (L)						1		1	1	1			
Chironomus riparius (L)			1										
Chironomini (L)	4	4	2			1							
Tanytarsini (L)			5			1	1	1	2		3	13	6
Diamesinae (L)	5				1	3		5			19		
Orthocladiinae (L)	7		8			2	3		13		1	2	2
Tanypodinae (L)		3			1	11		7					2
Chironomidae (P)	1		1									1	
Dicranota sp.													
Empididae								1			1		
Simulium spp.						1	187	9	8320	5	200	194	244
Ancylus fluviatilis									1				
Lymnaea peregra	17	16	23		38	59	72	218	116	40	11	60	229
Potamopyrgus jenkinisi					1		2	4	3	1	9	1	10
Zonitoides nitidus			1										
Pisidium spp.		15			4	9	22	4	1		7	5	
Erpobdella testacea		1					1	2					
E.octoculata					1								
Glossiphonia complanata													
Oligochaeta	2124	4448	388	228	796	504	456	4		1	720		

TABLE 4.2c: CHANNEL B (Upper Pool)

†heavily clogged with *Cladophora spp.*

TAXON ↓ Removal date →	17.4	15.5	12.6	10.7+	1979 7.8+	4.9+	2.10	30.10	27.11	3.1*	1980 29.1	26.2	25.3
Asellus aquaticus	150	5472	1616	662	308	102	576	464	2528	920	2528	1440	2928
Gammarus pulex					1		1		1	2	9		2
Limnephilidae							2			2	1		3
Dytiscinae (1)									6		1		
Hydrophilidae (A)											1		
Sialis lutaria								1					
Chironomus riparius (L)					7	2							
Chironomini (L)												1	
Tanytarsini (L)											4	1	3
Diamesinae (L)	1				2	1		3	2	1	20		
Orthocladiinae (L)	1	3	5								1	1	2
Tanypodinae (L)					1	4	1	1			1		2
Chironomidae (P)	2		1										
Dicranota sp.	2	1			1						1		
Simulium spp.										66			5
Ancylus fluviatilis			1					3					
Lymnaea peregra	22	1	9	1	10	4	6		2	3	1	12	51
Potamopyrgus jenkinsi										2			1
Pisidium spp.	1	1	9	4	19	12	170	40	18	9	7	2	167
Erpobdella testacea	1												
E. octoculata											2		
Glossiphonia complanata	1				1				1				
Piscicola geometra												1	1
Oligochaeta	744	3240	3168	297	1184	1224	748	1184	1296	3	320	212	21

TABLE 4.2 d : CHANNEL B (Lower Pool)

TAXON ↓ Removal date →	17.4	1979 15.5	12.6	10.7+	7.8+	4.9+	2.10	30.10	27.11	3.1*	1980 29.1	26.2	25.3
Asellus aquaticus	356	1792	784	134	360	960	432	1332	3032	11520	9695	33232	1416
Gammarus pulex				1						1	4	29	
Limnephilidae								1			2	3	
Brychius elevatus (L)				1		1							
Dytiscinae (L)								1					
Chironomus riparius (L)				10		2							
Chironomini (L)		5	5							1			
Tanytarsini (L)			7	5			1						
Diamesinae (L)	4		1		1	1	1	5	46	4	14	1	69
Orthocladiinae (L)	23	3	6	38							1		1
Tanypodinae (L)					1	6	1	1	2	1			
Chironomidae (P)	1			2									
Simulium spp.					1		484			23	1	1	
Lymnaea peregra	39	13	17	3	3	37		9	42	91	22	4	33
Pisidium spp.				1	5	5		18	2	4	10		4
Erpobdella testacea	2												
E. octoculata					1								
Glossiphonia complanata													1
Oligochaeta	168	128	124	603	312	254	116	1456	9	5	1	2	280

TABLE 4.2.a - CHANNEL C (Upper Pool)

REMOVAL DATE → / ↓TAXA	17.4	15.5	12.6	19 10.7+	79 7.8+	4.9+	2.10	30.10	27.11	3.1*	19 29.1	80 26.2	25.3
Asellus aquaticus	34	416	2992	67	732	189	33	588	1568	9888	3084	6576	3008
Gammarus pulex			1							1	1	5	
Limnephilidae							1						1
Dytiscinae (L)							1		1	2			
Chironomus riparius (L)				7									
Chironomini (L)	3		1							1			
Tanytarsini (L)			1	1							2	4	
Diamesinae (L)					1	1			1			3	2
Orthocladiinae (L)	2	6	12				1			1	1	1	
Tanypodinae (L)					1			2		3		3	2
Chironomidae (P)	12												
Simulium spp.										816	4	3	
Lymnaea peregra	2	2	8	4	6	1	3			35	6	3	3
Pisidium spp.												1	
Erpobdella testacea			2			1		1	1				
Oligochaeta	190	688	122	1884	692	672	788	30	176		81		3

TABLE 4.2f : CHANNEL C (Lower Pool)

Ancylus fluviatilis and Potamopyrgus jenkinsi, were recorded from channels A and B but not C, while two species, both characteristic of organically polluted rivers, Chironomus riparius and Erpobdella octoculata were found only in channels B and C. The major differences in abundance between channels involved A. aquaticus, P. jenkinsi and oligochaetes. A. aquaticus and the oligochaetes both preferred the effluent-containing channels; A. aquaticus reached peak numbers on single S.Auf.U. of 304, 4465 and 33232 in channels A, B and C respectively while oligochaetes achieved peaks of 528, 4448 and 1884 respectively (Tables 4.2 a - f.). In contrast, P. jenkinsi reached a much higher peak of 2280 in channel A than channel B where it was 10.

The reduction in species richness with increasing effluent concentration is reflected in corresponding decreases in the values of the pollution indexes; the maximum monthly values recorded for pairs of S.Auf.U. were IX, VI and V for the Trent Biotic, 768, 494 and 262 for the Chandler Score and 82, 51 and 27 for the B.M.W.P. Score in channels A, B and C respectively (Table 4.3). This, together with the vast numbers of A. aquaticus in the effluent-containing channels, caused a decrease in diversity with increasing effluent concentration; values of the Shannon-Weaver diversity index ranged from 1.0011 to 2.1328, 0.0242 to 0.7713 and 0.0135 to 0.7554 in channels A, B and C respectively (Table 4.4 a). Simpson's diversity indexes followed a similar pattern (Table 4.4b). All indexes were rather lower than those normally obtained in riffles to which they are usually applied, e.g. values obtained from the R. Cynon (Learner et al., 1971) and the R. Derwent (Hellawell, 1978). Without doubt these lower indexes were partly a consequence of the impoverished fauna in pools compared to riffles which is largely associated with the unstable substratum. The fact that the Checkley channels are artificial and completely straight could also have an effect in that the number of microhabitats is lower than in a "natural" river. As it was many of the colonising taxa, e.g. Baetis rhodani, probably drifted downstream from a riffle. Supporting evidence for this was given in Chapter 3.

Since the D.O. levels remained fairly high in the effluent containing channels (Table 9.4) the presence of toxicants was probably responsible for inter-channel differences. The combined effects of

INDEX → / IMMERSION ↓DATES CHANNEL →	Trent Biotic			Chandler Score			B.M.W.P. Score		
	A	B	C	A	B	C	A	B	C
1979									
20. 3. to 17. 4.	VI	IV	III	375	205	89	40	23	12
17. 4. " 15. 5.	VI	IV	III	351	178	65	42	20	9
15. 5. " 12. 6.	VII	V	V	451	203	129	45	24	18
12. 6. " 10. 7.	IX	III	V	768	87	198	82	10	23
10. 7. " 7. 8.	IX	VI	IV	623	310	156	73	36	20
7. 8. " 4. 9.	VII	V	IV	468	255	193	59	28	20
4. 9. " 2.10.	VIII	VI	V	539	306	198	63	36	26
2.10. " 30.10.	VI	VI	V	445	359	247	50	34	27
30.10. " 27.11.	VIII	VI	IV	523	465	167	63	52	20
27.11. " 3. 1.	VIII	V	IV	598	376	221	63	38	28
1980									
3. 1. " 29. 1.	VI	VI	V	571	494	241	60	51	27
29. 1. " 26. 2.	VII	V	V	553	339	262	62	37	27
26. 2. " 25. 3.	VII	V	V	354	300	165	42	33	19

TABLE 4.3 : THREE POLLUTION INDEXES FOR PAIRS OF S.AUF.U. LOCATED IN THE CHECKLEY CHANNELS.

CHANNEL → ↓ IMMERSION DATE	A	B	C
1979			
20. 3. to 17. 4.	1.9547	0.6190	0.6157
17. 4. " 15. 5.	1.7052	0.0575	0.0823
15. 5. " 12. 6.	1.9920	0.1375	0.1005
12. 6. " 10. 7.	2.1328	0.0478	0.9119
10. 7. " 7. 8.	1.0324	0.3730	0.1165
7. 8. " 4. 9.	1.5649	0.5461	0.2359
4. 9. " 2.10.	1.4581	0.6400	0.7554
2.10. " 30.10.	1.7467	0.7713	0.1239
30.10. " 27.11.	1.0011	0.7473	0.1185
27.11. " 3. 1. 1980	1.7602	0.0242	0.2018
3. 1. " 29. 1.	1.3325	0.2067	0.0355
29. 1. " 26. 2.	1.3267	0.2865	0.0135
26. 2. " 25. 3.	2.1127	0.5332	0.1417

(a) SHANNON-WEAVER DIVERSITY INDEX.

CHANNEL → ↓ IMMERSION DATE	A	B	C
1979			
20. 3.to 17. 4.	0.8316	0.2716	0.2864
17. 4." 15. 5.	0.7447	0.0156	0.0257
15. 5." 12. 6.	0.8281	0.0440	0.0310
12. 6." 10. 7.	0.8284	0.0149	0.4309
10. 7." 7. 8.	0.4448	0.1427	0.0356
7. 8." 4. 9.	0.6990	0.2245	0.0883
4. 9." 2.10.	0.6424	0.2923	0.5907
2.10 " 30.10.	0.7047	0.3721	0.0383
30.10." 27.11.	0.4028	0.5026	0.0399
27.11." 3. 1.1980	0.7410	0.0060	0.0844
3. 1." 29. 1.	0.6756	0.0722	0.0090
29. 1." 26. 2.	0.5161	0.1099	0.0025
26. 2." 25. 3.	0.8486	0.2248	0.0497

(b) SIMPSONS DIVERSITY INDEX.

TABLE 4.4 : DIVERSITY INDEXES FOR PAIRS OF S.AUF.U. LOCATED IN THE CHECKLEY CHANNELS

elevated metal levels could have limited the occurrence of P. jenkinsi and Polycelis felina in the effluent containing channels as both gastropods (Laurie and Jones, 1938; Jones, 1940; Wurtz, 1962; Brown, 1980) and flatworms (Carpenter, 1924; Jones, 1940) have often been eliminated by metal pollution. However, it is highly unlikely that metals restrict the occurrence of several insect species to channel A since insects are highly resistant in general to metal pollution (Hynes, 1960). Elevated ammonia levels in the effluent containing channels could be responsible but there is a virtual complete absence of published studies of ammonia toxicity on invertebrates both in the field and in the laboratory.

The macroinvertebrates colonising S.Auf.U. in the adjacent R. Tean are displayed in Table 4.5. The taxa at sites 1 and 3 on the R. Tean were basically similar to channel A and the effluent-containing channels respectively. However, Lymnaea peregra and Simulium spp. which were very abundant from time to time in channels B and C, were absent from Tean 3 (Tables 4.2 c-f and 4.5). The dairy effluent from Fole entering the river just above this site may have exerted a detrimental effect. Tean 2, immediately below the Checkley effluent discharge had a wide range of taxa including the mayfly R. semicolorata the caddis, P. flavomaculatus and the snail P. jenkinsi (Table 4.5). It is likely that some of these taxa particularly R. semicolorata and P. flavomaculatus,which are intolerant of organic pollution, had drifted from above the source of the effluent and/or channel A. Therefore this site was very different from channel C despite both carrying approximately 50% effluent.

S.Auf.U. in the channels often collected far more individuals of a variety of taxa than those in the river, e.g. on 2.10.79 a single S.Auf.U. in channel A lower pool collected 99 Gammarus pulex and 307 P. jenkinsi whereas three S.Auf.U. at Tean 1 collected only 11 G. pulex and 196 P. jenkinsi. A similar situation applied to the abundance of A. aquaticus in the effluent-containing channels and Tean 3. Therefore, although the channels are comparable with each other, they cannot be considered as "natural" rivers. The controlled constant flow rate in the channels compared with the regular spates in the R. Tean may in part account for the higher numbers in the channels.

SITE →	Tean 1			Tean 2	Tean 3		
TAXON↓ RECOVERY DATE →	15.5	10.7	2.10	3.1	10.7	2.10	3.1*
Asellus aquaticus		8		672	3375	988	162
Gammarus pulex	30	96	11	29	180	84	39
Baetis rhodani	3	2		3			
Ephemerella ignita		10					
Habrophlebia fusca		1					
Rhithrogena semicolorata				1			
Hydropsyche angustipennis	1						
Limnephilidae	12			6	1		3
Polycentropus flavomaculatus		1		1			
Agabus didymus (A)			3				
Brychius elevatus (L)				1			
Dytiscinae (L)			1	2		1	
Hydroporus sp.		1					
Corixa punctata						6	
Sialis luteria				1			
Chironomus riparius (L)		9		1			
Chironomini (L)	110	15	3	10			
Tanytarsini (L)		4		3			
Diamesinae (L)	5	196		89	1		12
Orthocladiinae	18	33	1	62	1		10.5
Tanypodinae (L)	11	8		9			9
Chironomidae (P)	1		1				
Dicranota sp.	1			3			
Empididae	2						
Simulium spp.				783			
Tipula spp.			1	2			
Ancylus fluviatilis	2			1			1.5
Lymnaea peregra	2	3	30	145			
Potamopyrgus jenkinsi		130	196	18		1	
Pisidium spp.	7	5	11	6	2		
Erpobdella octoculata					55	4	3
E. testacea				3			
Glossiphonia complanata		1	4	4	3		3
Helobdella stagnalis						1	
Theromyzon tessulatum	1						
Oligochaeta	164	12	1	191	153	340	171
Polycelis felina			1		9	82	

* only 2 S.Auf.U. recovered, calculated totals for 3 S.Auf.U given.

TABLE 4.5 : NUMBERS OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED ON THREE S. AUF.U. IN THE R. TEAN.

4.4.3 Gastropod Populations and Biomass

Numbers and biomasses of gastropods collected in individual cylinder samples and on S.Auf.U. are displayed in Appendix Tables 8.12 to 8.15.

Lymnaea peregra had just one annual cohort at Checkley, the old one survived until about July shortly prior to which, in about May, a new one appeared (Figure 4.3). Peak numbers occurred in the lower riffle and upper pool of all 3 channels in late spring and early summer just before the dying out of the old cohort and the start of the new one (Figures 4.3 and 4.4). Numbers fell rapidly after this for 3 reasons: the dying off of the old cohort, high mortality amongst newly hatched snails and because of migration from the bottom to the sides of the channels particularly into crevices which was observed to occur. This migration made sampling inaccurate particularly as large numbers of adult snails re-appeared just prior to the breeding season.

Biomass followed a similar pattern to populations but decreased earlier in summer as snails belonging to the new cohort were very light at first (Figures 4.5 and 4.6). Numbers and biomass of snails collected on S.Auf.U. varied erratically from month to month, reaching winter peaks in all 3 channels (Figures 4.7 and 4.8).

Populations and biomass increased channel A<channel B<channel C in the lower riffle (Figure 4.3). Population peaks of $160m^{-2}$ in May 1980, $1173m^{-2}$ in August 1979 and $1486m^{-2}$ in May 1979 were recorded in channels A, B and C respectively. Peaks in biomass of $2.6647gm^{-2}$ in May 1980, $19.7gm^{-2}$ in June 1979 and $42.0783gm^{-2}$ in June 1979 were achieved in the respective channels (Figure 4.5). Cumulative biomasses for the year June 1979 to 1980 were $9.8447gm^{-2}$ for channel A, $34.6674gm^{-2}$ for B and $96.5064gm^{-2}$ for C.

In the pools, populations and biomasses were much lower than in the riffles and there was much less difference between channels (Figures 4.4 and 4.6) there being little difference between channels B and C, while A was lower. Peak populations in unvegetated areas of $110m^{-2}$ in December 1979, $402m^{-2}$ in May 1980 and $335m^{-2}$ in May 1980

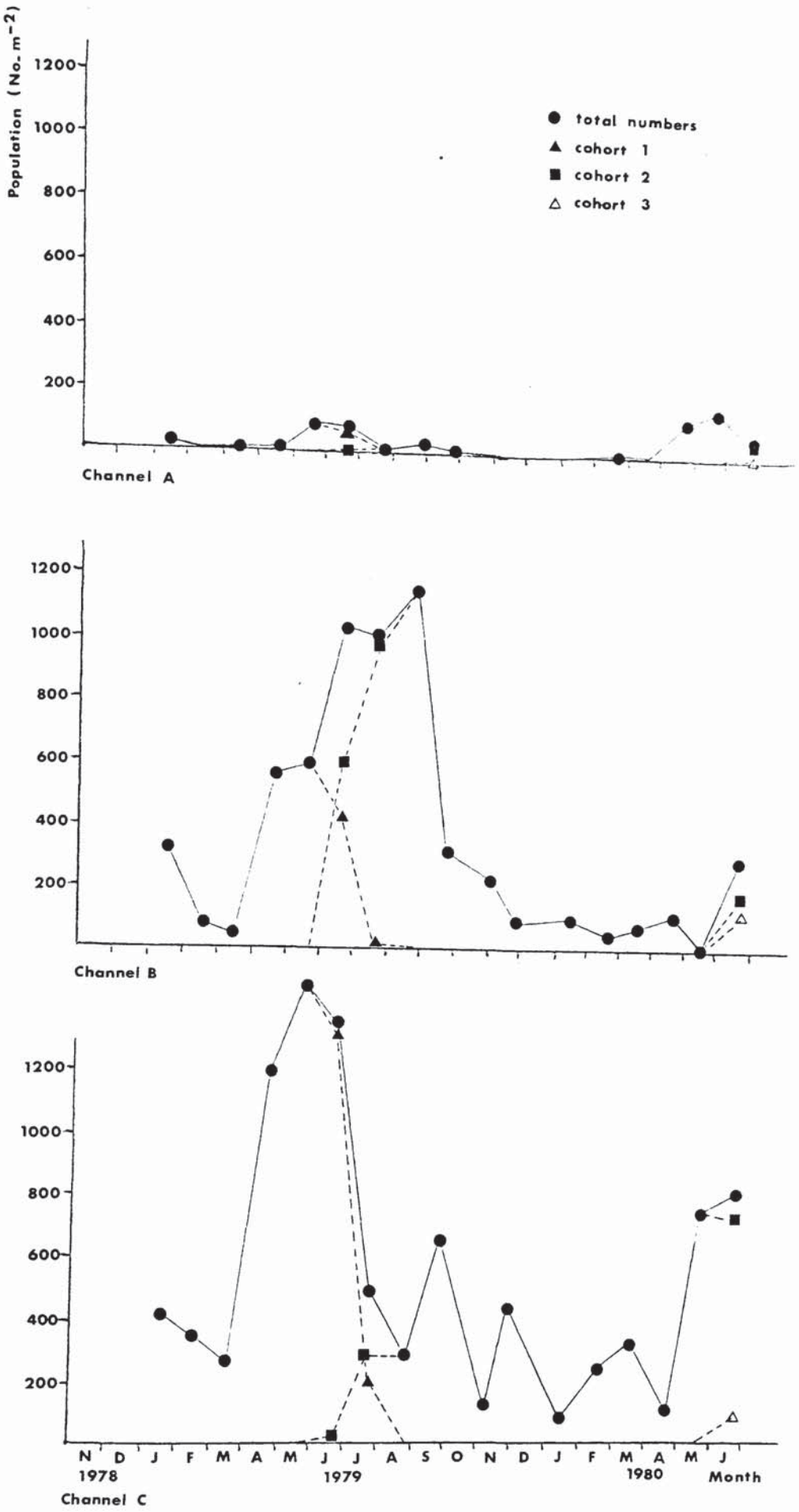


FIGURE 4.3 : *Lymnaea peregra* POPULATIONS IN THE CHECKLEY CHANNEL LOWER RIFFLES.

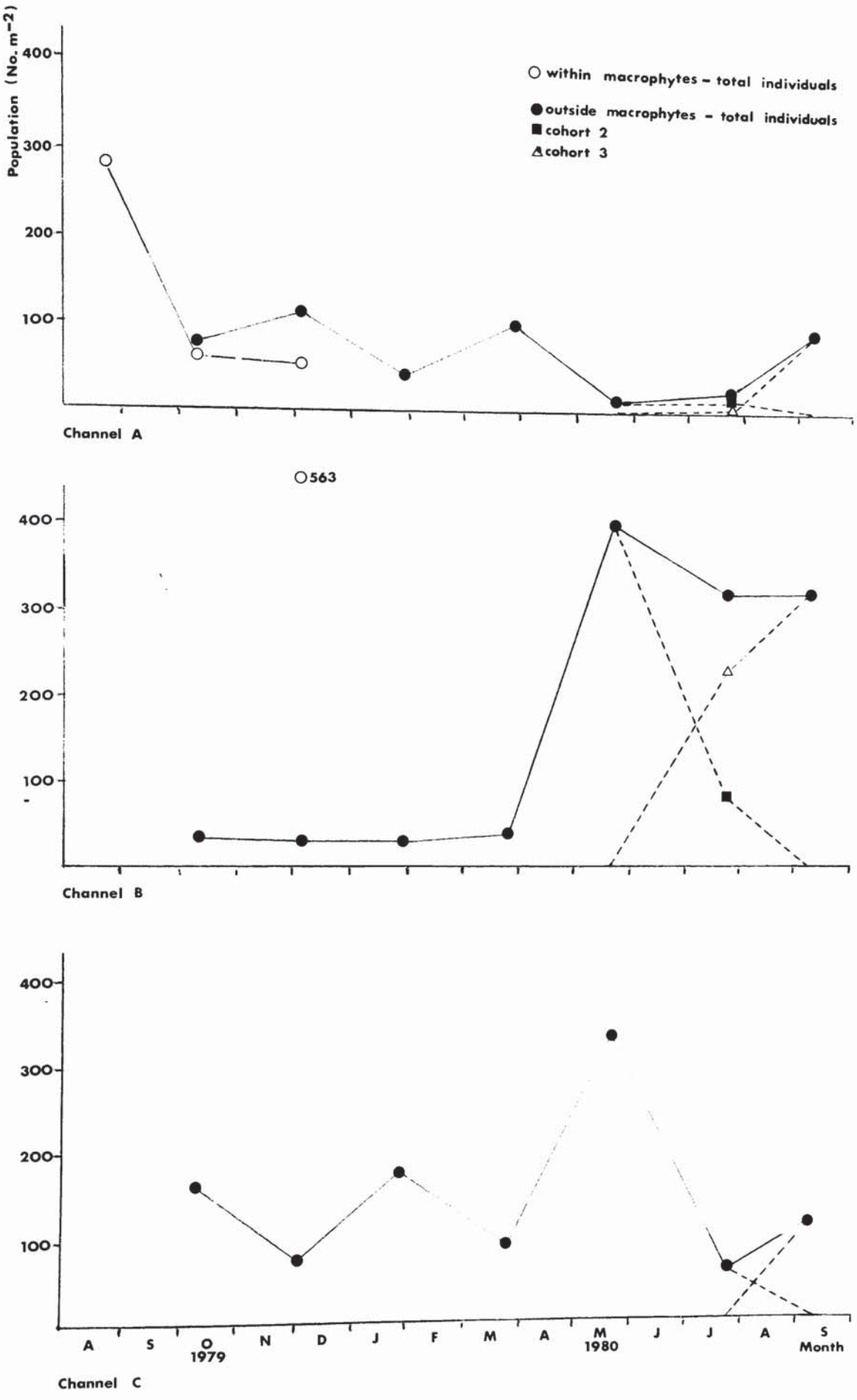


FIGURE 4.4 : *L. peregra* POPULATIONS IN THE CHECKLEY CHANNEL UPPER POOLS.

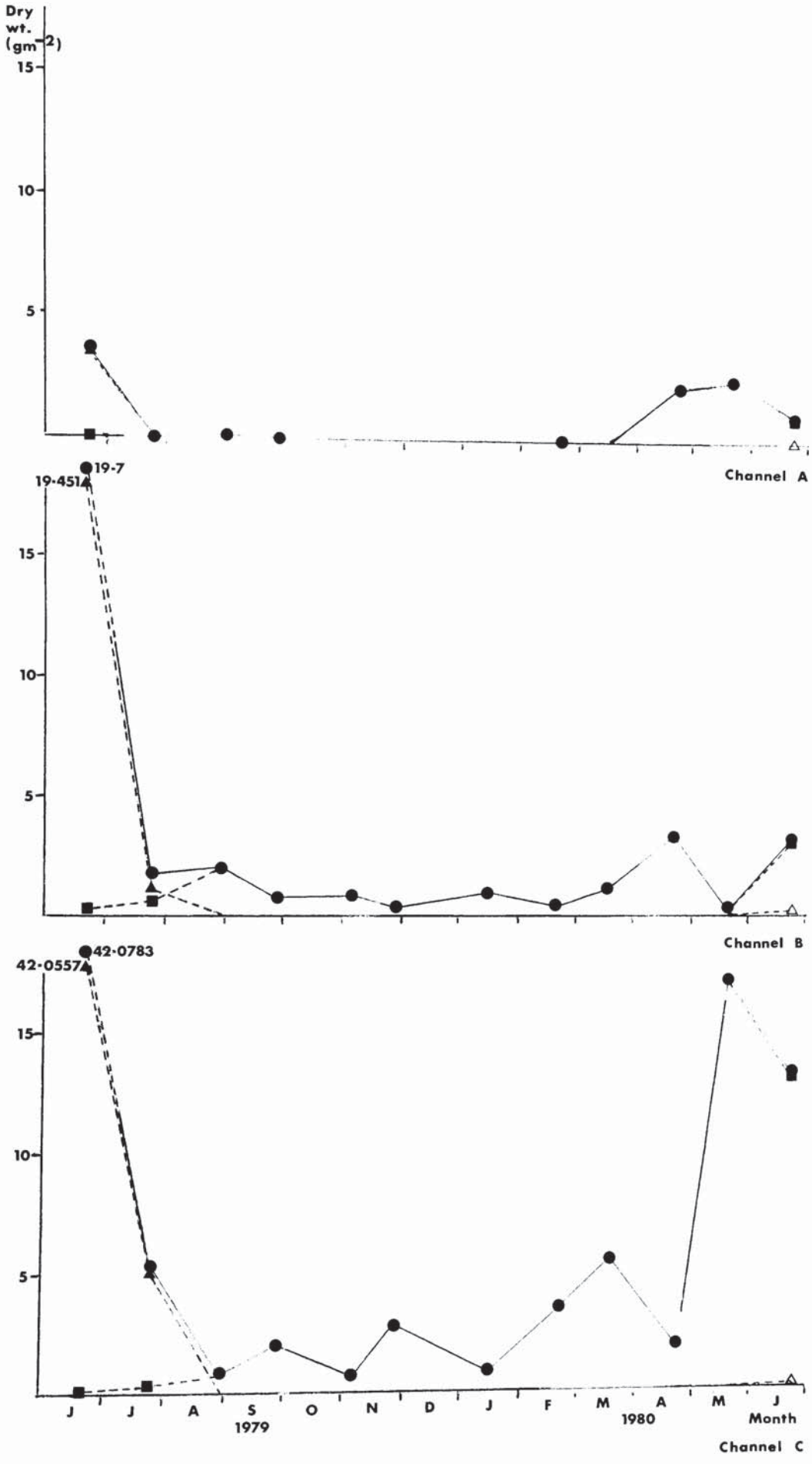


FIGURE 4.5. : *L. peregra* BIOMASS IN THE CHECKLEY CHANNEL LOWER RIFFLES.

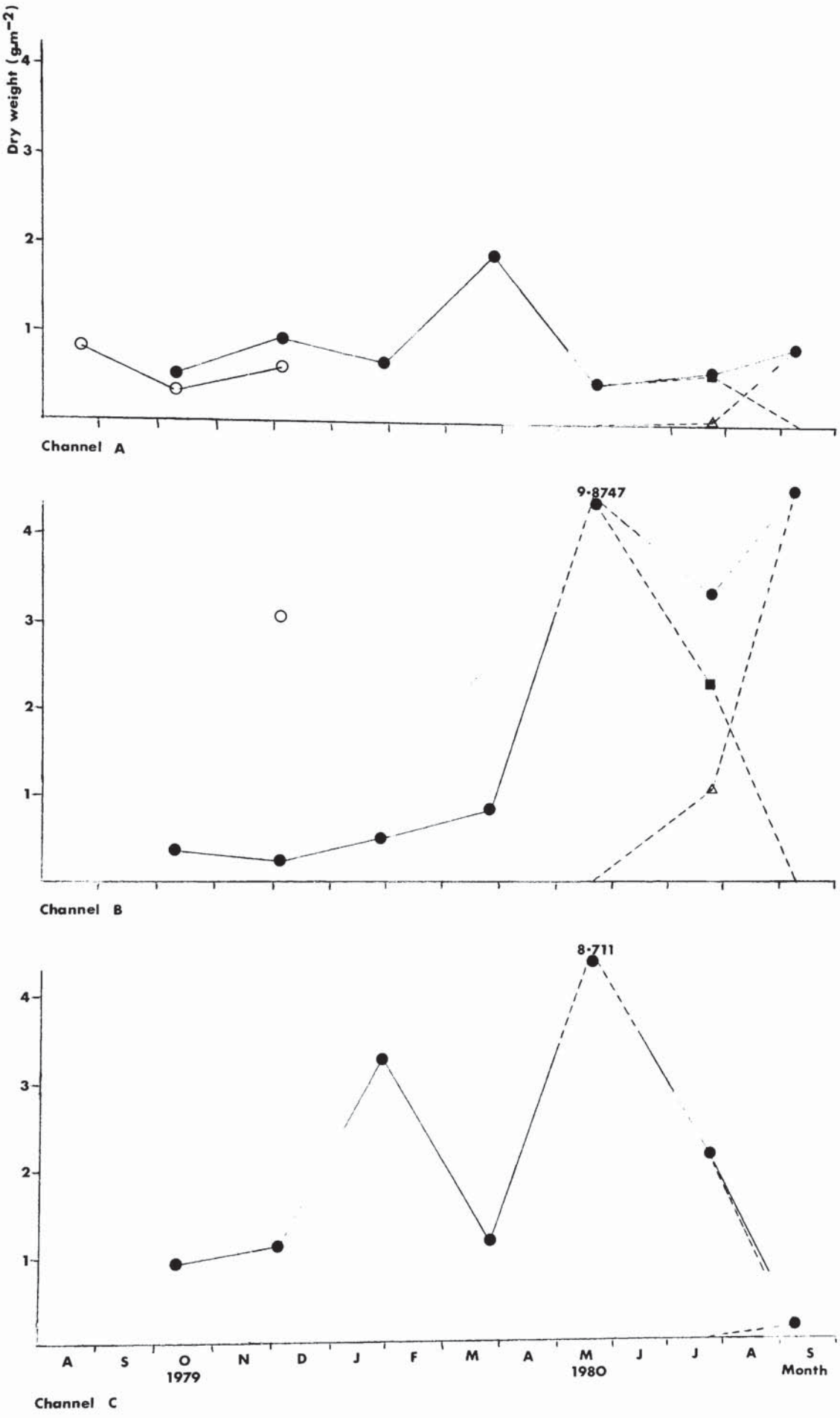


FIGURE 4.6 : *L. peregra* BIOMASS IN THE CHECKLEY CHANNEL UPPER POOLS.

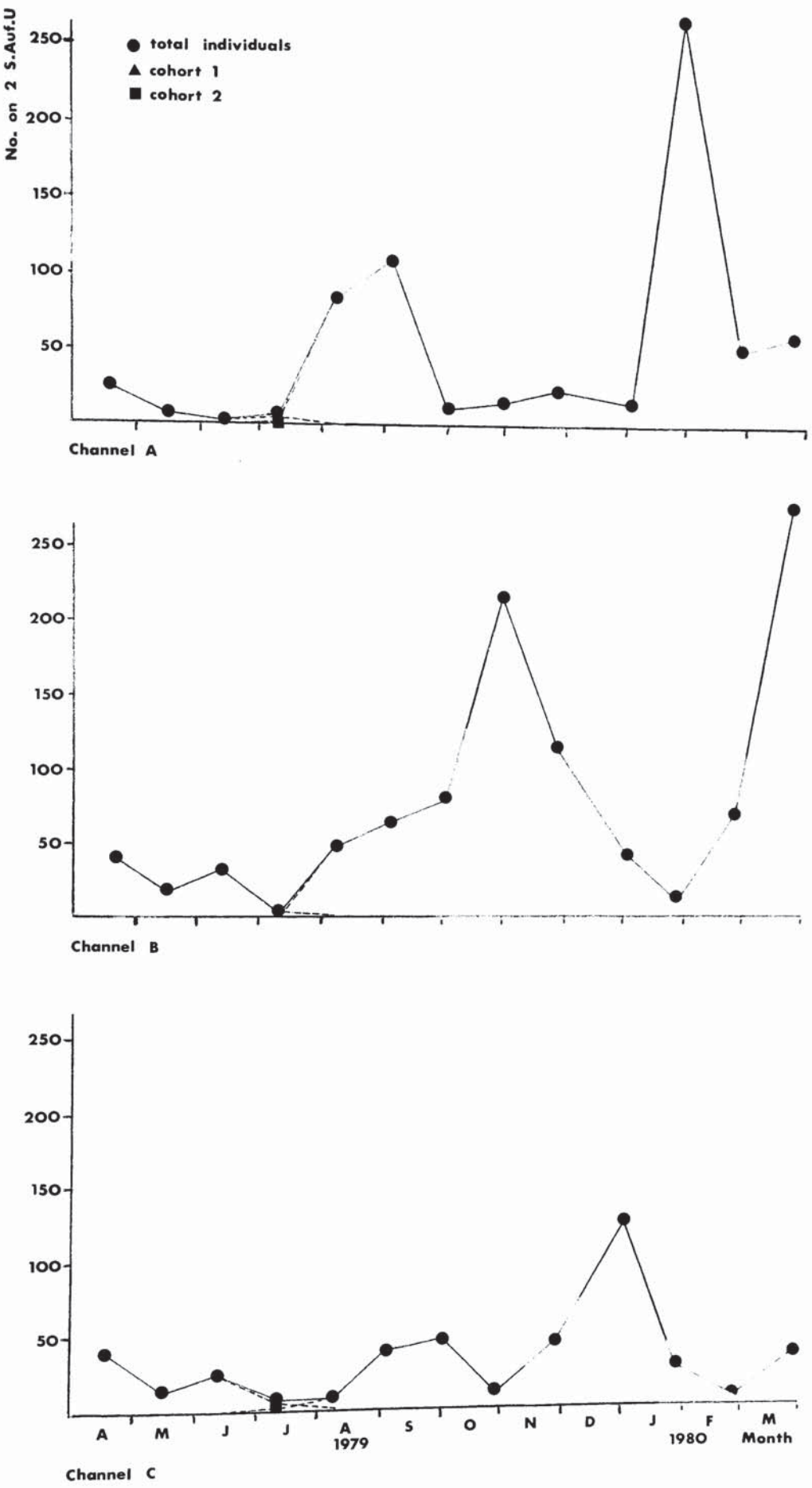


FIGURE 4.7 : NUMBERS OF *L. peregra* COLLECTED ON CHECKLEY CHANNEL S.AUF.U.

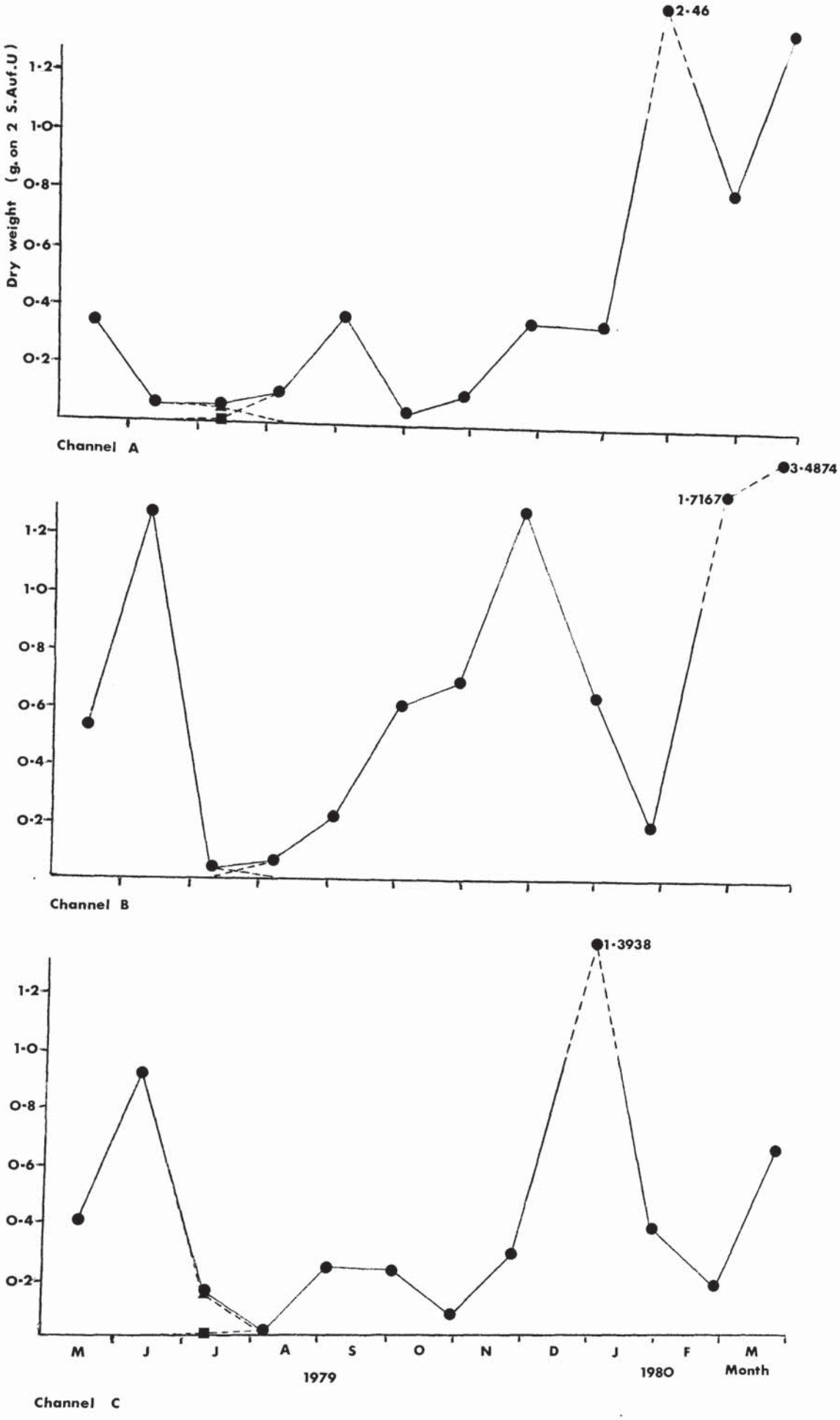


FIGURE 4.8 : BIOMASS OF *L. peregra* COLLECTED ON CHECKLEY CHANNEL S.AUF.U.

were recorded for channels A, B and C respectively (Figure 4.4). Peak biomasses of 1.937gm^{-2} in March 1980, 9.8747gm^{-2} in May 1980 and 8.711gm^{-2} in May 1980 were achieved in the same 3 channels (Fig. 4.6). Cumulative biomasses for the period of sampling were 6.0646gm^{-2} for channel A, 19.6991gm^{-2} for B and 17.3417gm^{-2} for C.

A possible reason for the higher populations and biomasses in the channels containing some effluent is an improved food supply. L. peregra primarily feeds on filamentous green algae (Calow, 1970) which increased in quantity channel A<B<C. The algae itself reflects the differences in water quality since increased nutrient levels in the effluent channels are responsible for its much greater abundance there.

The number of P. jenkinsi in the lower riffle increased from a small number in the spring of 1979 (Figure 4.9). As cohort 1 snails died out causing an initial fall in numbers, cohort 2 snails were born resulting in peak numbers during Spring 1980. Cohort 3 snails then began replacing dying cohort 2 snails. There was thus a large overlap of the different generations unlike in L. peregra but only 2 cohorts were present at any one time.

In the upper pools numbers of P. jenkinsi similarly increased through the Spring of 1980 to reach Summer peaks (Figure 4.10). Biomass in both the riffles and pools followed the trend in populations very closely (Figures 4.11 and 4.12). Fluctuation in the numbers and biomass of snails collected on S.Auf.U. was again much greater than in the cylinder samples and these were not clearly associated with additional births (Figures 4.13 and 4.14).

Channel A had vastly more P. jenkinsi than the effluent-containing channels reaching peak numbers of 15933m^{-2} during March 1980 in the lower riffle and 2267m^{-2} during July 1980 in the upper pool compared with peaks of 286m^{-2} in June 1980 and 50m^{-2} in September 1980 respectively in channel B (Figures 4.9 and 4.10). P. jenkinsi only appeared in channel C for the first time near the end of the sampling period in April 1980 (Figure 4.9). Indeed, snails only began appearing regularly in channel B after sampling

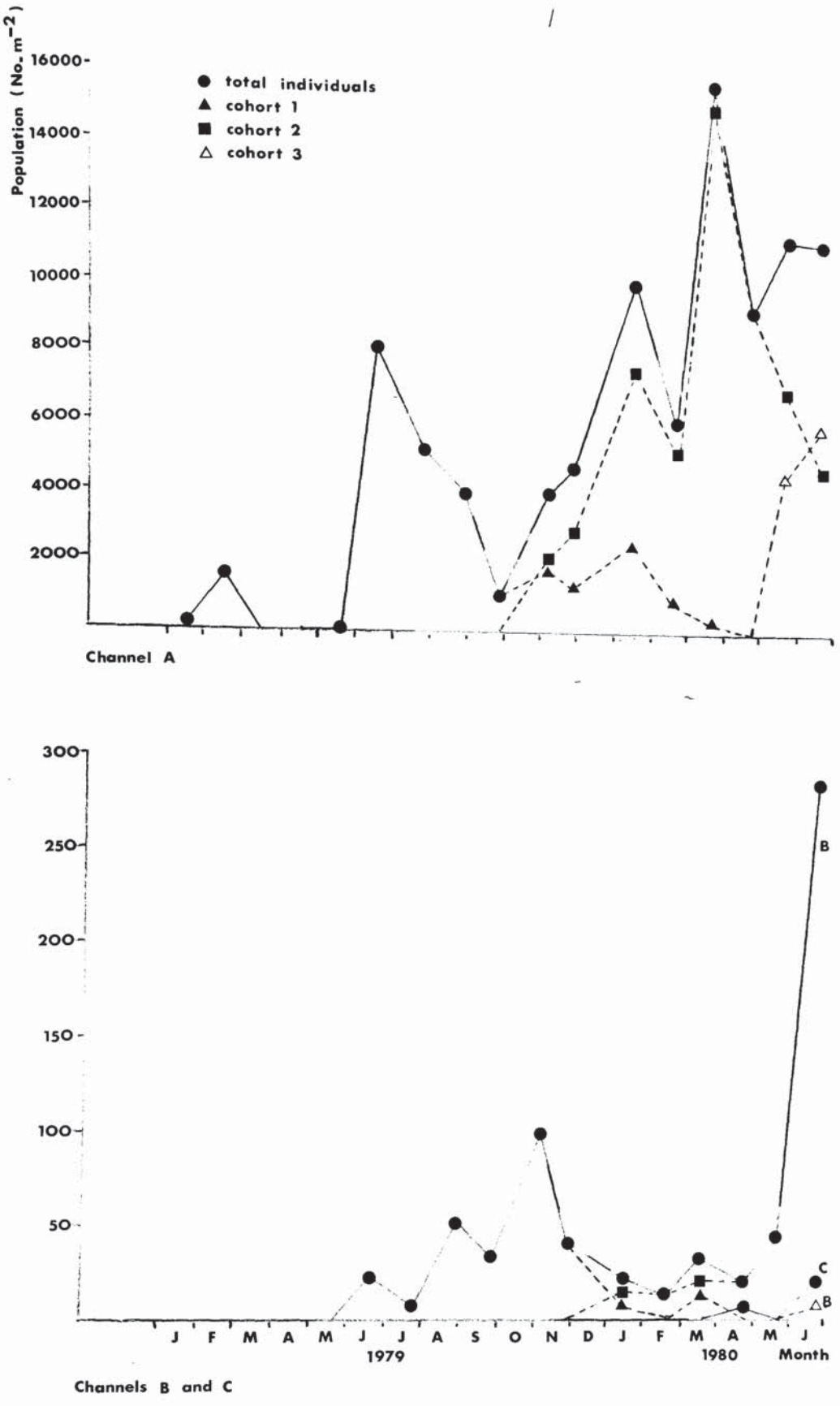


FIGURE 4.9 : *Potamopyrgus jenkinsi* POPULATIONS IN THE CHECKLEY CHANNEL LOWER RIFFLES.

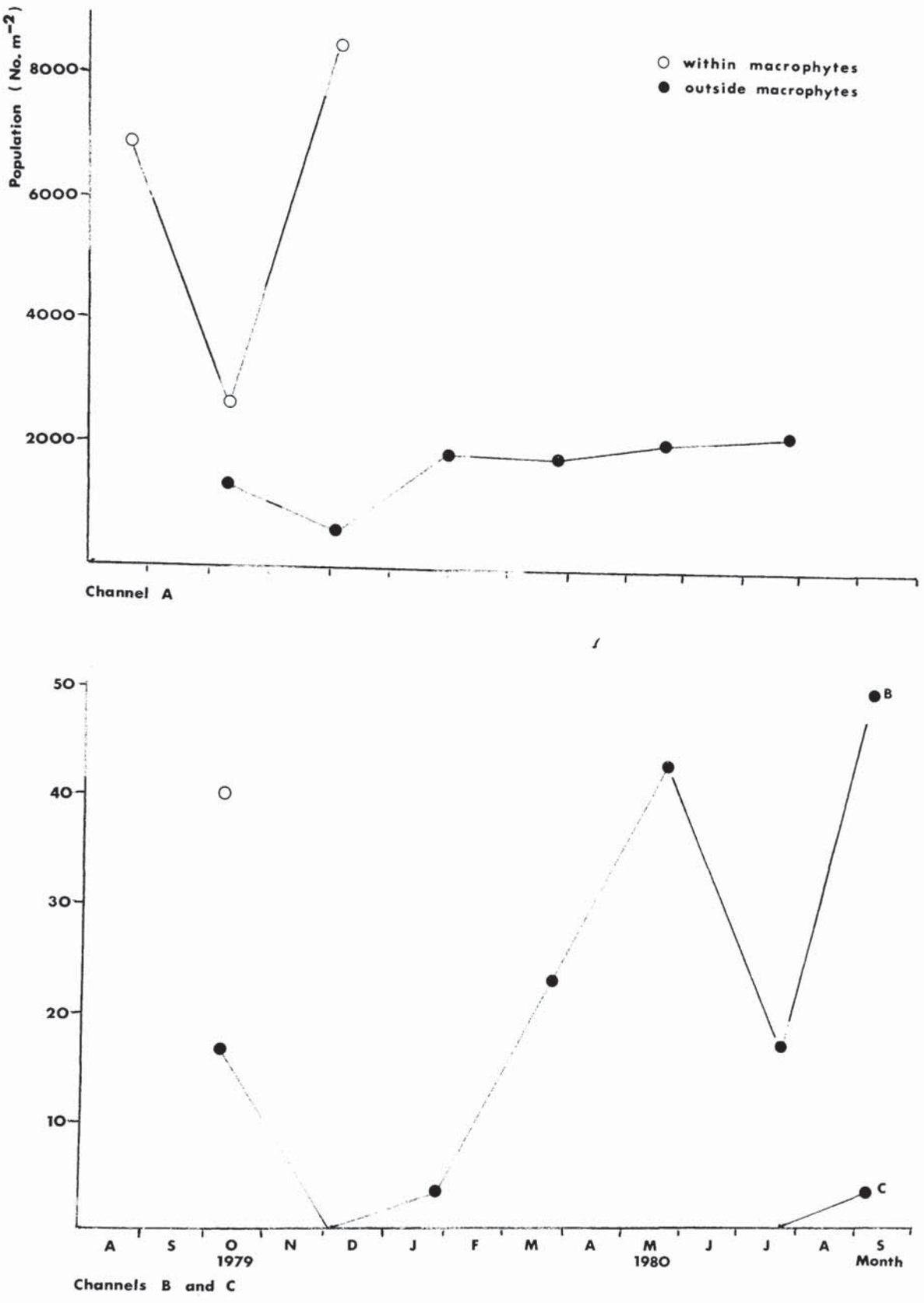


FIGURE 4.10: *P. jenkinsi* POPULATIONS IN THE CHECKLEY CHANNEL UPPER POOLS.

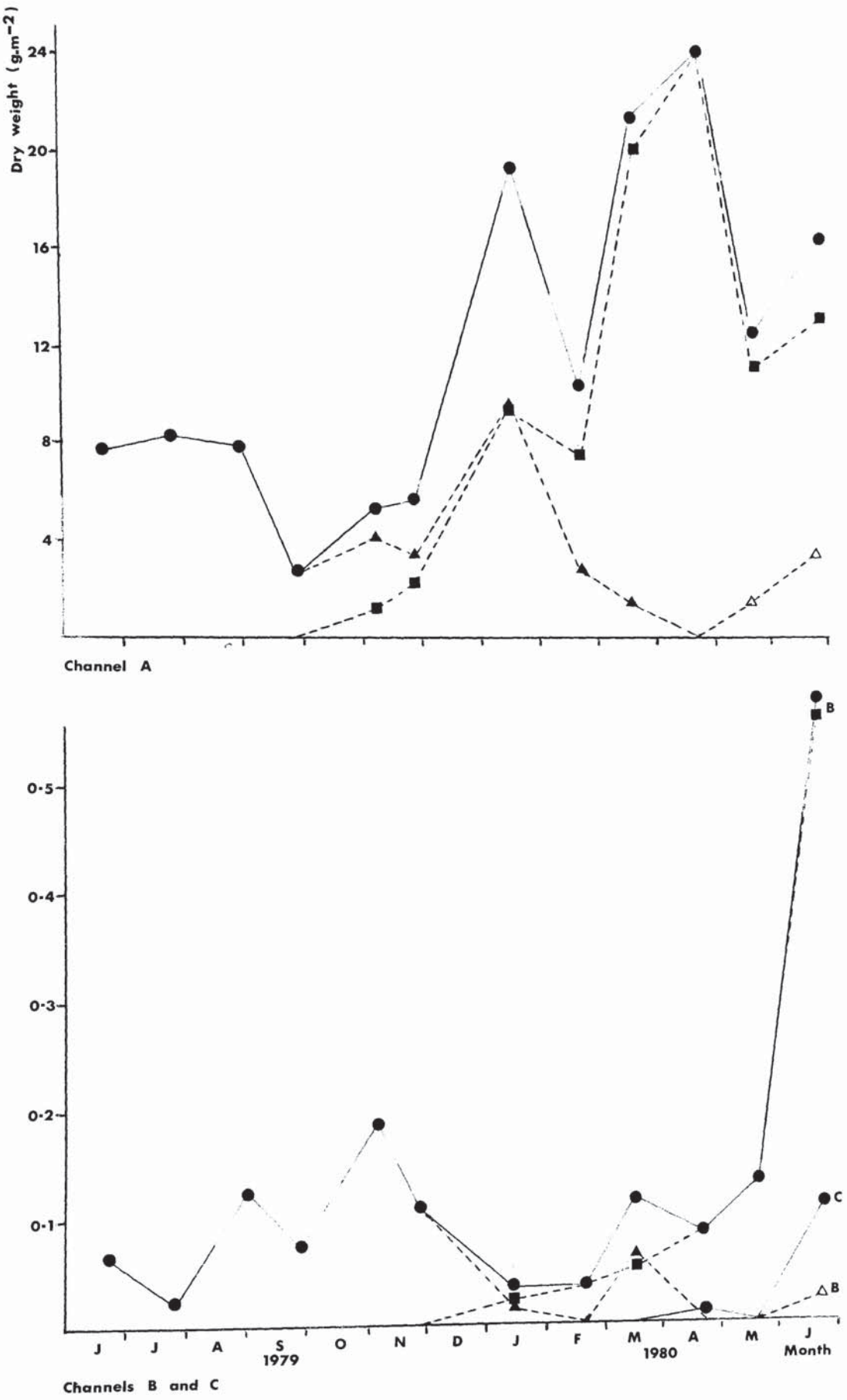


FIGURE **4.11** : *P. jenkinsi* BIOMASS IN THE CHECKLEY CHANNEL LOWER RIFFLES.

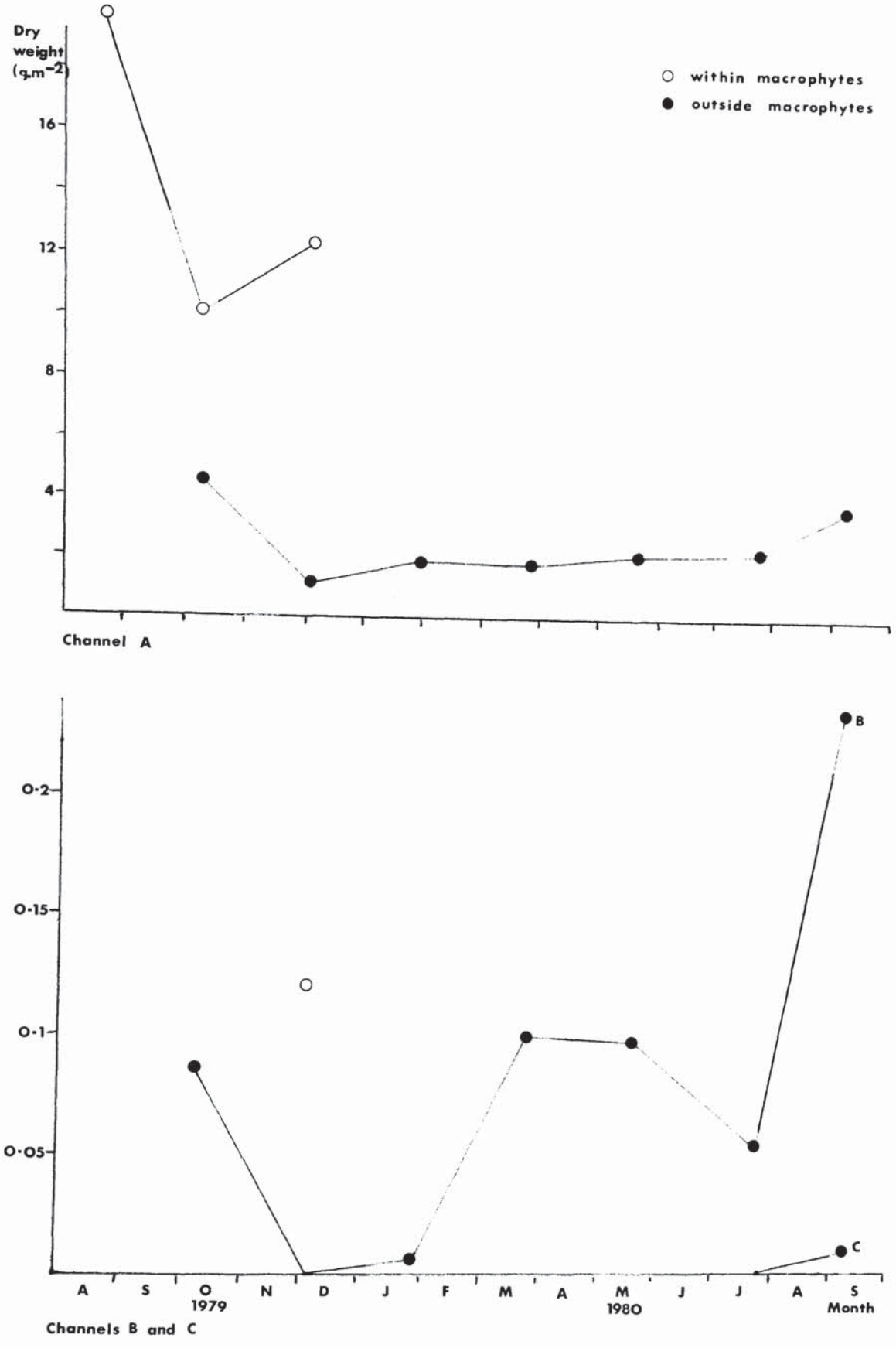


FIGURE **4.12** -: *P. jenkinsi* BIOMASS IN THE CHECKLEY CHANNEL UPPER POOLS.

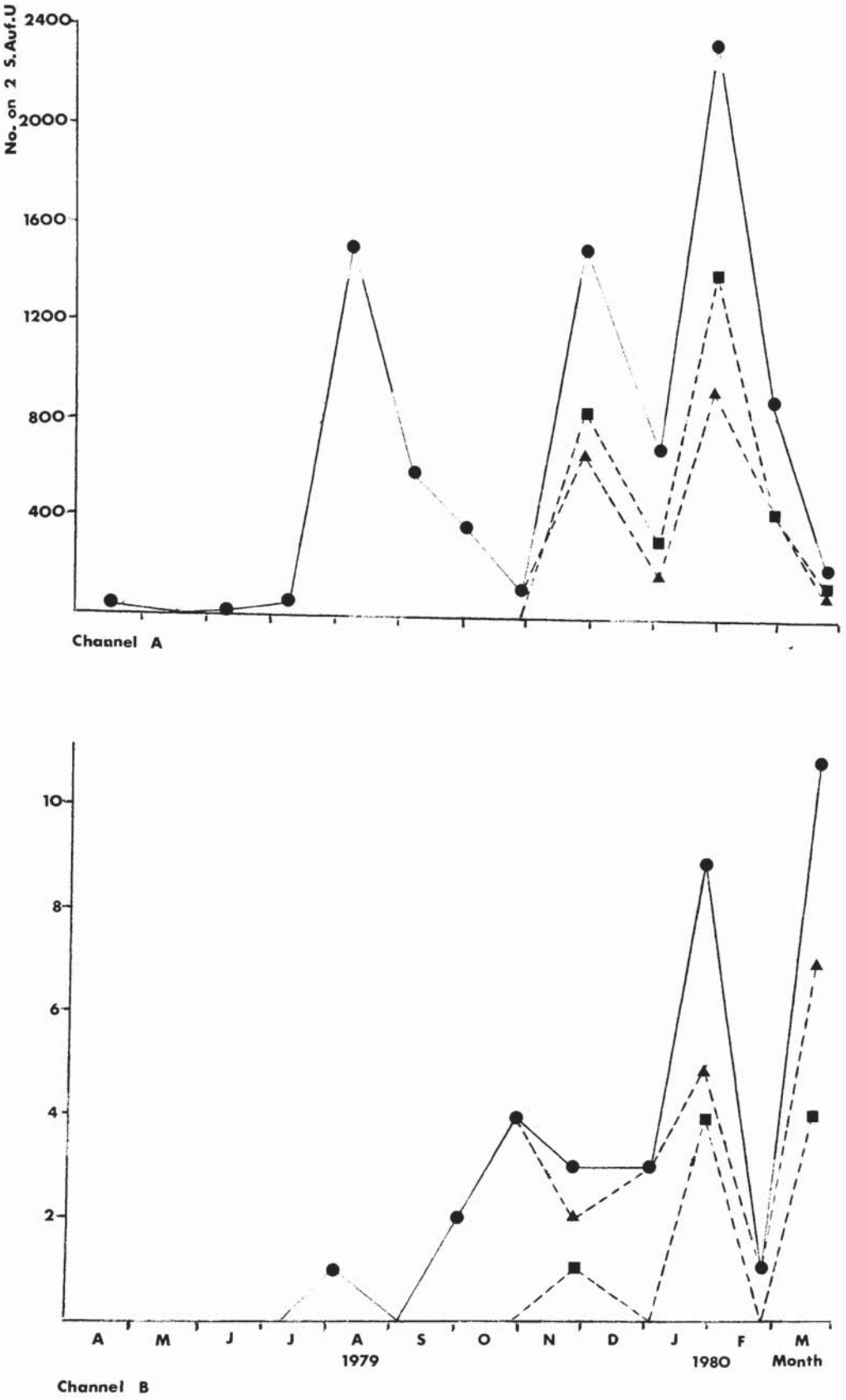
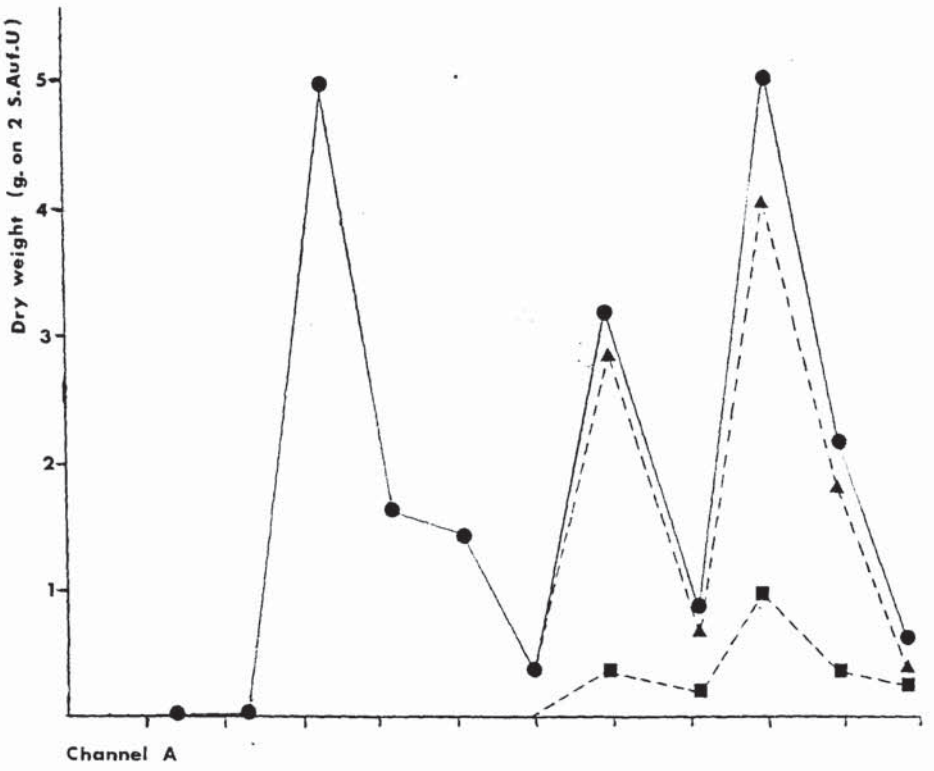


FIGURE **4.13**: NUMBERS OF *P. jenkinsi* COLLECTED ON CHECKLEY CHANNEL S.AUF.U.



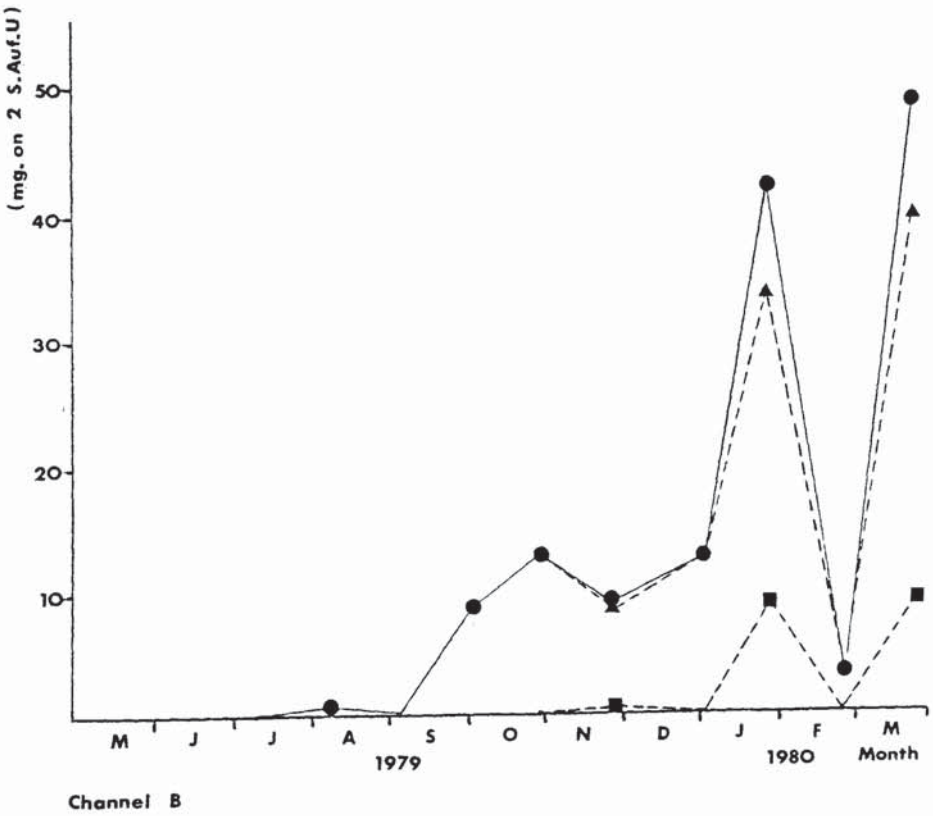


FIGURE **4.14**: BIOMASS OF *P. jenkinsi* COLLECTED ON CHECKLEY CHANNEL S.AUF.U.

started; they were not recorded during the first 5 months of sampling, first appearing in the June 1979 riffle samples (Figure 4.9). The population differences clearly imply that the effluent has a serious deleterious effect on P. jenkinsi - whether this is due to mortality or reduced reproduction is discussed in the section on reproduction. Furthermore it appears that P. jenkinsi is able to adjust to the pollution colonising first channel A, then gradually channel B and finally C (Fig. 4.9).

The differences in P. jenkinsi biomass reflected the population differences reaching peaks of $24.5473gm^{-2}$ in April 1980, $0.5873gm^{-2}$ in June 1980 and $0.1087gm^{-2}$ in June 1980 in the lower riffles of channels A, B and C respectively. Cumulative biomasses in the lower riffle were $143.4836gm^{-2}$ in channel A, $1.6004gm^{-2}$ in B and $0.12gm^{-2}$ in C for the period June 1979 to 1980.

As mentioned before it is quite likely that the levels of metals are responsible for the inter-channel population differences in P. jenkinsi. Brown (1980) found that combined levels of chromium and copper below the 95-percentiles recorded for the respective metals in both channels B and C killed P. jenkinsi in the laboratory and caged individuals in the R. Holme. Extence (1978a) observed that total copper levels as low as $0.0025mgl^{-1}$, which is well below the levels recorded in channel C, suppressed reproduction in the same species. It is unlikely that ammonia levels at Checkley exerted a deleterious effect since subsequent laboratory tests showed P. jenkinsi to be tolerant of much higher levels than recorded in the channels.

4.4.4 Macrophytes and Algae as Factors in Gastropod Ecology

Snail counts and biomass in relation to the quantities of macrophyte are displayed in Appendix Table 8.16, and L. peregra counts in relation to the quantity of filamentous green algae are displayed in Appendix Table 8.17.

There were significantly more P. jenkinsi and L. peregra in vegetated areas of the upper pool than unvegetated areas in channels A and B respectively (Table 4.5**A**). There were also more P. jenkinsi in the macrophyte section of channel B (Figure 4.10) but this

↓ TAXON	DATE → / CHANNEL↓	9.10.79	4.12.79
L.peregra	A	-0.01	-0.06
	B	-	2.75*
P.jenkinsi	A	0.64	4.02**
	B	-	-0.23

TABLE 4.5A: VALUES OF STUDENTS - t (WITH SIGNIFICANCE LEVELS FOR A ONE-TAILED TEST) FOR DIFFERENCES IN SNAIL ABUNDANCE BETWEEN UPPER POOL SAMPLES FROM THE CHECKLEY CHANNELS WITH AND WITHOUT MACROPHYTES.

(Positive values of t indicate abundance of snails greater in samples with macrophytes, negative values vice versa)

difference was not significant. Little difference in the abundance of L. peregra between vegetated and unvegetated areas in channel A existed (Figure 4.4). The increased numbers on macrophytes was probably due to the plants offering a greater surface area over a given area of bottom. This tendency of macrophytes to elevate population levels does not, however, on the whole overshadow the effects of the effluent as values of r^2, which represent the proportion of the variance in snail abundance attributable to its linear regression on macrophyte biomass, were only 0.21 for L. peregra and 0.18 for P. jenkinsi. Furthermore the population of P. jenkinsi in the vegetated areas of channel B was still much less than its population in the unvegetated areas of channel A (Figure 4.10). Nevertheless the presence of Elodea canadensis in channel B did elevate the population of L. peregra above that of channel C where higher numbers were recorded in unvegetated areas during autumn and winter (Figure 4.4). However, there were no clear differences in L. peregra populations between the pools of channels B and C over the whole year anyway.

Values of r^2 for the association between L. peregra abundance and biomass of filamentous green algae both within channels and considering all channels together were low with the exception of an $r^2 = 0.72$ in the channel C lower riffle (Table 4.6). Indeed correlation in channel B was negative. Therefore, L. peregra abundance does not appear to be directly affected by the quantity of filamentous green algae. Both snails and algae appear to be independently benefited by the addition of sewage effluent.

4.4.5 Size Classes and Growth

Size class frequency distribution histograms for L. peregra are shown in Figures 4.15 and 4.16. Young snails were born between June and September, during which snails less than 6mm long dominated. Maximum lengths were achieved in April, May and June of the following year, the largest recorded being in the 16.0-16.9mm size class. During the intervening period weight increments (v) were constant (Table 4.7) since the lines of best fit for mean individual weights against time were, with one exception, linear (Figures 4.17 to 4.19). The raw data for mean individual weights is shown in Appendix Table 8.18.

↓SITE / CHANNEL→	r^2			
	A	B	C	All
Upper Riffle	0.00	0.26	0.34	0.42
Lower Riffle	0.00	0.14	0.72	0.28

TABLE 4.6 : VALUES OF r^2 FOR THE RELATIONSHIP BETWEEN ALGAE DRY WEIGHT AND ABUNDANCE OF L. peregra IN $0.1m^2$ RIFFLE CYLINDER SAMPLES

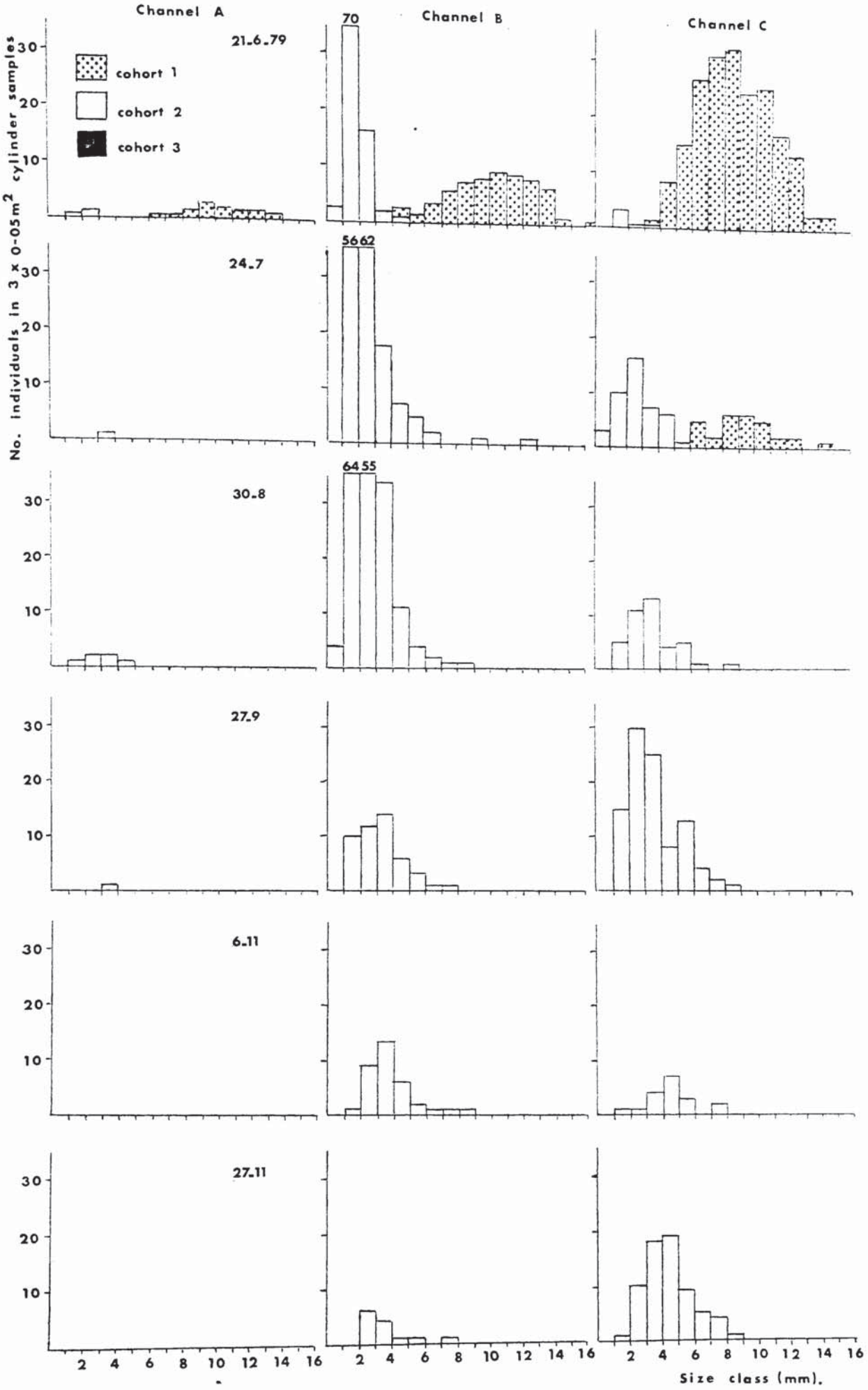


FIGURE 4.15 : SIZE CLASS - FREQUENCY DISTRIBUTION OF *L. peregra* IN THE CHECKLEY CHANNEL LOWER RIFFLES.

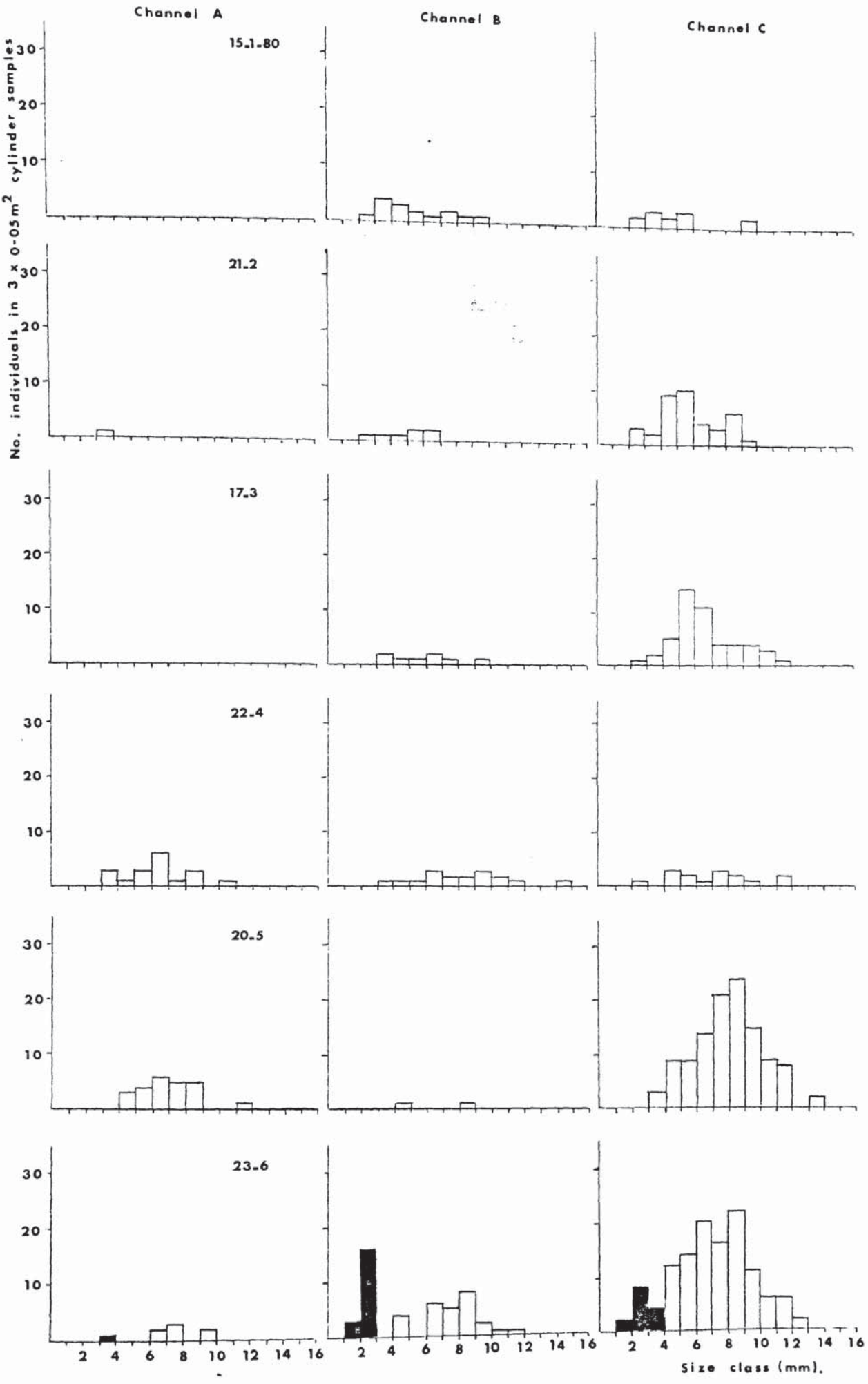


FIGURE 4.15 continued

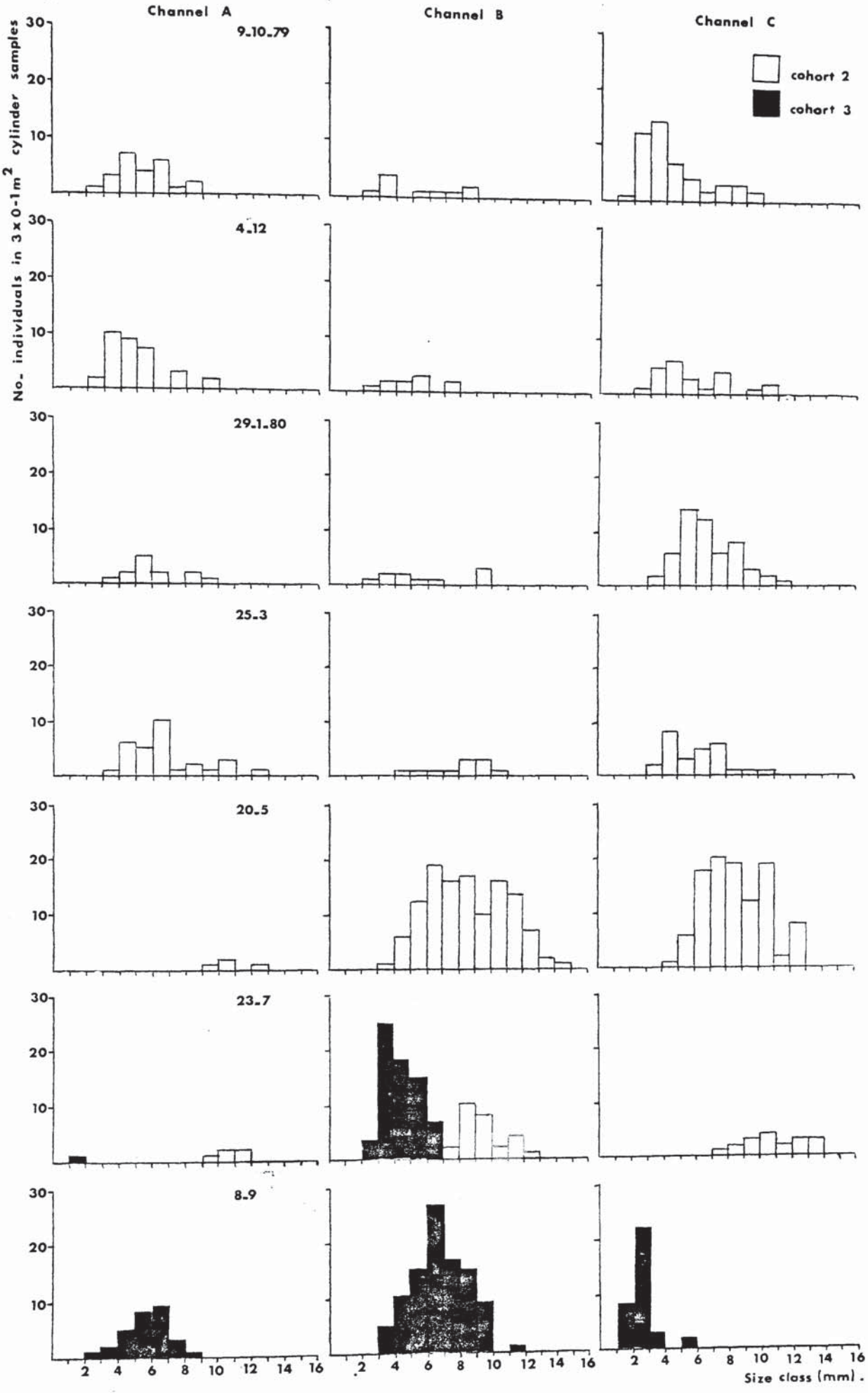


FIGURE 4.16 : SIZE CLASS - FREQUENCY DISTRIBUTION OF *L. peregra* IN THE CHECKLEY CHANNEL UPPER POOLS.

DATE ↓ CHANNEL →	CORRECTED MEAN WEIGHT (mg)			V (mg d^{-1})			v' (mg d^{-1} mg^{-1})			g		
	A	B	C	A	B	C	A	B	C	A	B	C
Lower Riffle												
27. 9.79	-	2.0721	2.9795	-	0.0480	0.0718	-	0.0162	0.0167	-	0.0167	0.0172
6.11	-	3.8491	5.6361	-	0.0261	"	-	0.0063	0.0112	-	0.0063	0.0113
27.11.	-	4.3965	7.1439	-	0.0447	"	-	0.0078	0.0078	-	0.0080	0.0079
15. 1.80	-	7.0353	11.3801	-	0.1259	"	-	0.0134	0.0057	-	0.0137	0.0057
21. 2	-	11.6924	14.0367	-	0.2175	"	-	0.0151	0.0048	-	0.0153	0.0049
17. 3.	-	17.1303	15.8317	-	0.3389	"	-	0.0146	0.0042	-	0.0149	0.0042
22. 4.	-	29.3324	18.4165									
Upper Pool												
9.10.79	3.8187	8.3986	7.1727	0.1146	0.0663	0.0915	0.0163	0.0065	0.0094	0.0176	0.0065	0.0096
2.12.	10.2363	12.1114	12.2967									
29. 1.80	16.6539	15.8242	17.4207	"	"	"	0.0085	0.0047	0.0062	0.0087	0.0048	0.0062
25.3	23.0715	19.5370	22.5447	"	"	"	0.0058	0.0037	0.0046	0.0058	0.0038	0.0046
20.5	29.4891	23.2498	27.6687	"	"	"	0.0044	0.0031	0.0036	0.0044	0.0031	0.0036
23.7.	36.8235	27.4930	33.5247	"	"	"	0.0035	0.0026	0.0030	0.0035	0.0026	0.0030
S.Auf.U.												
2.10.79	4.9276	4.3282	5.2180	0.0961	0.1172	0.0968	0.0153	0.0196	0.0147	0.0156	0.0202	0.0149
30.10	7.6184	7.6098	7.9284	"	"	"	0.0107	0.0127	0.0104	0.0108	0.0128	0.0105
27.11	10.3092	10.8914	10.6388	"	"	"	0.0080	0.0090	0.0078	0.0080	0.0091	0.0078
3. 1.	13.8649	15.2278	14.2204	"	"	"	0.0064	0.0070	0.0063	0.0064	0.0070	0.0063
29. 1.	16.3635	18.2750	16.7372	"	"	"	0.0054	0.0059	0.0054	0.0054	0.0059	0.0054
26. 2.	19.0543	21.5566	19.4476	"	"	"	0.0047	0.0051	0.0047	0.0047	0.0051	0.0047
25. 3.	21.7451	24.8382	22.1580									

TABLE 4.7 : CORRECTED MEAN WEIGHT, ABSOLUTE DAILY WEIGHT GAIN PER INDIVIDUAL (V), ABSOLUTE DAILY WEIGHT GAIN PER INDIVIDUAL PER UNIT WEIGHT (V') AND INSTANTANEOUS GROWTH RATE (g) IN *L. peregra* IN THE CHECKLEY CHANNELS.

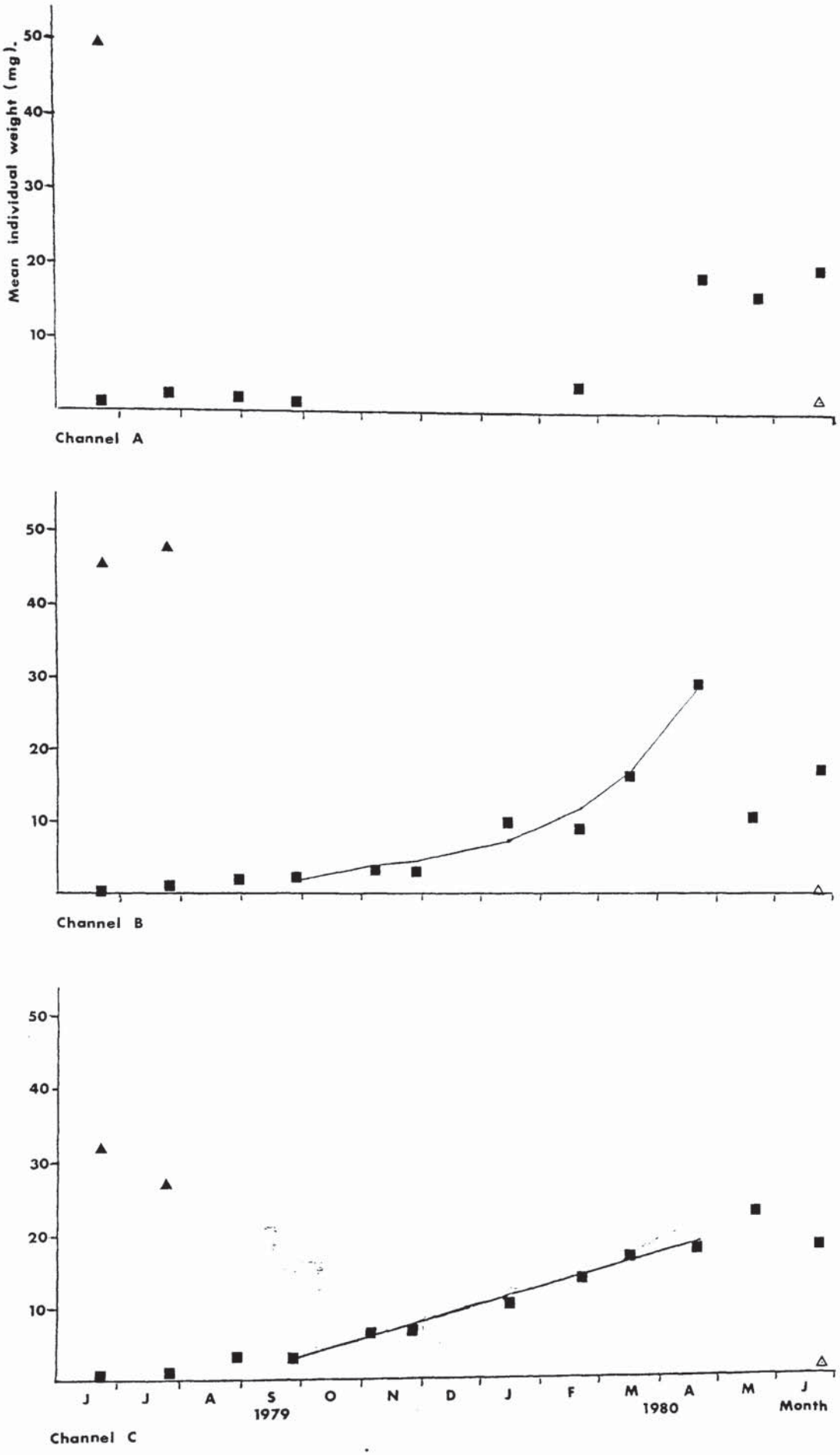


FIGURE 4.17: MEAN INDIVIDUAL WEIGHTS OF COHORTS OF *L. peregra* COLLECTED FROM THE CHECKLEY CHANNEL LOWER RIFFLES.

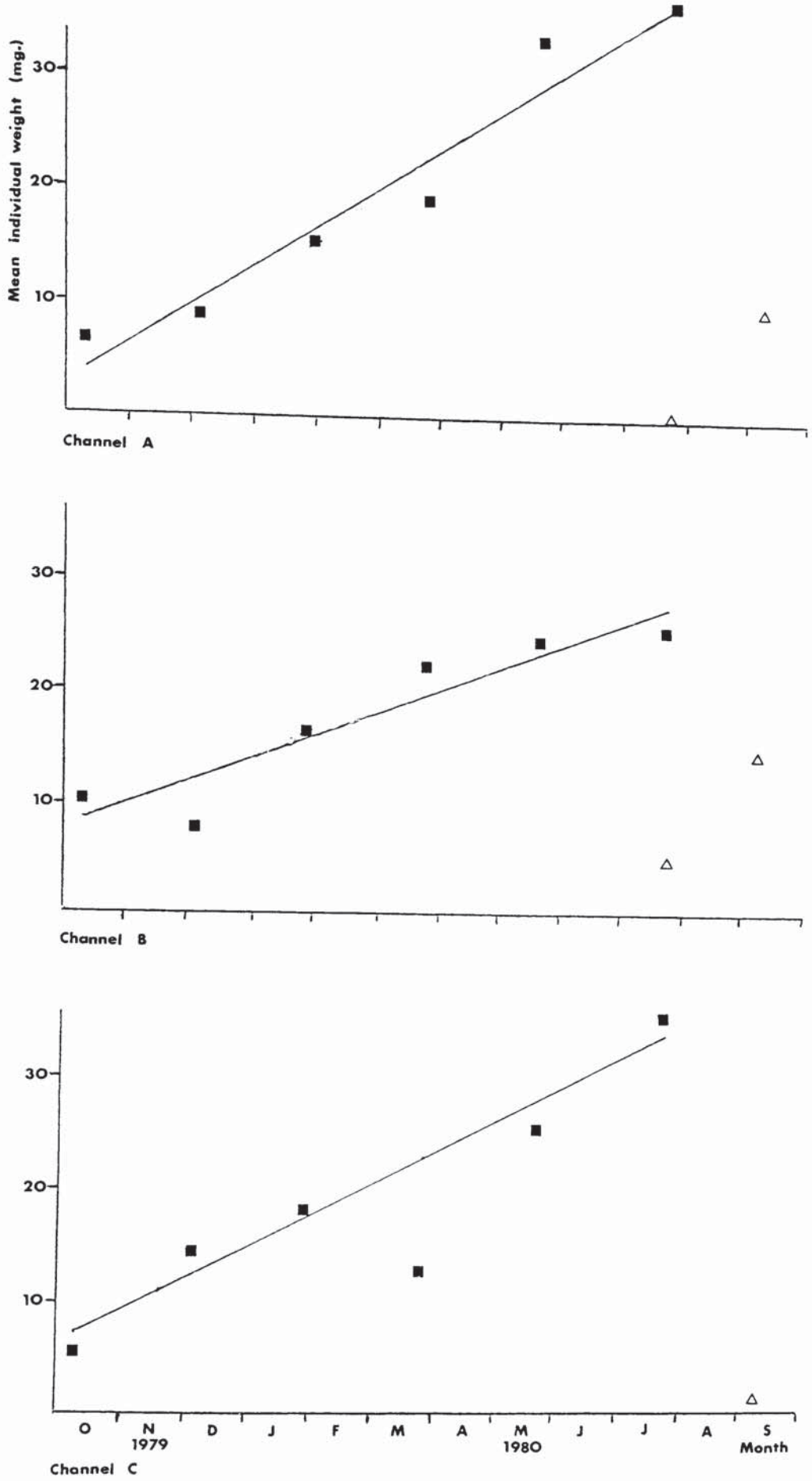


FIGURE 4.18 : MEAN INDIVIDUAL WEIGHTS OF COHORTS OF *L. peregra* COLLECTED FROM THE CHECKLEY CHANNEL UPPER POOLS.

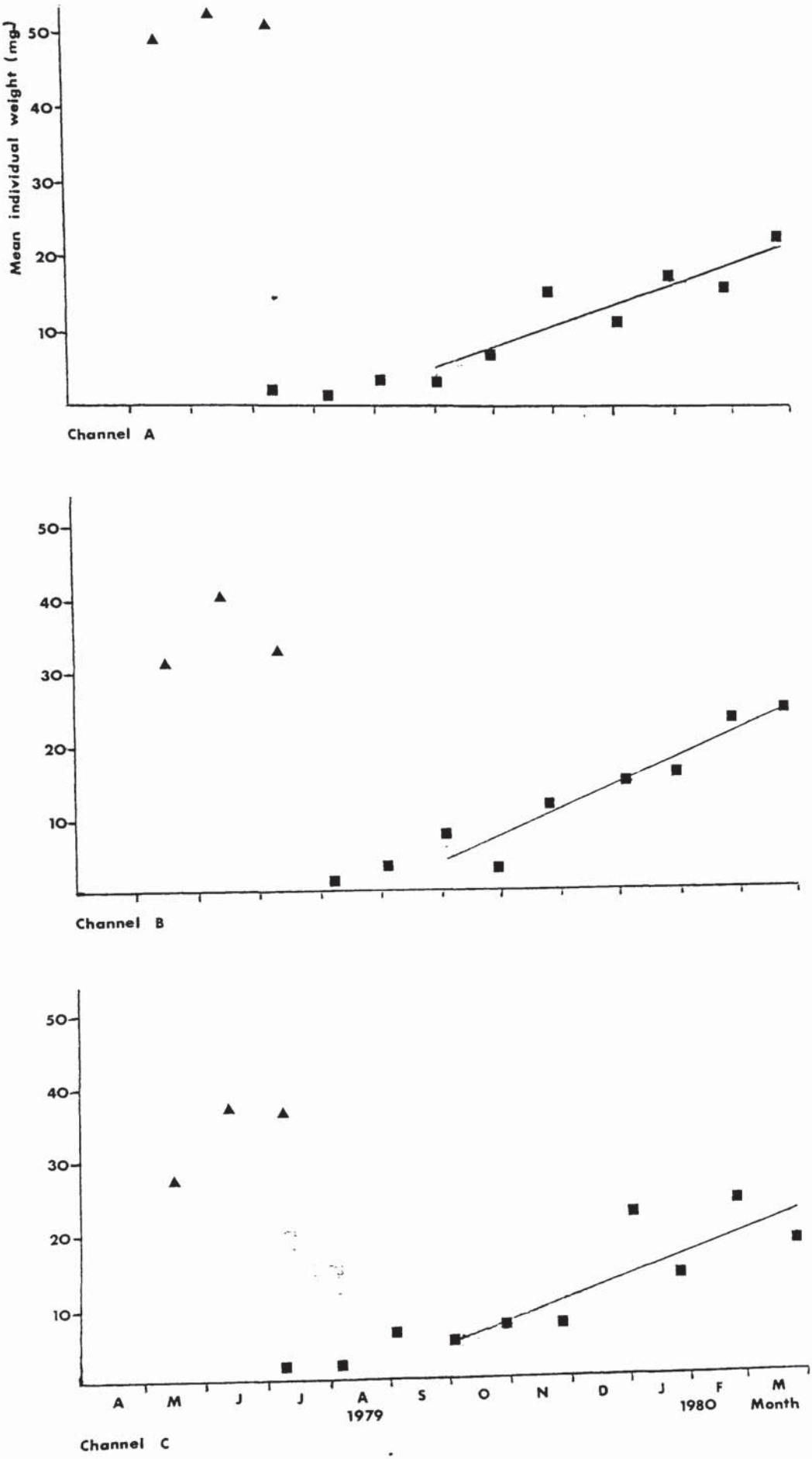


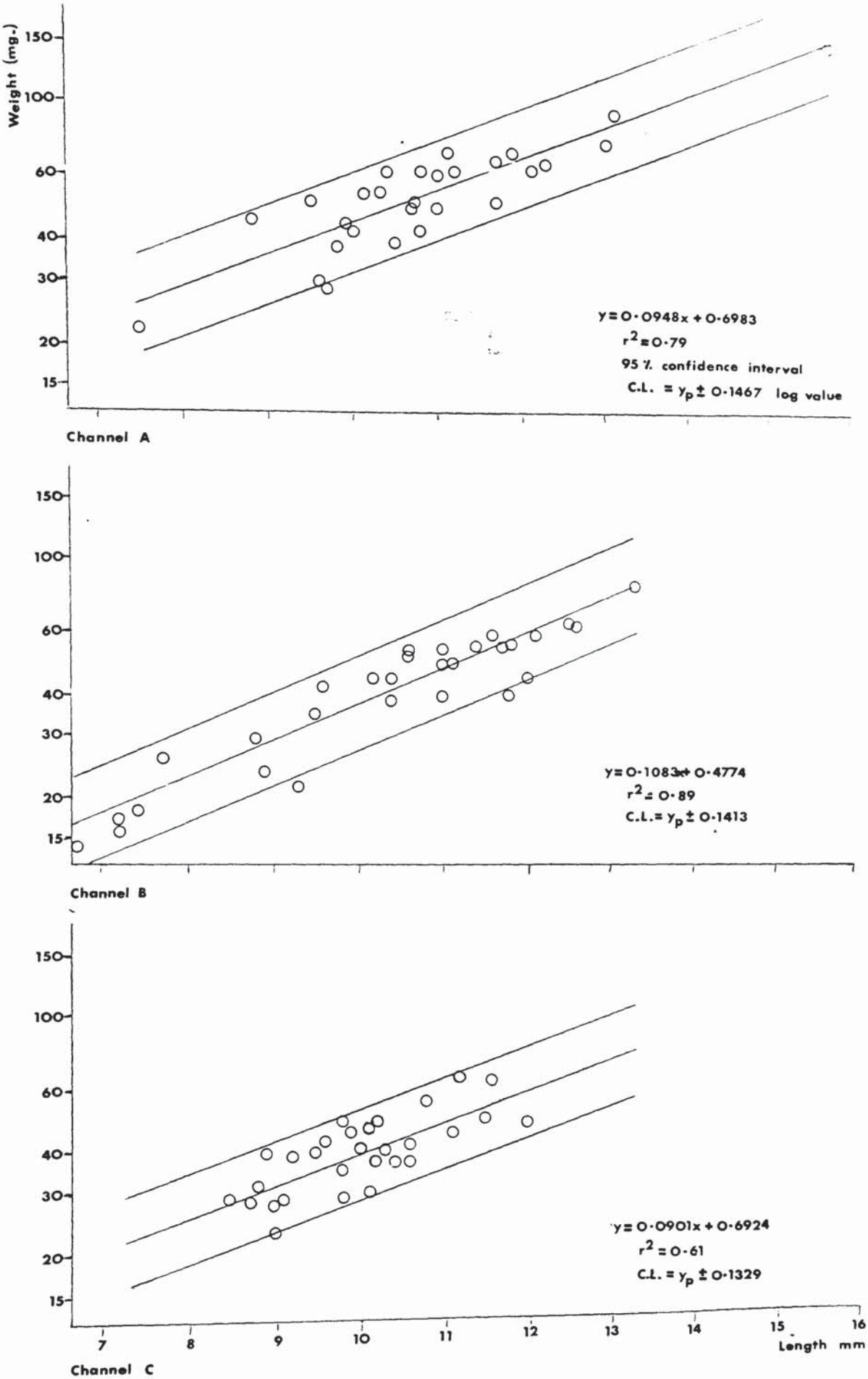
FIGURE 4.19: MEAN INDIVIDUAL WEIGHTS OF COHORTS OF *L. peregra* COLLECTED ON CHECKLEY CHANNEL S.AUF.U.

The even increase in weight throughout the life of L. peregra resulted in a fall in weight gain per individual per unit weight (v') and instantaneous growth rate as the snails aged (Table 4.7).

Snails from the upper pools were heavier and larger than those from the riffles in all channels throughout the year (Table 4.7, Figures 4.15 and 4.16). For example, L. peregra in riffle samples taken on 27.11.79 had mean weights of **3.2** mg and **6.6** mg in channels B and C respectively while those in pool samples taken one week later had mean weights of **7.9** mg and **14.4** mg respectively. Furthermore snails 10mm long were sampled before the end of 1979, 5 months before any were found in the lower riffle. It is conceivable that there was a greater food supply in the pools that was responsible for these distinct differences and/or that, because pool populations were lower, competition for food was less. Alternatively, larger snails might be more likely to be washed downstream from the faster flowing riffles.

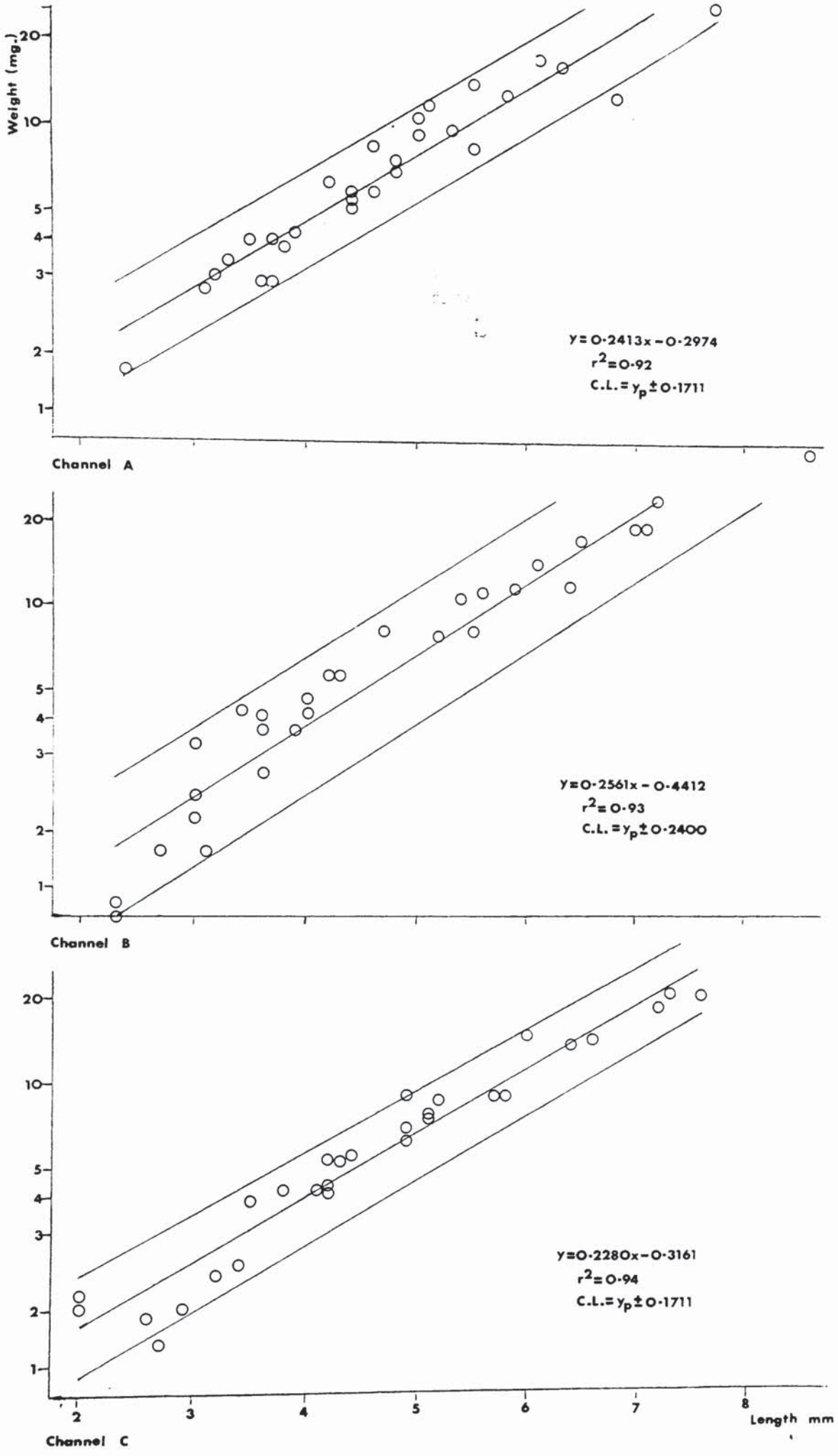
Adult L. peregra seemed to achieve similar weights and sizes in all 3 channels, the maximum mean weight for cohort 2 for an individual month being 36.6 mg for an upper pool sample from channel A in July 1980 (Figure 4.18). Snails in channels B and C also achieved mean weights around or in excess of 30mg in particular months (Figures 4.17 and 4.18 respectively). Furthermore adults in excess of 14mm long occurred in all channels (Figures 4.15 and 4.16).

There were no significant differences in growth rates of L. peregra between channels, analysis of covariance produced values of $F_{2,12} = 2.83$ and $F_{2,15} = 0.46$ for pool cylinder and S.Auf.U. samples respectively for the tests for significant differences in the slopes of the mean individual weight - time relationships. Indeed, the variability between different samples appeared to be as great as that between channels, e.g. direct pool sampling showed growth to increase B<C<A whereas S.Auf.U. pool sampling showed exactly the opposite trend (Table 4.7). The anovar table for the above significance test is shown in Appendix Table 10.6. Although the gradients of the log weight - length regression lines increased C<A<B for both old and young cohorts (Figure 4.20), differences between the respective gradients were small.



(a).

FIGURE 4.20: LOG WEIGHT - LENGTH RELATIONSHIPS OF (a) AN OLD COHORT AND (b) A YOUNG COHORT OF *C. paragus* IN THE CHECKLEY CHANNELS.



(b).

FIG. 4.20 continued

One difference between the channels did exist: the life cycle in channel C appeared to lag slightly behind that in the other 2 channels. During 1979 large snails of the first cohort were still present in large numbers in the lower riffle of channel C in July, whereas none were present in channel A and very few in channel B (Figure 4.15). Furthermore, very few young snails of the second cohort were present the previous month while a cohort 2 population of $613m^{-2}$ was recorded for channel B (Figures 4.3 and 4.15) and, young snails in the upper pool sample from channel C in September 1980 were much smaller than those recovered from channels A and B (Figure 4.16).

Size class frequency distribution histograms for P. jenkinsi from lower riffle and upper pool cylinder samples are shown in Figures 4.21 and 4.22 respectively. Many small individuals were present when the riffle was first sampled for size classes in June 1979 the mean individual weight being only **0.9** mg in channel A (Figure 4.23). Snails in this cohort grew quite rapidly during the summer until the mean weight had increased to **2.8** mg in September 1979. Once again snails in the pool sections tended to be clearly heavier, those collected from the upper pool cylinder samples one week later having a mean weight of **4.0** mg. The heavier pool animals are also reflected in the mean weights of snails collected on S.Auf.U. (Figure 4.23). The same explanations as for the similar differences in L. peregra weights probably apply. Snails in the same cohort seemed to grow at widely differing rates. P. jenkinsi in the first cohort were recruited to the 4.0-4.9mm size class for over 6 months the cohort not becoming dominated by mature adult snails until January 1980 (Figure 4.21). Cohort 2 snails born in the autumn and winter of 1979-80 grew rather slowly the mean weight only increasing from **0.5** mg on 6.11.79, when first recovered from the lower riffle, to **1.3** mg on 17.3.80, when the first mature adults in excess of 4mm long were recorded (Figure 4.21). The seasonal effect of temperature was probably resonsible.

Growth rates up to October 1979 are shown for P. jenkinsi collected in lower riffle samples and on S.Auf.U. in Table 4.8. These could not be calculated thereafter because of large scale deaths of larger snails following reproduction. Very few snails were recovered from channel B, this was probably due to sampling error so no comparison of size classes or growth was applicable.

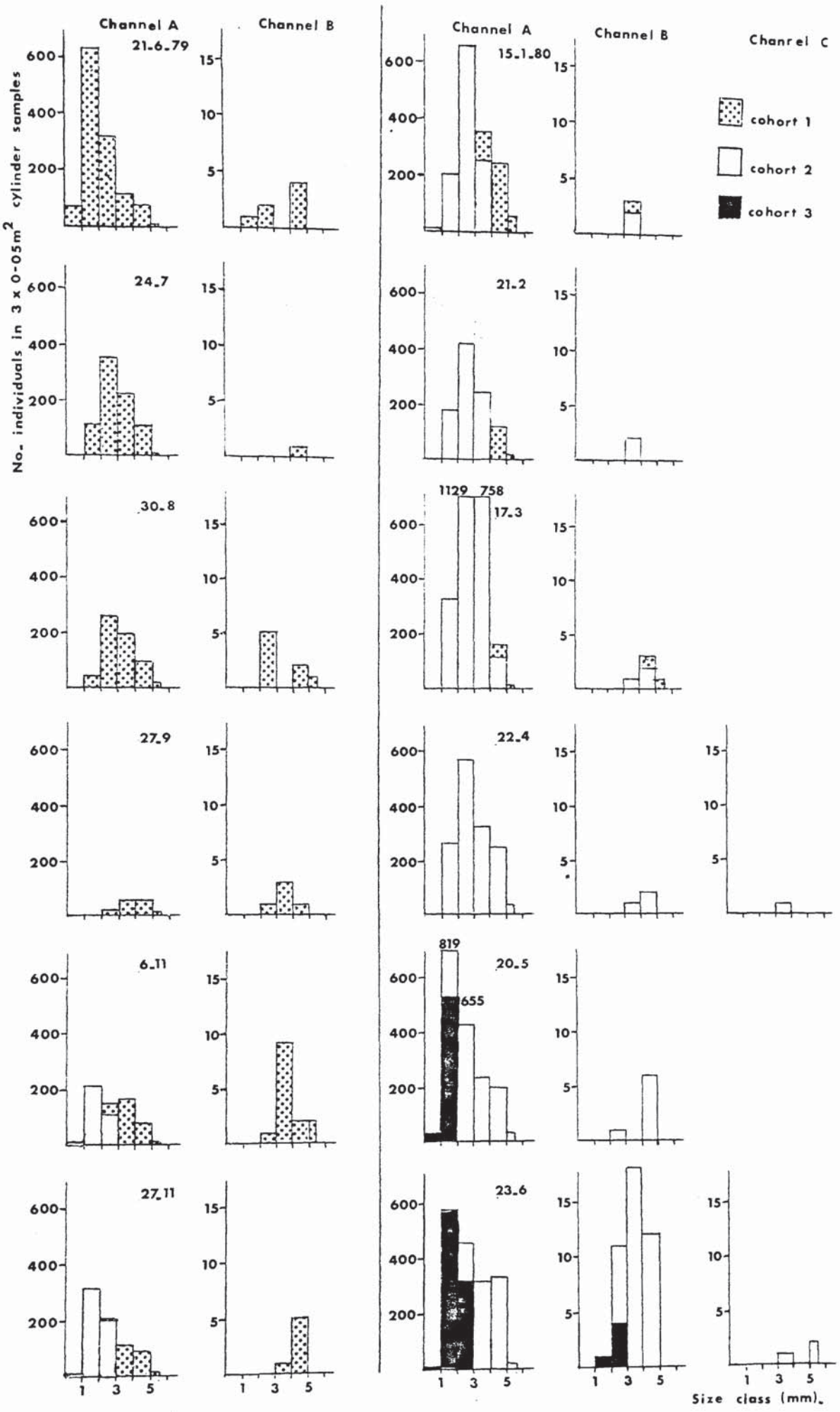


FIGURE 4.21 : SIZE CLASS - FREQUENCY DISTRIBUTION OF *P. jenkinsi* IN THE CHECKLEY CHANNEL LOWER RIFFLES.

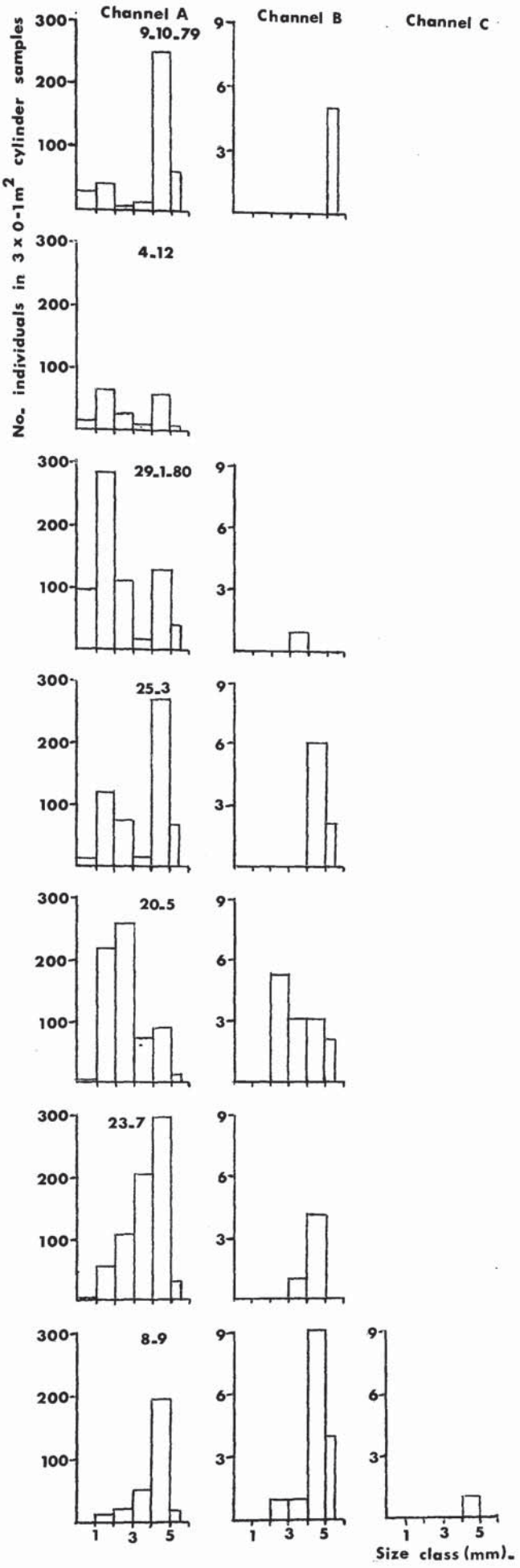


FIGURE 4.22 : SIZE CLASS-FREQUENCY DISTRIBUTION OF *P. jenkinsi* IN THE CHECKLEY CHANNEL UPPER POOLS.

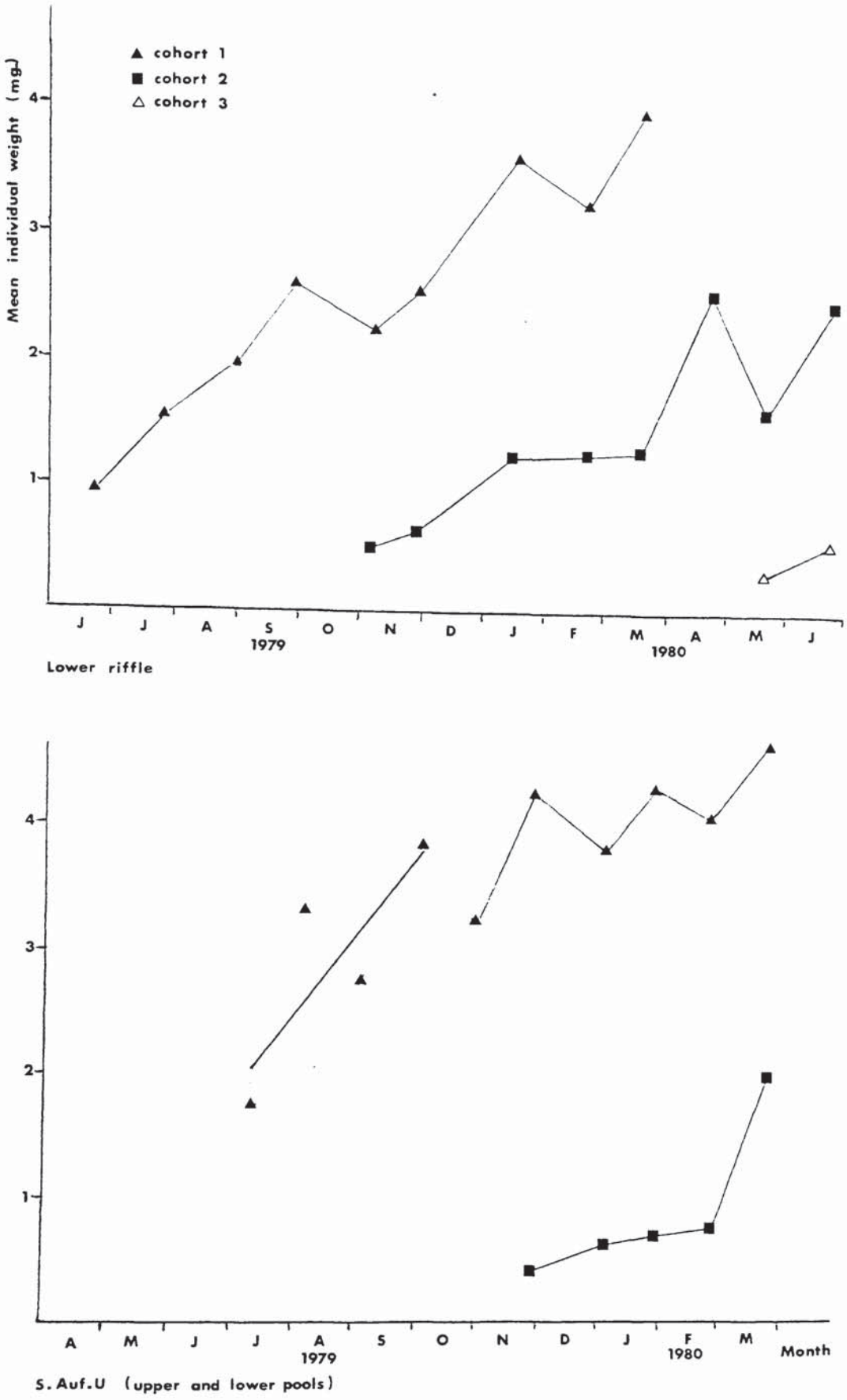


FIGURE 4.23 : MEAN INDIVIDUAL WEIGHTS OF COHORTS OF *P. jenkinsi* COLLECTED FROM THE CHECKLEY CHANNELS.

Date	Corrected mean weight (mg)	$v(mgd^{-1})$	$v'(mgd^{-1}mg^{-1})$	g
Lower Riffle				
21.6.79				
24.7.79	Raw	0.0184	0.0146	0.0150
	data	0.0108	0.0061	0.0061
30.8.79	used			
27. 9.79		0.0235	0.0102	0.0103
S.Auf.U				
10.7.79	2.0320			
		0.0208	0.0089	0.0090
7.8.79	2.6134			
		0.0208	0.0072	0.0072
4.9.79	3.1949			
		0.0208	0.0060	0.0060
2.10.79	3.7764			

TABLE **4.8** : CORRECTED MEAN WEIGHT, ABSOLUTE DAILY WEIGHT GAIN PER INDIVIDUAL (v), ABSOLUTE DAILY WEIGHT GAIN PER INDIVIDUAL PER UNIT WEIGHT (v') AND INSTANTANEOUS GROWTH RATE (g) IN *P.jenkinsi* IN CHECKLEY CHANNEL A.

4.4.6 Reproduction

Individual counts of the numbers of egg masses and eggs laid by L. peregra and collected on polythene strips are shown in Appendix Tables 8.19 and 8.20 respectively.

Few significant differences in the numbers of egg masses and eggs laid between channels were recorded (Table 4.9) because of the large numbers of polythene strips in all channels which had no masses laid on them. Nevertheless Tables 4.10 and 4.11 clearly show that the number of masses and eggs increased channel A<C<B in both the lower riffle and the upper pool. A peak of 26.80 egg masses/strip was achieved in the lower riffle of channel B, compared with 6.00 masses/strip and 3.60 masses/strip in channels C and A respectively, all peaks being in June. Similarly June peaks of 18.80 masses/strip, 51.25 masses/strip and 31.67 masses/strip were found in the upper pools in channels A, B and C respectively. These values did not directly reflect population differences between the channels since the C lower riffle had higher populations than the B lower riffle (Figure 4.3). This can be seen in the results for the number of eggs laid per individual adult (Tables 4.10 and 4.11) where channel C had fewer than either A or B. Channel B had the largest number of eggs per individual adult on the whole with the exception of a 46.96 value for channel A in the June pool samples which was the result of very few adult L. peregra being collected in the pool cylinder samples the previous month. Differences in the number of eggs laid per individual adult were not, however, significant statistically (Table 4.9), basically because of the large number of strips in all channels which had no masses laid on them.

The length of the breeding season in L. peregra also increased channel A<C<B extending from April to July in A while stretching from March to September in B. This would also increase the number of new-born channel A<C<B.

Significant differences in the number of eggs laid per mass between channels occurred in all months (Table 4.9). However, although there were 4 significant values each channel had the highest number of eggs per mass at least once among these. Consequently,

Date ↓	KRUSKAL WALLIS ANOVAR (K)						PARAMETRIC ANOVAR (F)	
	No.of egg masses/ strip		No. of eggs/strip		No. of eggs/strip/ adult/m^2		No.of eggs/mass	
	Lower Riffle	Upper Pool	Lower Riffle	Upper Pool	Lower Riffle	Upper Pool	Lower Riffle	Upper Pool
25.3.80	1.26	-	1.26	-	1.26	-	-	-
22.4.80	2.05	2.70	2.00	2.27	2.01	2.42	1.11	7.30**
20.5.80	8.19*	1.13	3.19	0.53	2.77	-	8.27**	1.93
23.6.80	0.56	3.35	0.04	3.35	+	3.43	4.87*	0.60
23.7.80	0.10	10.67**	0.13	9.77**	3.32	-	7.47**	0.92
19.8.80	2.84	4.19	2.84	4.19	-	4.91	-	-
8.9.80	6.05*	2.47	6.05*	2.42	-	-	-	-

TABLE 4.9 : ONE-WAY ANALYSES OF VARIANCE (WITH SIGNIFICANCE LEVELS) ON REPRODUCTION OF *L. peregra* IN THE CHECKLEY CHANNELS DURING 1980.

+ only one snail recorded in channel B lower riffle.

↓Date Channel →	No. of Egg Masses/Strip			No. of Eggs/Strip			No. of Eggs/Strip/ Individual/m^2 of Riffle			No.of Eggs/Mass ($\bar{x} \pm$ 95%C.L		
	A	B	C	A	B	C	A	B	C	A	B	C
26. 2. 80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-
25. 3. 80	0.00	0.33 (0-2)	0.00	0.00	5.67 (0-34)	0.00	0.00	0.43	0.00	-	17.00 ± 38.09	-
22.4.80	0.17 (0-1)	1.50 (0-4)	2.33 (0-7)	5.17 (0-31)	78.50 (0-193)	86.17 (0-234)	∞	2.36	0.48	31.00 ± 0.00	46.25 ± 17.42	37.79 ± 14.72
20.5.80	1.67 (0-8)	8.60 (1-25)	1.40 (0-3)	88.33 (0-425)	257.45 (18-756)	55.40 (0-109)	1.20	2.76	0.92	54.00 ± 12.83	29.89 ± 4.26	39.57 ± 85.05
23.6. 80	3.60 (0-14)	26.80 (0-78)	6.00 (0-21)	148.60 (0-584	1057.45 (0-2161)	160.04 (0-613)	1.31	†	0.26	41.28 ± 12.52	32.33 ± 6.81	26.59 ± 4.86
23.7. 80	3.20 (0-6)	8.17 (0-29)	3.17 (0-6)	50.60 (0-88)	188.00 (0-635)	53.83 (0-110)	1.08	1.23	0.10	15.81 ± 5.97	23.28 ± 3.12	17.00 ± 2.99
19. 8.80	0.00	2.00 (0-10)	0.00	0.00	34.33 (0-166)	0.00	0.00	-	0.00	-	17.45 ± 5.49	-
8.9.80	0.00	2.50 (0-11)	0.00	0.00	36.17 (0-142)	0.00	0.00	-	0.00	-	14.47 ± 5.01	-

† only one snail recorded in lower riffle.

TABLE **4.10** :

EGG LAYING BY *L. peregra* ON POLYTHENE STRIPS IN THE CHECKLEY CHANNEL LOWER RIFFLES
(Figures given are mean with range in parentheses except where otherwise stated).

↓ DATE CHANNEL →	No. of Egg Masses/Strip			No. of Eggs/Strip			No. of Eggs/Strip/ Individual/m^2 of Pool			No. of Eggs/Mass ($\bar{x}$ ± 95%(		
	A	B	C	A	B	C	A	B	C	A	B	C
26. 2.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-
25. 3.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-
22. 4.80	0.17 (0-1)	1.33 (0-5)	0.50 (0-3)	4.67 (0-28)	30.67 (0-117)	33.00 (0-198)	0.08	1.02	0.71	28.00± 0.00	23.00± 10.33	66.00± 71.10
20. 5.80	0.67 (0-2)	5.00 (0-13)	0.50 (0-1)	22.83 (0-77)	160.40 (0-445)	22.50 (0-51)	-	-	-	34.25± 18.43	28.04± 5.33	45.00± 76.28
23. 6.80	18.80 (0-49)	15.25 (11-77)	31.67 (7-47)	625.93 (0-1517)	1511.23 (423-2549)	499.14 (225-1154)	46.96	4.44	0.07	32.78± 4.73	29.41± 4.10	30.74± 3.77
23. 7.80	1.00 (0-4)	22.33 (7-73)	31.00 (8-58)	31.20 (0-148)	579.17 (62-2143)	724.67 (317-1441)	-	-	-	31.20± 18.93	23.61± 2.40	23.32± 2.27
19. 8.80	0.00	1.50 (0-5)	1.50 (0-3)	0.00	24.83 (0-93)	22.67 (0-55)	0.00	0.22	0.38	-	16.56± 7.39	14.11± 6.52
8. 9.80	0.00	0.80 (0-2)	1.00 (0-4)	0.00	9.00 (0-26)	16.67 (0-60)	0.00	-	-	-	11.25± 7.51	16.67± 11.94

TABLE **4.11** : EGG LAYING BY *L. peregra* ON POLYTHENE STRIPS IN THE CHECKLEY CHANNEL UPPER POOLS

(Figures given are mean with range except where otherwise stated).

it is unlikely that there were differences in the number of eggs laid per mass between channels.

Reproduction in P. jenkinsi was continuous. No embryos approaching hatching were present for the first 9 weeks after cohort 1 appeared in June 1979, but some were in this state every month thereafter until June the following year (Table 4.12). Reproduction seemed to occur in waves both the total number of embryos and the number near hatching fluctuating over a wide range from month to month (Tables 4.12 and 4.13).

Only the 5.0-5.4mm and 4.0-4.9mm size classes of P. jenkinsi contained embryos near to hatching usually (Table 4.14). Embryo capsules were additionally found in the 3.0-3.9mm size class while embryoid material was first clearly distinguishable in the 2.0-2.9mm snails. This early development of embryoid material supports the tremendous reproductive potential of P. jenkinsi.

There was no clear suppression of reproduction in channel B snails. Significant differences in the numbers of embryos in the 4.0-4.9mm adults between channels A and B occurred in 3 of the 6 months where comparisons were made (Table 4.15), but the number in adults from B was significantly greater than in A on one of these occasions (6.11.79) and more embryos were also present in B on one further occasion (23.6.80) (Table 4.13). Furthermore, on only one occasion (6.11.79) was there a significant difference between the number of embryos approaching hatching in adult snails and, on this occasion, the number in B exceeded that in A. Despite these significant differences in the majority of months there were no significant differences in either the total number of embryos or the number near hatching in either size class of adult.

Similarly there did not appear to be any inhibition of embryo development in channel B. Proportions of snails having either embryos near hatching, embryo capsules or any embryoid material did not differ much for any size class between channels (Table 4.14); on some occasions the proportion was slightly greater in A, on others B had the slightly greater proportion. Nor was there much difference in the proportion of embryos approaching hatching between channels except for the 3.0-3.9mm size class on 6.11.79 when only 2 snails from

Size Class (mm) →		Number Embryo Capsules/ Snail			
		5.0 - 5.4		4.0 - 4.9	
↓Date Channel → Age of cohort (wk) ↓		A	B	A	B
10. 7.79	2	0, 00	-	0. 00	-
7. 8.79	6	0. 00	-	0. 00	-
21. 8.79	8	0. 00	-	0. 00	-
4. 9.79	10	6.45± 0.90	-	5.96± 1.11	-
2.10.79	14	11.63± 1.89	-	10.31± 1.97	-
6.11.79	19	4.20± 1.41	6.00± 30.55	2.33± 0.78	5.22± 2.16
27.11.79	22	9.14± 1.66	4.20± 53.37	8.88± 1.14	3.03± 5.69
3. 1.80	27	9.76± 3.49	-	9.38± 1.53	-
5. 2.80	31	4.90± 1.21	5.18± 2.31	4.44± 0.71	3.00± 1.05
26. 2.80	35	5.82± 1.48	1.38± 2.20	5.99± 0.69	2.98± 2.68
25. 3.80	39/25	6.36± 1.51	-	4.88± 0.91	-
22. 4.80	29	1.80± 0.24	0. 00	1.07± 0.13	0.19± 0.06
21. 5.80	33	15.46± 7.37	-	2.43± 0.42	-
23. 6.80	38	6.53± 0.60	11.69± 1.78	0.96± 0.21	1.90± 0.44

TABLE **4.12**: A COMPARISON OF THE NUMBER OF EMBRYO CAPSULES APPROACHING HATCHING IN ADULT *P. jenkinsi* IN CHECKLEY CHANNELS A AND B. (Figures given are means with 95% confidence intervals).

Size Class (mm) → / Channel → / ↓Date / Age of cohort (wk)↓		No. Embryo Capsules/Snail			
		5.0 - 5.4		4.0 - 4.9	
		A	B	A	B
10. 7.79	2	36.00 ± 32.30	-	11.60 ± 4.22	-
7. 8.79	6	34.23 ± 4.69	-	18.53 ± 3.87	-
21. 8.79	8	33.77 ± 3.81	-	21.03 ± 3.11	-
4. 9.79	10	37.63 ± 5.25	-	21.27 ± 3.97	-
2.10.79	14	24.93 ± 4.04	-	13.10 ± 2.50	
6.11.79	19	4.20 ± 1.41	10.00 ± 50.85	6.60 ± 1.44	12.00 ± 4.97
27.11.79	22	15.93 ± 2.87	7.00 ± 88.95	16.17 ± 8.07	6.67 ± 12.50
3. 1.80	27	13.67 ± 4.88	-	12.50 ± 2.04	-
5. 2.80	31	9.03 ± 2.24	7.69 ± 3.40	10.27 ± 1.65	6.31 ± 2.21
26. 2.80	35	10.15 ± 2.59	2.75 ± 4.38	12.83 ± 1.47	3.50 ± 3.16
25. 3.80	39/25	14.45 ± 3.43	-	13.67 ± 2.54	-
29. 4.80	29	26.83 ± 3.49	7.75 ± 1.53	25.50 ± 3.07	12.00 ± 3.56
21. 5.80	33	78.50 ± 3.74	-	40.50 ± 7.05	-
23. 6.80	38	54.40 ± 5.05	50.17 ± 7.67	24.10 ± 5.26	28.43 ± 6.61

TABLE **4.13** : A COMPARISON OF THE NUMBER OF EMBRYO CAPSULES IN ADULT *B. jenkinsi* IN CHECKLEY CHANNELS A AND B. (Figures given are means with 95% confidence intervals).

Date →	6.11.79		5.2.80		23.6.80	
↓ SIZE CLASS (mm) Channel →	A	B	A	B	A	B
5.0 - 5.4						
Sample size (no.of snails)	30	2	30	13	30	6
% snails with embryoid material	100.0	100.0	100.0	100.0	100.0	100.0
embryo capsules	86.7	100.0	93.3	84.6	100.0	100.0
embryos near hatching	66.7	100.0	93.3	84.6	40.0	66.7
% embryos near hatching	55.6	60.0	54.2	67.3	12.0	23.3
4.0 - 4.9						
Sample size (no.of snails)	30	5	30	26	30	30
% snails with embryoid material	100.0	100.0	100.0	100.0	100.0	100.0
embryo capsules	100.0	100.0	96.7	88.5	100.0	100.0
embryos near hatching	86.7	100.0	86.7	84.6	13.3	26.7
% embryos near hatching	59.7	43.5	43.2	47.5	4.0	6.7
3.0 - 3.9						
Sample size (no.of snails)	30	2	10	5	30	20
% snails with embryoid material	90.0	100.0	100.0	100.0	100.0	100.0
embryo capsules	13.3	50.0	0.0	0.0	20.0	20.0
embryos near hatching	6.7	50.0	-	-	0.0	0.0
% embryos near hatching	9.1	100.0	-	-	-	-
2.0 - 2.9						
Sample size (no.of snails)	30	3	30	6	30	30
% snails with embryoid material	53.3	66.7	40.0	16.7	67.7	83.3
embryo capsules	0.0	0.0	0.0	0.0	0.0	0.0
embryos near hatching	-	-	-	-	-	-
% embryos near hatching	-	-	-	-	-	-
1.0 - 1.9						
Sample size (no.of snails)	-	-	30	4	4	4
% snails with embryoid material	-	-	0.0	0.0	0.0	0.0
embryo capsules	-	-	-	-	-	-
embryos near hatching	-	-	-	-	-	-
% embryos near hatching	-	-	-	-	-	-

TABLE 4.14 : A COMPARISON OF EMBRYO DEVELOPMENT IN *P. jenkinsi* IN THE CHECKLEY CHANNELS

↓ Date	Size Class (mm) →	Difference in the No. of embryos		Difference in the No. of embryos near hatching	
		5.0-5.4	4.0-4.9	5.0-5.4	4.0-4.9
6.11. 79		-	- 3.95***	-	- 2.35*
27.11. 79		-	1.94	-	0.70
5. 2. 80		- 0.30	- 0.08	- 0.22	- 1.53
26. 2. 80		1.88	4.72***	1.11	0.98
22. 4. 80		1.49	4.10***	0.31	1.27
23. 6. 80		0.39	- 1.53	- 1.31	- 1.84

TABLE **4.15** :

VALUES OF STUDENTS - t (WITH SIGNIFICANCE LEVELS) FOR DIFFERENCES IN THE TOTAL NUMBER OF EMBRYOS AND THOSE NEAR HATCHING IN ADULT *P. jenkinsi* BETWEEN CHECKLEY CHANNELS A AND B.
(Positive values are for when A > B, negative when B > A)

channel B were sampled anyway (Table 4.14). Significant differences in the size class - frequency distribution of all embryos occurred on 2 of 3 occasions (Table 4.16) but on both occasions this was because embryos were larger in adults from channel B (Table 4.17). This difference was shown to be attributable to significant differences in the size class - frequency of differentiated rather then undifferentiated embryos (Table 4.15) on 23.6.80. No significant differences in the size class - frequency distribution of embryos near hatching existed on any of the 3 occasions comparisons were made (Table 4.15). The actual size class - frequency distributions are shown in Tables 4.17 to 4.20.

Overall, therefore, it would seem that as reproduction is not inhibited in channel B the much lower population in this channel is in the long run due to higher mortality.

↓ Date	All Embryos	Embryos near hatching	Undifferen-iated Embryos	Differentia-ted Embryos
6. 11. 79	9.93	-	-	-
Nov. 79	-	4.81	-	-
5. 2. 80	17.10*	7.27	-	-
26. 2. 80	-	16.14	-	-
23. 2. 80	39.36***	-	10.87	30.93***

TABLE **4.16** :

VALUES OF χ^2 (WITH SIGNIFICANCE LEVELS) FOR DIFFERENCES IN THE SIZE CLASS FREQUENCY DISTRIBUTION OF EMBRYOS IN ADULT *P. jenkinsi* (≥4 mm LONG) BETWEEN CHECKLEY CHANNELS A AND B.

SIZE CLASS (μm) ↓ Date → / Channel →	PROPORTION OF EMBRYOS (%)					
	6.11.79		5.2.80		23.6.80	
	A	B	A	B	A	B
Embryo indistinguishable	16.67	4.00	4.96	0.80	0.12*	3.90
200 - 245	2.48	8.50	8.79	1.78	23.06	22.29
250 - 295	15.32	8.00	7.03	3.57	58.87	32.38
300 - 345	7.70	8.50	13.49	9.72	9.52	19.71
350 - 395	10.00	13.00	25.96	23.12	3.96	5.33
400 - 445	25.41	29.00	22.53	34.87	0.70	14.76
450 - 495	19.54	27.00	12.94	20.60	2.67	1.62
500 - 545	2.87	2.00	4.31	5.60	0.00	0.00
Total No. of Embryos examined.	162	37	146	111	150	105

*1.21% 190 μm diameter

Relative ratios of 5.0 - 5.4 mm size class and 4.0 - 4.9 mm size class based on S.A.U. data.

TABLE **4.17** : SIZE CLASS - FREQUENCY DISTRIBUTION OF EMBRYOS IN *P. jenkinsi* AT 3 POINTS IN THE YEAR.
(FIGURES BASED ON TWO LARGEST SIZE CLASSES)

SIZE CLASS (μm) ↓ Date→ / Channel→	PROPORTION OF EMBRYOS (%)					
	NOV. 79		5.2.80		26.2.80	
	A	B	A	B	A	B
300 - 320	0.65	0.00	0.00	0.00	0.00	0.00
325 - 345	0.65	0.00	0.00	1.61	0.00	0.00
350 - 370	6.49	8.33	5.63	9.68	4.29	0.00
375 - 395	5.84	16.67	15.49	14.52	10.00	0.00
400 - 420	25.97	20.83	26.76	16.13	14.29	15.79
425 - 445	24.03	25.00	15.49	11.29	30.00	15.79
450 - 470	18.18	12.50	14.08	17.74	15.71	31.58
475 - 495	13.64	8.33	12.68	17.74	24.29	15.79
500 - 520	4.55	4.17	7.04	11.29	1.43	21.05
525 - 545	0.00	0.00	2.82	0.00	0.00	0.00
Total No. of Embryos examined	154	24	71	62	70	19

TABLE **4.18** :SIZE CLASS - FREQUENCY DISTRIBUTION OF EMBRYOS APPROACHING HATCHING IN *P. jenkinsi* AT 3 POINTS DURING THE BREEDING SEASON

Embryo size class (μm) ↓ / Snail size class (mm) → / Channel →	PROPORTION OF EMBRYOS (%)					
	5.0 - 5.4		4.0 - 4.9		BOTH	
	A	B	A	B	A	B
Embryo indistinguishable	4.35	7.69	0.00	8.33	0.42	8.24
175 - 195	0.00	0.00	1.72	0.00	1.55	0.00
200 - 220	13.04	7.69	8.62	8.33	9.05	8.24
225 - 245	21.74	30.77	20.69	36.11	20.79	35.35
250 - 270	43.48	15.38	34.48	16.67	35.35	16.49
275 - 295	17.39	38.46	25.86	25.00	25.05	26.92
300 - 320	0.00	0.00	6.90	5.56	6.24	4.77
325 - 345	0.00	0.00	0.00	0.00	0.00	0.00
350 - 370	0.00	0.00	1.72	0.00	1.55	0.00
Total No. of Embryos examined	23	13	58	36	81	49

Relative ratios of 5.0 - 5.4 mm size class and 4.0 - 4.9 mm size class based on S.A.U. data

TABLE **4.19** : SIZE CLASS - FREQUENCY DISTRIBUTION OF UNDIFFERENTIATED EMBRYOS OF *P. jenkinsi* TAKEN FROM THE CHECKLEY CHANNELS ON 23.6.80

Embryo size class (μm) ↓ / Snail size class (mm) → / Channel →	PROPORTION OF EMBRYOS (%)					
	5.0 - 5.4		4.0 - 4.9		BOTH	
	A	B	A	B	A	B
200 - 245	1.92	5.88	0.00	2.56	0.18	3.03
250 - 295	21.15	5.88	64.71	28.21	60.52	25.02
300 - 345	36.54	17.65	17.65	35.90	19.47	33.29
350 - 395	25.00	23.53	5.88	7.69	7.72	9.95
400 - 445	11.54	41.18	0.00	23.08	1.11	25.67
450 - 495	3.85	5.88	11.76	2.56	11.00	3.03
500 - 545	0.00	0.00	0.00	0.00	0.00	0.00
Total No.of Embryos examined	52	17	17	39	69	56

Relative ratios of 5.0 - 5.4 mm size class and 4.0 - 4.9 mm size class based on S.A.U. data

TABLE **4.20** : SIZE CLASS - FREQUENCY DISTRIBUTION OF DIFFERENTIATED EMBRYOS OF *P. jenkinsi* TAKEN FROM THE CHECKLEY CHANNELS on 23.6.80

4.5 Conclusions

1. The S.Auf.U. show up biological differences between the 3 channels. The number of taxa, pollution indexes and diversity indexes decrease channel A>B>C.

2. Pollution and diversity indexes are depressed compared to values obtained by direct sampling of riffles.

3. The population and biomass of L. peregra in the channels increases channel A<B<C; the presence of more food in the effluent containing channels may explain this. Exactly the opposite is true of P. jenkinsi, very few of this species are found in either channel B or C. It is likely that the metal levels in these two channels have a deleterious effect.

4. The populations and biomasses of both species of snail are higher in the riffles than the pools.

5. Macrophytes elevate population levels of both species of snail.

6. Populations of L. peregra are only indirectly correlated with the quantity of filamentous green algae. Pollution primarily affects both.

7. Snails achieve the same sizes and weights in all channels, but within a particular channel L. peregra from the pools are heavier than those from the riffles throughout most of the year.

8. The life cycle of L. peregra in channel C lags slightly behind the other 2 channels.

9. Differences in the populations of P. jenkinsi between channels are due to different mortality and / or invasion rates; reproduction does not seem to differ.

10. Reproduction of L. peregra increases channel A<C<B. Snails in channel C seem to lay fewer eggs each.

5. S.AUF.U. SAMPLING AND GASTROPOD STUDIES ON LOWLAND RIVERS

5.1 Introduction

Following work on S.Auf.U. in a previous "Water Data Unit" Contract, it was decided that using S.Auf.U. in biological surveillance became the prime proposition only in lowland rivers and drains with extensive depositing stretches and very few or no riffles (Dept. of Env., 1979). This conclusion was reached because the presence of riffles allowed the use of direct sampling methods such as hand nets and the "Aston" cylinder sampler which collected more species, provided data more readily and were not subject to vandalism. In contrast where prolonged depositing stretches existed S.Auf.U. collected more taxa than direct sampling methods, which were often difficult to use anyway.

In a previous contract field trials on S.Auf.U. in slow flowing lowland rivers and potamon zones were carried out at 27 sites on 19 rivers chosen to cover a wide range of types of river and water qualities (Girton and Hawkes, 1979). The results indicated that, although S.Auf.U. immersed at heavily polluted sites attracted similar assemblages of colonisers, clean and mildly polluted sites had a high degree of dissimilarity even at stations of similar water quality (Girton and Hawkes, 1979). These differences were probably largely due to differences in the physical type of river and the proximity of riffles. Consequently in this study all the sites chosen were lowland rivers. A total of 27 sites on 14 rivers were selected to provide a range of water qualities and correspond to water authority chemical sampling sites. In connection with this, the majority of sites were located at harmonised monitoring stations which provided a wide range of chemical data using the same analytical techniques throughout the year.

In a similar way that nearby riffles influence S.Auf.U. colonisation (Dept. of Env., 1979), large growths of macrophytes could provide an important source of colonising taxa as they provide a firm substratum and shelter from the current. For this reason macrophyte abundance was estimated at each site and its influence on colonisation investigated by correlation analysis.

More emphasis was laid on sampling the R. Avon and R. Severn than elsewhere as these two rivers offered a comparison of chemical classes 1 and 2 within the same catchment. In connection with this, a detailed study of the six regularly colonising gastropod species was carried out as work at Checkley had been restricted to Lymnaea peregra and Potamopyrgus jenkinsi and little is known about the life-cycle of snails in lowland rivers.

Finally, it was decided to carry out an assessment of the applicability of different pollution and diversity indexes to S.Auf.U. sampling as it has been argued that, in general widespread pollution surveys, indexes are required to simplify the vast amounts of data generated by species - abundance lists (Hawkes, 1979) and to present data in a form acceptable to non-biologists. To this end the three most commonly used pollution indexes in Britain - the Trent Biotic Index (TBI) (Woodiwiss, 1964), the Chandler Score (1970) and the B.M.W.P. Score (Dept. of Env., 1980) - were compared. The old TBI system was used as this seemed slightly more applicable to lowland rivers than the revised version (Woodiwiss, 1978) since fewer taxa were needed to achieve near maximum scores. Of the diversity indexes, the Shannon-Weaver (1947) has almost exclusively been applied to freshwater pollution studies, but this has been chosen in preference to other indexes on very little evidence. Wilhm and Dorris (1968) chose the Shannon-Weaver index on the grounds that, in contrast to several other indexes, it was independent of sample size - something which is not true according to Bullock (1971), expressed the relative importance of the different species and was dimensionless. Nevertheless, they did not compare its performance with other indexes. Although Learner et al. (1971) and Hellawell (1978) have found the Shannon-Weaver index to perform well in relation to other indexes on the R. Cynon and R. Derwent respectively, no detailed assessment of diversity indexes on wide ranging sites on different rivers has been carried out. Furthermore, this index has been widely criticised on the grounds that it is too sensitive to the few commonest species (Kempton and Taylor, 1976; Southwood, 1978). Indeed Southwood (1978) says that it "should in general be regarded as a distraction rather than an asset in ecological analysis". Other non-parametric indexes such as Simpson's (1949) and McIntosh's (1967) have also been criticised on fundamental grounds. (Sheldon, 1969; Bullock, 1971; Whittaker, 1972; May, 1975; Peet, 1975). Consequently it was decided to compare

the Shannon-Weaver index with an index based on a model describing the species - abundance relationship and the Kempton-Taylor index (1976) which overcomes the main drawback of the Shannon-Weaver index by concentrating on species of intermediate abundance. This indexes' value is dependent on the slope of the cumulative species - abundance curve between the two quartiles.

5.2 Site Description

Twenty-seven sites on 14 different rivers in 4 different Water Authority areas were selected (Figure 5.1). All sites were distant from riffles, most being located on potamon or canalised rivers. No station was placed near an upstream weir except for Tewkesbury on the R. Avon.

In contrast to the other sites, the two sites at Mythe (Figure 5.2) were chosen to assess the effect of a point discharge into a river. A large quantity of suspended solids and aluminium used in the control of algae were discharged into the river from a water intake works between these sites. Other sites in the Severn-Avon catchment are also shown in Figure 5.2. A complete list of the sampling sites, together with chemical class in the 1975 river survey is given in Table 5.1.

The substratum at all sites was depositing ranging from silt to a firm sandy-loam but some canalised sites had banks reinforced with large stones. Macrophytes ranged from being absent to lining the whole of the banks and/or much of the open water surface. A description of the macrophytes present is given in the results section.

5.3 Methods

5.3.1 Physicochemical Sampling

As most sites were visited only twice - to immerse and remove S.Auf.U's - physical and chemical data was collected mainly from the Water Authorities (W.A.). Their sampling sites corresponded to the S.Auf.U. sampling sites with the following exceptions:-

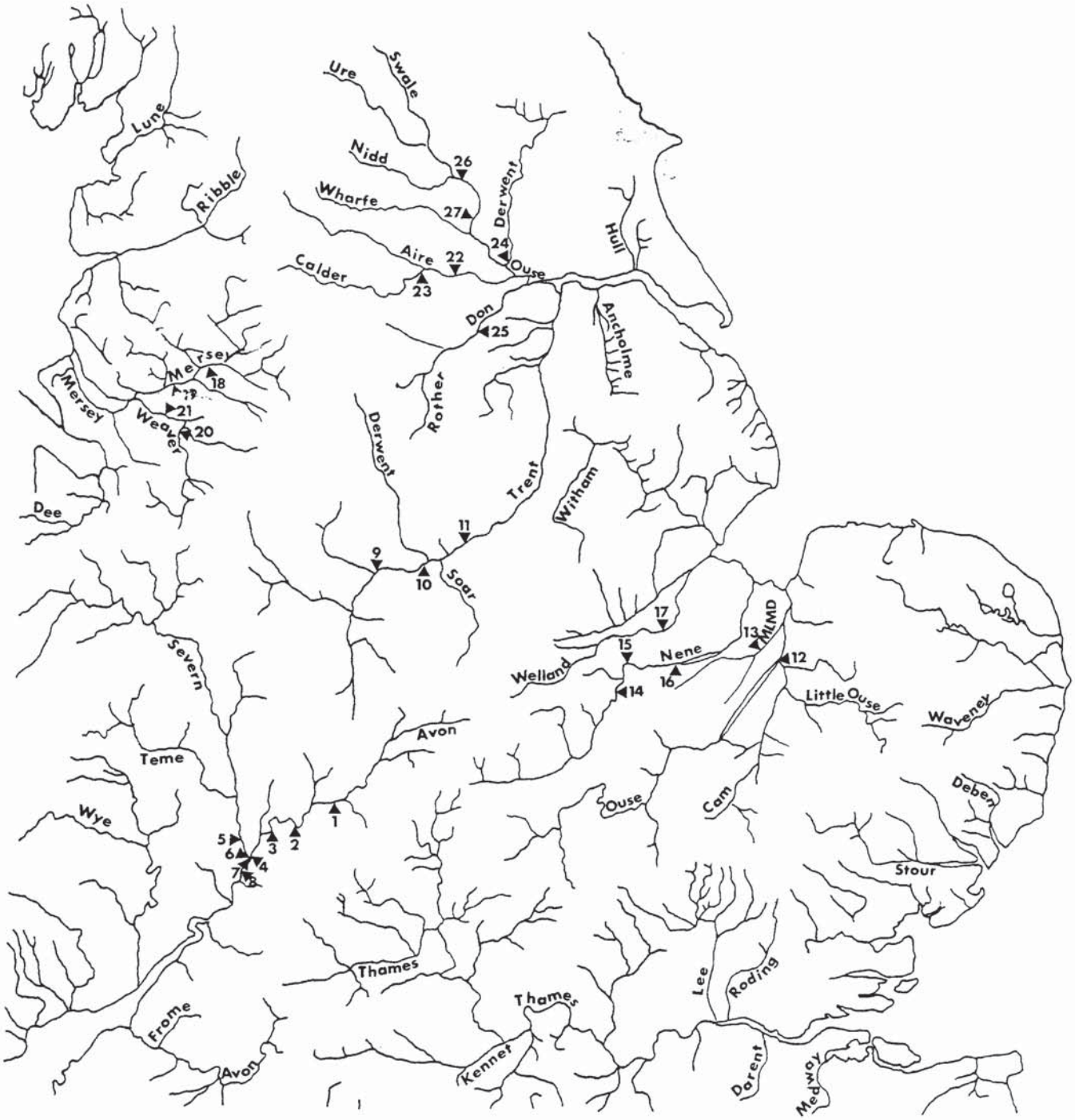


FIGURE 5.1: LOWLAND RIVER SAMPLING SITES

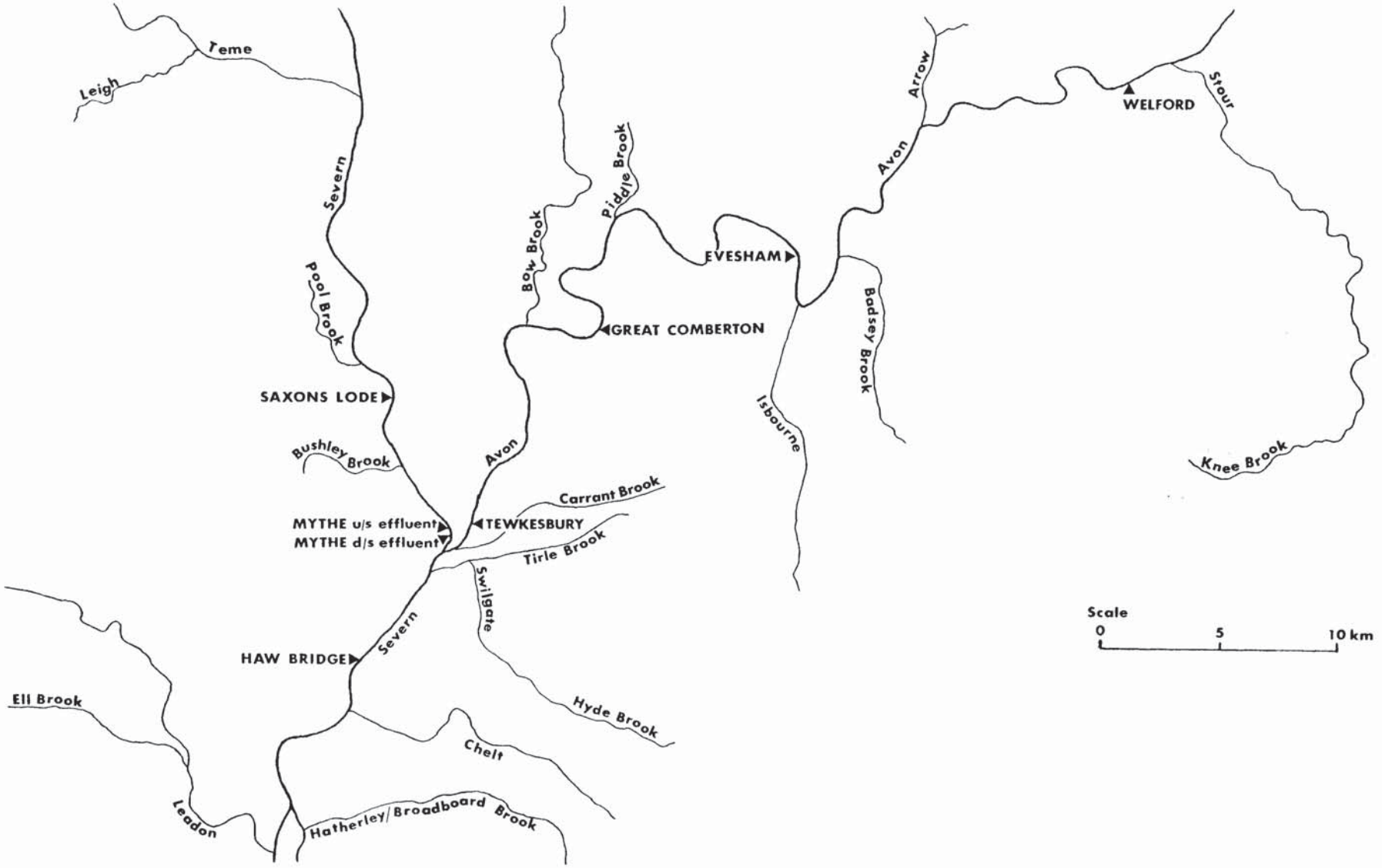


FIGURE 5.2.: R. AVON AND R. SEVERN SAMPLING SITES

River	Site	Grid Reference	Chemical Class	Recovery Date
SEVERN-TRENT WATER AUTHORITY				
Avon	1. Welford	SP 144531	2	28 8 80
	2. Evesham*	SP 034431	2	28 8 80
	3. Gt. Comberton	SO 953426	2	28 8 80
	4. Tewkesbury*	SO 893343	2	28 8 80
Severn	5. Saxons Lode	SO 864391	1	28 8 80
	6. Mythe 1	SO 889336	1	28 8 80
	7. Mythe 2	SO 889334	1	28 8 80
	8. Haw Bridge*	SO 845278	1	8 5 80
Trent	9. Willington	SK 295278	4	22 8 80
	10. Shardlow	SK 446299	3	22 8 80
	11. Nottingham*	SK 581383	2	22 8 80
ANGLIAN WATER AUTHORITY				
Ely Ouse	12. Denver Sluice*	TF 598009	1	22 9 80
Middle Level Main Drain	13. Mullicourt Priory Sluice*	TF 531029	2	22 9 80
Nene	14. Oundle	TL 045890	2	22 9 80
	15. Wansford*	TL 085946	1	22 9 80
	16. Dog-in-a-Doublet Sluice*	TL 272994	2	22 9 80
Welland	17. Crowland*	TF 229107	1	22 9 80
NORTH-WEST WATER AUTHORITY				
Mersey	18. Flixton*	SJ 742938	4	LOST
	19. Warrington (above Howley weir)*	SJ 616880	3	8 10 80
Weaver	20. Hartford Bridge	SJ 648714	2	8 10 80
	21. Acton Bridge	SJ 601760	3	8 10 80
YORKSHIRE WATER AUTHORITY				
Aire	22. Beal Weir*	SE 534255	4	4 9 80
Calder	23. Methley *	SE 409258	4	4 9 80
Derwent	24. Barmby *	SE 687288	1	LOST
Don	25. Doncaster*	SE 563031	4	4 9 80
Ouse	26. Nether Poppleton*	SE 557552	1	LOST
	27. Naburn Weir*	SE 594445	1	4 9 80

* Harmonised or automatic monitoring stations.

TABLE 5.1 : LOWLAND RIVER SAMPLING SITES

(1) No W.A. data was available for Mythe 2.

(2) Welford lay between two W.A. sites at Stratford and Bidford. These two sites were too public to immerse S.Auf.U. at.

(3) Gt. Comberton, Wansford and Hartford Bridge lay a few km upstream of W.A. sampling sites at Eckington, Wansford and Northwich Lock respectively.

(4) Metal and detergent data for Acton Bridge was taken from Frodsham several km downstream and the other side of the tidal limit.

Means, standard errors, minima and maxima for the year 1980 (1979 for N.W.W.A. and pesticides for the Welland-Nene division of the Anglian W.A.) are displayed for temperature, suspended solids, dissolved oxygen (mg ℓ^{-1} and % saturation) 5-day BOD (ATU), chloride fluoride, conductivity, pH, total alkalinity, total hardness, anionic detergents, ammoniacal nitrogen ($N\text{-}NH_3$), total oxidised nitrogen (TON), nitrogenous nitrate ($N\text{-}NO_3$), nitrogenous nitrite ($N\text{-}NO_2$), orthophosphate (as $P\text{-}PO_4$), sulphate, total iron and manganese, the heavy metals cadmium, chromium, copper, lead, mercury, nickel and zinc (as total and filtrate) and the pesticides α-BHC (HCH), γ-BHC (HCH), aldrin, dieldrin, endrin, pp-DDE, pp-DDT and heptachlor.

In addition, as the Severn-Avon catchment was visited throughout the year, chemical analysis for the following variables was carried out at Evesham, Tewkesbury, Saxons Lode, Mythe 1, Mythe 2 and Haw Bridge:-

dissolved oxygen (Winkler Method)
5 - day BOD (unsuppressed)
chloride
pH
total alkalinity
total, magnesium and calcium hardness (Schwarzenbach Method)

$N\text{-}NH_3$)
$N\text{-}NO_3$) by Technicon auto-analyser
$N\text{-}NO_2$)
$P\text{-}PO_4$)

Sampling was approximately monthly except at the Mythe sites. Water samples were also taken from a wider range of sites and analyses for total iron, cadmium, chromium, copper, lead, nickel and zinc by atomic absorption spectrophotometry on a less frequent basis.

During September 1981 a study of the effect of discharges from Mythe waterworks into the R. Severn was carried out. Water samples were taken upstream of the waterworks as well as 10, 20, 40, ca. 80 and ca. 160m below its discharges. These samples were analysed for suspended solids, pH and total and filtrable aluminium (by atomic absorption spectrophotometry.

5.3.2 S.Auf.U. Sampling - General

In a general survey all 27 sites were sampled once between August and October 1980 except for Haw Bridge on the R. Severn which was sampled earlier. This particular season was chosen because it was the most likely period of the year for a variety and abundance of gastropods to be present since most species reproduce during the summer. The precise recovery dates are shown in Table 5.1. In accordance with the recommendation of Girton (Dept. of Env., 1979) and substantiating evidence previously reported in immersion period experiments, three S.Auf.U. were removed from each site after an immersion period of 28 days. All S.Auf.U. were anchored in the littoral zone using house bricks at all sites except Evesham where 7mm diameter steel rods were used in the same manner as at Checkley (see previous report). At all sites with public access six S.Auf.U. were anchored to allow for losses by vandalism and other factors, four were immersed at private sites.

Three sites in the Severn-Avon catchment, namely Evesham and Tewkesbury on the R. Avon and Saxons Lode on the R. Severn, were sampled consecutively for one year. Some deviation from the four-week immersion period was unavoidable owing to high river levels from time to time, particularly around winter. These periods varied from 3 to 7 weeks (Tables 5.4 a-c). Initially a fourth site, Haw Bridge on the R. Severn, was included in this part of the sampling programme but sampling here was discontinued after June 1980 since all S.Auf.U. tended to silt up heavily with the result that physical

conditions on the S.Auf.U. were not really comparable with the other three sites.

Macroinvertebrates were removed, transported, preserved and counted as described earlier. The only subsampling necessary was with chironomids where ¼ subsamples were taken as before (See Section 4.3.2).

5.3.3 Calculation of Pollution and Diversity Indexes

Three pollution indexes - the TBI, the Chandler Score and the B.M.W.P. Score - along with the Shannon-Seaver diversity index (natural logs) were calculated for each sample of 3 S.Auf.U. In addition, as part of the general site survey, two other diversity indexes were calculated. Plots of log abundance against rank were made for one site from each chemical class in order to ascertain which diversity index based on an underlying model, if any, should be calculated (Figure 5.3). The data appeared to conform fairly well to the log series on which the diversity index of Fisher et al. (1943) was based. Diversity was roughly estimated using the nomograph of Williams (1947) and then determined to one decimal place by guessing values of α in the equation:

$$S_T = \alpha \ln (1 + N/\alpha)$$

where α is the diversity, S_T the number of species and N the total number of individuals. Finally the Kempton-Taylor diversity index (1976) was calculated. Here the diversity

$$Q = S/_2 \log (^{R_2}/_{R_1})$$

where R_1 and R_2 are the quartiles on a cumulative species - log abundance plot. R_1 and R_2 were determined graphically, an example is shown in Figure 5.4. Only data from Hartford Bridge on the R. Weaver failed to conform well to the required S-shaped curve. Worms were excluded from diversity calculations for the same reasons as before (See Section 3.2.2).

5.3.4 Macrophytes

The relative abundance of macrophytes at each sampling site was estimated visually on a scale of 0 to 5. This scale was defined as follows:-

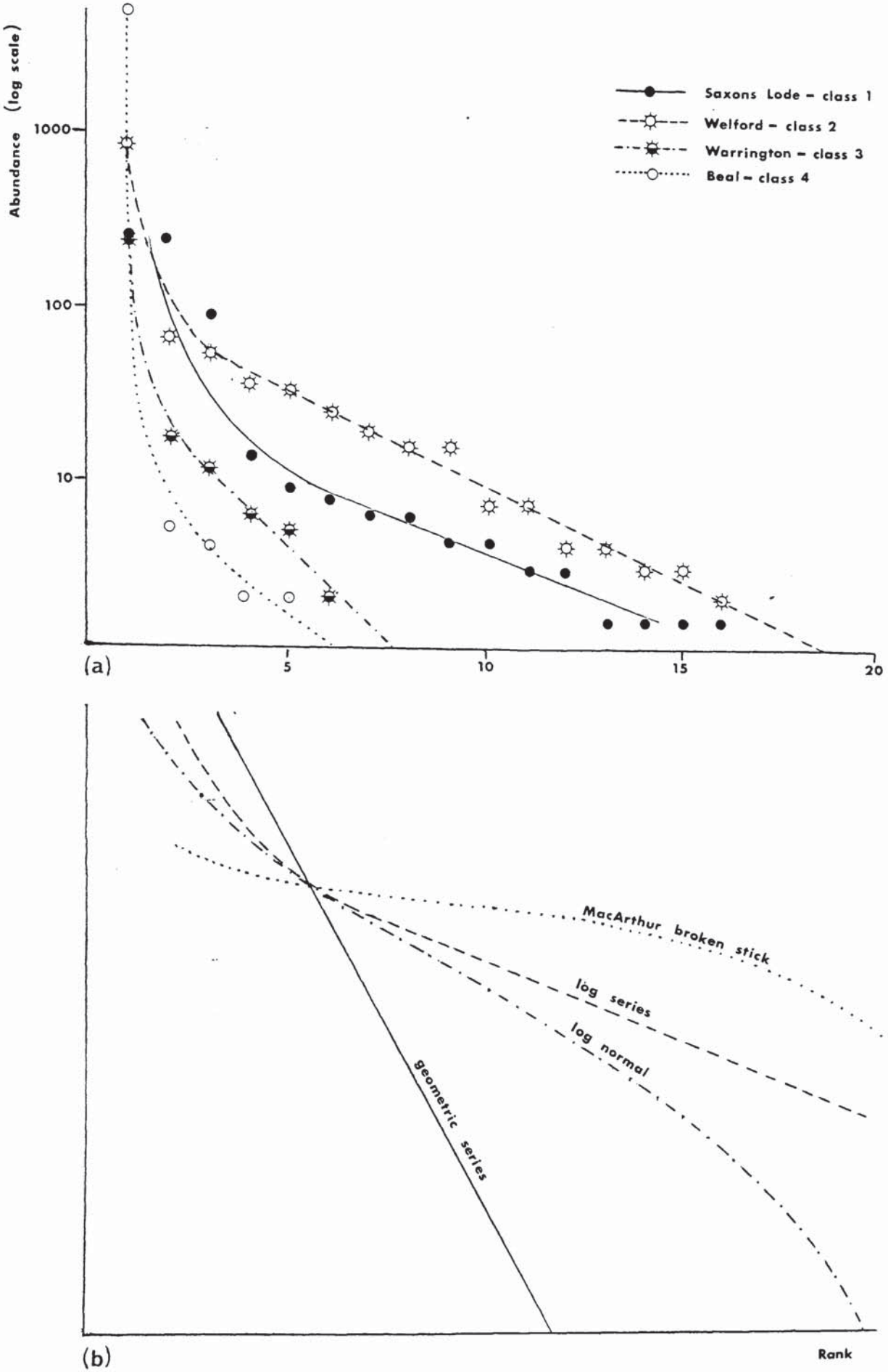


FIGURE 5.3 : RANK-ABUNDANCE CURVES FOR (a). S.AUF.U. DATA FROM ONE SITE OF EACH MAJOR CHEMICAL CLASS AND (b) DIFFERENT UNDERLYING DISTRIBUTIONS (AFTER WHITTAKER, 1972).

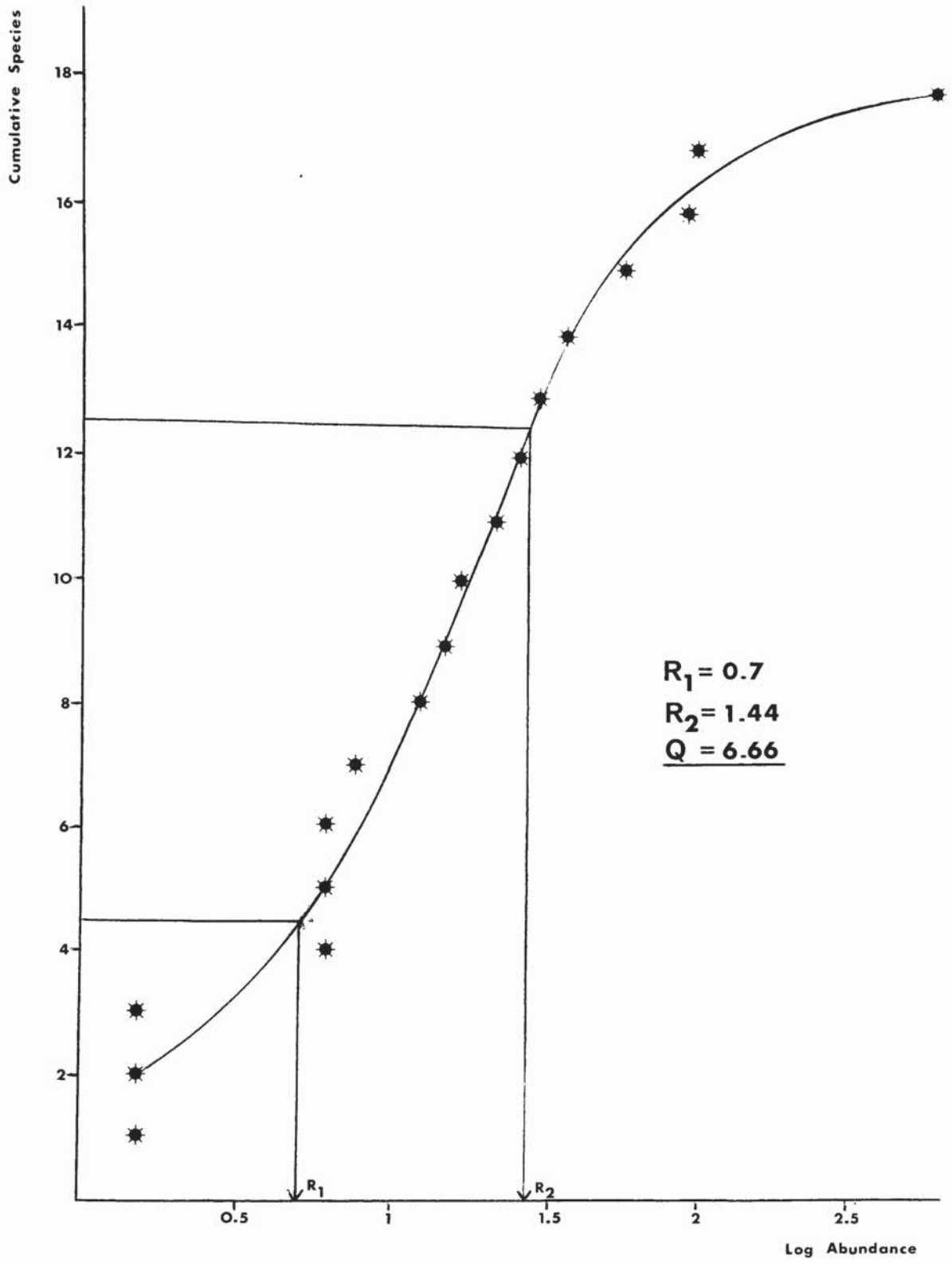


FIGURE 5.4 : EXAMPLE OF THE CALCULATION OF THE KEMPTON-TAYLOR DIVERSITY INDEX USING EVESHAM DATA.

0 - macrophyte absent
1 - macrophyte present but very scattered with only a few leaves
2 - macrophyte scattered but with quite a few leaves
3 - macrophyte fairly abundant forming clumps of vegetation in places
4 - macrophyte abundant covering large sections of the littoral zone or open water
5 - macrophyte very abundant covering virtually the whole of the littoral zone or water surface.

Abundance ratings were determined seaprately for each species and for all species together. Values of Spearman's rank correlation coefficient (r_s) were determined for relationships between (i) total number of taxa, (ii) total numbers of individuals excluding worms, (iii) numbers of gastropod taxa and (iv) number of gastropods and relative macrophyte abundance for (i) all sites and (ii) sites of chemical classes 1, 2 and 4 separately. Significance levels were obtained from table P in Siegel (1956). Hence it was assessed whether macrophytes were a primary or secondary influence on S.Auf.U. colonisation.

5.3.5 Gastropod Studies

As part of the general survey χ^2- tests were carried out to establish whether there were any significant differences in the presence - absence of various gastropod taxa between sites of the four major chemical classes of river. The Mythe 2 site was classified as class 4 for this exercise because of the discharge immediately upstream of it. Ranges and medians of maximum levels of toxicants recorded in which a specific gastropod taxon occurred were compared with levels where the taxon was absent. Additionally, minimum dissolved oxygen levels were compared along with both minumum and maximum pH values. t-tests were carried out to see if there were significant differences between mean values of toxicants where a taxon was present and absent. To supplement the relative population data for the six species of snails regularly colonising S.Auf.U. at Evesham, Tewkesbury and Saxons Lode, biomass was estimated by the same methods used at Checkley (see Section 4.3.3) and snails were

measured and divided into 1mm size classes except for Viviparus viviparus where 2mm size classes were used. It proved impossible to distinguish between cohorts in all species except Lymnaea peregra, which had already been studies at Checkley, so no data on growth rates could be calculated.

5.4 Results and Discussion

5.4.1 Physicochemical Data

Water Authority physicochemical data is shown in Appendix Tables 9.6a to f and data collected during S.Auf.U. sampling of the Severn-Avon catchment in Appendix Tables 9.7 to 9.9. All sites had a high alkalinity and hardness, the lowest total hardness of 60mgl^{-1} being recorded at Naburn Weir, so these variables should not have had an effect of the distribution of molluscs or crustaceans which require calcium for their shells and carapaces respectively. Boycott (1936) stated 20mgl^{-1} hardness to be the critical figure below which a number of molluscs do not occur. Concentrations of pollutants varied greatly, particularly high values in comparison to other sites were recorded at the following:-

Mythe 2	Suspended solids
	aluminium in the sediment (49,000mg/kg^{-1}) (S.T.W.A., 1979a)
Shardlow	temperature (28^{o}C)
Acton Bridge	N-NH_3 (22-64mgl^{-1})
	N-NO_2 (1.20mgl^{-1})
	total lead (0.28mgl^{-1})
	total mercury (34.1 + μgl^{-1})
	total copper (0.08mgl^{-1})
Beal Weir	N-NO_2 (2.14mgl^{-1})
Methley	N-NO_2 (2.24mgl^{-1})
Doncaster	Fluoride (5.00mgl^{-1})
	N-NH_3 (14.7mgl^{-1})
	N-NO_2 (1.89mgl^{-1})
	total chromium (0.079mgl^{-1})
	total copper (0.077mgl^{-1})
	total nickel (0.128mgl^{-1})
	total zinc (0.28mgl^{-1})
	γ-BHC (2884 ngl^{-1})

The lowest dissolved oxygen of 1.5mgl^{-1} was recorded at Warrington on the R. Mersey.

Results of the physicochemical sampling above and below Mythe waterworks are shown in Table 9.10. The effluent clearly raised levels of suspended solids and consequently total aluminium but this effect was mainly restricted to the area 20m below the outfall. Filtrable aluminium levels were below the limit of detection so all the detectable aluminium was in suspended form. Although soluble aluminium is known to be toxic (Burrows, 1977; Hunter et al., 1978) information on the effects of solid aluminium complexes is lacking.

5.4.2.1 S.Auf.U. Sampling - General Lowland River Study

The macroinvertebrate fauna colonising S.Auf.U. in the general lowland river survey is displayed in Table 5.2. Six sites had clearly fewer taxa than the others - Doncaster (R. Don) had 3, Mythe 2 (R. Severn) 6, Beal (R. Aire) and Acton Bridge (R. Weaver) 7, and Hartford Bridge (R. Weaver) and Methley (R. Calder) 11 (Table 5.3). With the exception of Hartford Bridge these were all D. of E. chemical class 3 or 4 sites so that impoverished fauna reflected heavy pollution which was principally by toxicants (see Section 5.4.1).

The absence of worms and all molluscs other than Physa fontinalis on the R. Don at Doncaster (Table 5.2) suggest that the high levels of the heavy metals chromium, copper, nickel and zinc recorded have a severe effect. A discharge from a base metal mine into the Northwest Miramichi River eliminated molluscs for 12 miles (Wurtz, 1962). Total zinc, lead and copper values reached a maximum of 0.57mgl^{-1} 9 miles downstream and molluscs had still not returned 4 months later when the metals were present at <0.2mgl^{-1}. Values for zinc alone at Doncaster exceeded the latter figure (Table 9.6d). Similarly, values of chromium and copper exceeded at Doncaster were found to kill caged Potamopyrgus jenkinsi in the R. Holme (Brown, 1980). As little as 0.033mgl^{-1} chromium VI in combination with 0.02mgl^{-1} copper had an effect. Molluscs and worms were still absent from the R. Ystwyth forty years after mining operations causing zinc pollution had ceased, zinc levels of 0.8-1.2mgl^{-1} were recorded at these sites (Jones, 1940). However, insects were recorded in both the Miramichi River and the

REMOVAL DATE →	28. 8. 80						8.5.80		22. 8. 80			22. 9. 80							8. 10. 80			4. 9. 80			
WATER AUTHORITY →	SEVERN - TRENT											ANGLIAN							NORTH - WEST			YORKSHIRE			
RIVER →	Avon				Severn				Trent			Ely Ouse	MLMD	Nene				Welland	Mersey	Weaver		Aire	Calder	Don	Ouse
SITE →	Welford	Evesham	Gt. Comberton	Tewkesbury	Saxons Lode	Mythe 1	Mythe 2	Haw Bridge	Willington	Shardlow	Nottingham	Denver Sluice	Mullicourt	Oundle	Wansford	Dog-in-Doublet Sluice	Crowland	Warrington	Hartford Bridge	Acton Bridge	Beal	Methley	Doncaster	Naburn Weir
+ TAXON SITE NO.→	1*	2*	3	4	5	6	7	8	9	10*	11	12	13	14	15	16	17	19	20	21	22	23	25	27
Asellus aquaticus	225	589.5	25		1	1		9	2066	1746	261	127	515	385	118	80	19	1	26	1	3280	19	2912	6
Corophium curvispinum		29.5	1075	1231	860	104	42	514					5			39								
Crangonyx pseudogracilis	82.5	94.5	23	2		10		9	3	13.5		143	20	12	14	28	7							57
Gammarus pulex	9					2	2		217	54				6	7									
G. tigrinus					32	1		1453			405		7						100					
Baetis rhodani			1											3	2									
Caenis moesta	1.5	1.5		1										1	1		1							
Centroptilum luteolum																5								
Cloeon dipterum													5											
Procloeon pseudorufulum														5	37									24
Hydropsyche contubernalis										18														
Hydroptilidae												1												
Limnephilidae								1																
Molanna angusta													1											
Phryganea grandis			1						1															
Plectrocnemia geniculata				1	3								119	5	10	20								55
Polycentropus flavomaculatus								1						25	30									
Agrion splendens					1	1		4	4															
Coenagrion mercuriale										1.5		1												
C. puella	45												2				7		26	13				
Ischnura elegans											1													
Platycnemis pennipes			4																					
Dytiscidae (A)												1	2	6	4									3
Dytiscinae (L)													1	1				1						
Haliplus spp. (A)	3		3						1			2					3							
Haliplus spp. (L)			4						3	3	1	2	1			1								
Hydrophilidae (L)																1				1				
Oulimnius tuberculatus (L)			1					1							1		1							
Sigara distincta												2												
Sigara spp.														1										
Sialis lutaria			1						1															
Chironomus riparius (L)								1	1									11						
Chironomini (L)	13.5	7.5	12	58	35	21	3	2	1		5		123	61	33	280	15	2	62	1631	4			7
Tanytarsini (L)			4	2				5	2			28	1	2	7		13	1						1
Diamesinae (L)																	1							1
Orthocladiinae (L)	7.5	1.5	7	11	16	6	13	21	15	22.5	1	3	1	115	414	249	180	6		114	2			11
Tanypodinae (L)	1.5		1		3	4	3	11		1.5	1			1				5		43	2			3
Chironomidae (P)	1.5			3	1			1					2		9	12	8			7				3
Diptera (L)																					1			
Ancylus fluviatilis				4																				
Lymnaea peregra	4.5	25.5	126	43	65	35		1				2	2	4	6	8	5	17	6			26		18
L. stagnalis														2				1						
Physa fontinalis		21	47	6	16	31							36	13	4	55	44	231	1			37	2	1
P. heterostropha																					5	47		
Planorbis albus	1.5		2								2	4	5				3		2					
P. carinatus									1															
P. corneus														1										
P. crista																	1							
P. planorbis														1	1		4							
P. vortex													7	2			5							
Segmentina complanata													1											
Bithynia tentaculata	232.5	105	321	1	21	135			3		38	283	26	12	12	28	27	1	52		1			12
Potamopyrgus jenkinsi	3		12	8	52	30					22	1060	134	2	1		346	1				29		4
Theodoxus fluviatilis			5		19	46									2			1						
Valvata cristata		6													1	5								5
V. piscinalis					4				1			8	1			8	117							35
Viviparus viviparus		1.5			7	19							1			1								
Pisidium spp.		36		20	7	17		1	1				4				18		1			17		5
Sphaerium spp.		15	84	1											2	5	6					206		
Batracobdella paludosa		6				1			12	4.5							1					12		
Erpobdella octoculata	6	54	6	3		1		1	137	118.5	39		2	13	8	5	2	1			1	75	1	
Glossiphonia complanata		16.5	3	1					3	4.5	2		4	1	2	1	2		3					
G. heteroclita									1					1										
Helobdella stagnalis	1.5							1	1	1.5	1			1	2	2	4							
Hemiclepsis marginata											2				1				2					1
Piscicola geometra			1		4	1					1			1		1	1							
Theromyzon tessulatum														2	1		1							
Oligochaeta	22.5	88.5	38		41	4	3	40	213	213	241		12	5	1	93	544	2100				8		35
Dendrocoelum lacteum		6	1						3	1.5	1			2										
Dugesia polychroa	6	88.5	19		1	22			11	4.5	12	340	2	3		1	15					4		2
Polycelis nigra														30	2		77							
P. tenuis		12	33		2	2			212	12														10

TABLE **5.2**: ABUNDANCES OF DIFFERENT TAXA COLLECTED ON 3 S.AUF.U. AT LOWLAND RIVER SAMPLING SITES.

* only 2 S.Auf.U. recovered calculated totals for 3 S.Auf.U. given.

SITE	Total Taxa	Total Indivs.	T.B.I.	Chandler Score	B.M.W.P. Score
SEVERN TRENT W.A.					
Welford*	18	635	VII	399	53
Evesham*	20	1118	VIII	443	62
Gt. Comberton	28	1822	VIII	685	87
Tewkesbury	16	1396	VII	420	52
Saxons Lode	20	1150	VII	425	67
Mythe 1	22	2290	VII	392	65
Mythe 2	6	63	IV	61	15
Haw Bridge	18	2037	VII	364	57
Willington	25	2701	VII	610	67
Shardlow*	16	2007	VI	343	44
Nottingham	18	795	VI	394	48
ANGLIAN W.A.					
Denver Sluice	15	2007	VI	359	49
Mullicourt Priory Sluice	28	1030	VIII	740	88
Oundle	32	720	IX	885	65
Wansford	28	731	IX	861	82
Dog-in-a-Doublet Sluice	22	835	VIII	585	67
Crowland	30	817	VIII	712	68
NORTH-WEST W.A.					
Warrington	15	280	V	304	29
Hartford Bridge	11	281	V	266	35
Acton Bridge	7	1810	III	91	16
YORKSHIRE W.A.					
Beal Weir	7	3296	IV	117	14
Methley	11	472	V	222	27
Doncaster	3	2915	III	64	9
Naburn Weir	21	264	VIII	521	54

TABLE **5.3** :NUMBERS OF TAXA AND INDIVIDUALS AND POLLUTION INDEXES AT LOWLAND RIVER SAMPLING SITES

*only 2 S.Auf.U. recovered.

R. Ystwyth and are generally regarded as tolerant of metal pollution. Their absence from Doncaster could be accounted for by the low dissolved oxygen (minimum 3.6mgl^{-1}), the high fluoride, the high concentrations of nitrogen compounds and/or the high γ-BHC. The same could be true of the Gammaridae. Dissolved oxygen levels around the minimum of 3.6mgl^{-1} recorded have killed Gammarus spp. (Sprague, 1963; Grant, 1974), Plecoptera (Nebeker, 1972) Ephemoptera (Nebeker, 1972; Gaufin, 1973), Trichoptera (Gaufin, 1973) and Simulium vittatum (Gaufin, 1973) in laboratory experiments whereas chironomids have survived almost complete deoxygenation (Davies, 1971; Gaufin, 1973). The highest concentration of undissociated ammonia present (ca. 0.5mgl^{-1}) would kill Crustacea (Daphnia magna) (Malacea, 1966) and Gammarus pulex and Ecdyonurus dispar at low dissolved oxygen levels (Davies, 1971) according to laboratory work. Finally the γ-BHC level of 2.4μgl^{-1} is similar to the maximum accepted toxicant concentration of 2.25 - 5.0 μgl^{-1} quoted for Chironomus tetans (Macek et al., 1976).

The unstable substratum resulting from the high suspended solids discharge above Mythe 2 (R. Severn) could account for the absence of molluscs, insects other than chironomids and worms along with a reduction in the numbers of Crustacea. The blanketing effect of the solids could also be important to those species with gills. Deposition of iron compounds from coal-waste was responsible for the elimination of all taxa except chironomids and worms in a Lancashire stream (Greenfield and Ireland, 1978). The high concentration of aluminium in the discharge could account for the absence of molluscs, leeches and worms all intolerant of metals. Hunter et al. (1980) found 3.7mgl^{-1} aluminium in combination with elevated pH, causing more metal to be in the soluble form, resulted in fish kills in Black Cart Water downstream of an anodising factory. Much lower concentrations kill Daphnia magna (Biesinger and Christensen, 1972).

Like Doncaster (R. Don), Acton Bridge (R. Weaver) had high levels of metals, principally lead, copper and mercury, which probably account for the absence of molluscs, leeches, oligochaetes and flatworms. These four groups were all absent from the Lower Rheidol during 1919-21, when filtrable lead concentrations of 0.2-0.5mgl^{-1}, below the maximum total lead level of 0.28mgl^{-1} at Acton Bridge, were recorded (Laurie and Jones, 1938). Levels of chromium and copper recorded (Table 9.6d)

would also kill P. jenkinsi according to Brown (1980) and the mercury concentration of 34.1+μgl^{-1} is vastly higher than at any other site. The two insect species present, Coenagrion puella and Haliplus sp. , emphasise the resistance of insects to metal pollution. Other insect species and the Gammaridae could well be absent because of the high concentrations of nitrogen compounds. Undissociated ammonia levels in excess of $2mgl^{-1}$ could have existed; in laboratory experiments most taxa were killed by such levels in the experiments of Davies (1971). The maximum value of $22.64mgl^{-1}$ $N\text{-}NH_3$ recorded together with the pH of 7.2 - 8.5 would also kill P. jenkinsi within 96h according to my own laboratory experiments (See Section 7.3.2.2).

In contrast Beal (R. Avon) and Methley (R. Calder) had both molluscs and leeches, oligochaetes were also present at Methley (Table 5.2). Presumably this was because no particularly high metal levels were recorded. However, Methley had no insects and Beal had none other than chironomids. The low dissolved oxygen content of the water (minima of $2.7mgl^{-1}$ and $2.8mgl^{-1}$ at Methley and Beal respectively) and/or the high nitrite content of the water ($>2mgl^{-1}$) could account for the absence of insects and Gammaridae from these two sites. Nitrite is highly toxic to human babies and fish but little work has been done on its effects on invertebrates. Russo et al. (1981) calculated LC50's of $0.11\text{-}1.67mgl^{-1}$ $N\text{-}NO_2$ for rainbow trout.

The reasons for Hartford Bridge (R. Weaver) having few taxa are unclear. No metal data were available but the presence of five molluscan taxa and two species of leech imply the metal concentrations were low. Neither ammonia nor nitrite concentrations were high (Table 9.6c) and the minimum dissolved oxygen concentration was $5.0mgl^{-1}$.

The R. Mersey at Warrington was also heavily polluted (class 3) but 15 taxa were recorded, similar to the numbers at Denver Sluice on the Ely Ouse and Tewkesbury on the R. Severn (classes 1 and 2 respectively) (Table 5.3). The S.Auf.U. colonisers were dominated by gastropods and chironomids whereas other insects except for a single Dytiscidae and Gammaridae were absent. This implies that the site is principally organically polluted and the physicochemical data supports this. The lowest dissolved oxygen value of $1.5mgl^{-1}$ was recorded here together with a high $N\text{-}NH_3$ ($11.4mgl^{-1}$). The low oxygen content of the water

could account for the absence of insect species and Gammaridae, whereas the presence of 6 gastropod taxa and 5 chironomid taxa support the widely held belief that they are tolerant to low oxygen levels. $1.5mgl^{-1}$ dissolved oxygen would kill most stoneflies, mayflies and caddises according to the work of Nebeker (1972) and Gaufin (1973) but have no effect of chironomid mortality (Davies, 1971; Nebeker, 1972). Tolerance of gastropods to low dissolved oxygen levels is discussed in Section 5.4.5.1. High ammonia levels in combination with low oxygen could also eliminate the Gammaridae. Two non-chironomid insect taxa occurred at Acton Bridge, which had the highest ammonia concentration of all the sites sampled, so ammonia could not be responsible for the absence of all insect taxa even though Davies (1971) showed most species to be killed by such levels.

The Anglian rivers tended to have the largest number of taxa, on the whole they had the most insect, mollusc and leech taxa (Tables 5.2 and 5.3). The Anglian sites all had high quantities of nutrients. Mean annual nitrate levels of 7.57 - $9.29mgl^{-1}$ reaching a maximum of $43.8mgl^{-1}$ at Mullicourt (M.L.M.D.), which also had a high mean sulphate level ($677mgl^{-1}$), were recorded. The three highest values of orthophosphate were also recorded at three Anglian sites, namely Mullicourt (M.L.M.D.), Oundle (R. Nene) and Wansford (R. Nene) (Table 9.6c). Such high nutrient values would encourage large populations of bacteria and algae together with their products on which greater numbers of invertebrates could feed. Possibly this could also account for an increase in the number of taxa.

Wansford (class 1) had a very similar fauna to the other two sites on the R. Nene which were both class 2. Gammaridae, mayflies, Polycentropidae, beetles, chironomids, flatworms and a wide range of gastropods and leeches were found at all three sites (Table 5.2). In contrast both the R. Avon and the R. Trent showed a change in fauna as they improved in water quality downstream (Table 5.2). The Gammaridae/*Asellus* ratio increased downstream in both rivers except for a depression at Evesham on the R. Avon, the values being 0.36 - 0.16 - 0.92 on the R. Trent. This ratio has been suggested as a good measure of organic pollution by Hawkes and Davies (1971). Caddises, along with larger numbers of *P. jenkinsi* occurred at the two cleanest sites on the R. Avon and *P. jenkinsi* was only present at the cleanest

site on the R. Trent (Table 5.2). Furthermore the number of leeches, dominated by Erpobdella octoculata, large numbers of which are generally associated with organic pollution, declined between Evesham and Tewkesbury on the R. Avon.

5.4.2.2 S.Auf.U. Sampling - Continuous Sampling of the R. Avon - R. Severn

Macroinvertebrate data for continuous sampling of the R. Avon and R. Severn throughout the year is shown in Tables 5.4a - d. The macroinvertebrates recovered from Haw Bridge (R. Severn) (Table 5.4d) were very different in composition to the other three sites (Tables 5.4a - c). There were fewer taxa recorded in the period up to June 1980, 26 compared with 27 to 32 at the other sites. In particular only 2 species of gastropod were recorded compared with 6 at the other sites and very few of these were present. This poorer biota was probably associated with the very fine and unstable substratum and this was why sampling was discontinued at this site. In contrast, more Corophium curvispinum, Crangonyx pseudogracilis and Gammarus tigrinus were collected than upstream at Saxons Lode. Presumably this was connected with the proximity of Haw Bridge to the tidal limit as these three species are of recent estuarine origin. This site emphasises the need for physically similar sites in biological surveillance even when colonisation samplers are used. The cleaner water at Saxons Lode (R. Severn) compared with the R. Avon was reflected in both the species present and the abundances of particular species. Forty-six taxa were recorded at Saxons Lode during the years sampling compared with 39 at Tewkesbury and 37 at Evesham, the two R. Avon sites.

The stoneflies Isoperla grammatica and Taeniopteryx nebulosa, Ephemerella ignita and Leptoceridae, all regarded as very intolerant of organic pollution, were unique to Saxons Lode (R. Severn), along with Centroptilum luteolum and Gammarus tigrinus, also regarded as intolerant of organic polluiton, and Simulium spp., Tipulidae, Lymnaea auricularia and Glossiphonia heteroclita. Batracobdella paludosa, Planorbis vortex and Porifera were unique to Evesham, while Hydropsyche angustipennis and Gyrinus sp were only found at Tewkesbury (Tables 5.4a - c). The species of Odonata found in the two rivers differed with only Agrion spendens regarded as less tolerant

TAXON	REMOVAL DATE→	1980 14.2	6.3	10.4	8.5	5.6	2.7	31.7	28.8	25.9	24.10	2.12	1981 6.1	3.2
	IMMERSION PERIOD (WKS) →	4*	3	5	4	4	4	4	4*	4*	4		5	4
Asellus aquaticus		25.5	3	31	225	128	251	389	589.5	280.5	187.5	210	230	146
Corophium curvispinum		1.5	1	8	17	47	236	762	29.5	87	213.5	86	32	3
Crangonyx pseudogracilis				12	44	6	30	43	94.5	18	18	126	16	54
Gammarus pulex		6	5		2	2	1						1	1
Baetis rhodani					3									
Caenis moesta						6	15	3	1.5					
Polycentropus flavomaculatus						2								
Aeshna cyanea					1	2				1.5	3	1		
Agrion splendens														1
Coenagrion puella				1	2	5	2							
Haliplus spp. (L)								1						
Chironomini (excl *C. rip.*) (L)				1	1	72	36	35	7.5		28.5	12	16	5
Tanytarsini (L)				7	15	28				3				
Diamesinae (L)		3		1								4	7	5
Orthocladiinae (L)		3	2	14	24	30		4	1.5		1.5			1
Tanypodinae (L)			1	2	6	1	1			6	3	4	9	7
Chironomidae (P)				2	3	8	3	1						
Lymnaea peregra		12			7	172	72	42	25.5	6	13.5	11	2	2
Physa fontinalis				1	1	39	37	26	21	12	16.5	13	14	3
Planorbis vortex														1
Bithynia tentaculata		1.5		4	231	239	94	151	105		63	8	11	6
Potamopyrous jenkinsi						2	1						1	2
Theodoxus fluviatilis										3				
Valvata crisata		1.5	1		5	8			6	1.5			1	4
Viviparus viviparus						9	47	4	1.5	1.5	3			
Anodonta spp.							1				1			
Pisidium spp.						17	25	11	36	24	33			
Sphaerium spp.				24	125	3	46	5	15	1.5		8	5	9
Batracobdella paludosa					2		1	6	6					
Erpobdella octoculata				9	23	8	13	37	54	7.5	9	6	3	5
Glossiphonia complanata							3	12	16.5	9			2	3
Helobdella stagnalis													1	
Piscicola geometra						3	1	2			4.5			
Oligochaeta		10.5		14	27	83	368	100	88.5	22.5	18	126	160	519
Dendrocoelum lacteum									6	1.5	1.5	8	3	5
Dugesia polychroa					13	2	15	10	88.5	49.5	10.5	17	22	10
Polycelis tenuis		3							12	6	1.5	4	9	5
Porifera					✓									

TABLE **5.4a**: R. AVON - EVESHAM

TABLES **5.4** a - d: NUMBERS OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED ON 3 S.AUF.U DURING CONTINUOUS SAMPLING OF THE R. AVON AND R.SEVERN FOR A YEAR.

* only 2 S. Auf.U recovered calculated totals for 3 S.Auf.U. given

TAXON	REMOVAL DATE→	6.3	10.4	8.5	1980 5.6	2.7	31.7	28.8	25.9	5.11	2.12	6.1 19	81 3.2
	IMMERSION PERIOD (WKS)	7	5	4 *	4	4	4	4	4	6	4	5	4
										LOST	LOST	LOST	LOST
Asellus aquaticus		9	6	3	3	1			6				
Corophium curvispinum		114	78	51	220	1072	3700	1231	4490				
Crangonyx pseudogracilis			6		13	7	8	2	1				
Gammarus pulex		23	4	6	1		4		3				
Baetis rhodani					1								
Caenis moesta			1	3	40	64	1	1	1				
Hydropsyche angustipennis			1										
Limnephilidae			1		1								
Pleotrocnemia geniculata							1	1	1				
Agrion splendens		6	2										
Coenagrion puella					5				1				
Dytiscidae (A)					1								
Gyrinus spp. (L)				3									
Haliplus spp. (L)						5			2				
Haliplus spp. (A)					2								
Hydroporus spp. (L)					5								
Oulimnius tuberculatus (L)									1				
Chironomus riparius (L)		1											
Chironomini (exl. *C.rip.*)(L		1	10	12	623	166	190	58	55				
Tanytarsini (L)		1	9	6	62	114	24	2	6				
Diamesinae (L)		14											
Orthocladiinae (L)		17	25	177	131	111	21	11	18				
Tanypodinae (L)			1	51	4	5	1		2				
Chironomidae (P)					11	8	8	3	2				
Tipulidae		1											
Ancylus fluviatilis								4					
Lymnaea peregra		30	3			71	166	43	49				
Physa fontinalis			1			2	6	6	4				
Bithynia tentaculata		3			1		2	1					
Potamopyrgus jenkinsi		9			1	2	5	8	3				
Theodoxus fluviatilis		1											
Valvata cristata		3											
Viviparus viviparus							1						
Pisidium spp.		11			3		12	20	3				
Sphaerium spp.		23					1	1	2				
Batracobdella paludosa									1				
Erpobdella octoculata						1	1	3	1				
Glossiphonia complanata								1	1				
Helobdella stagnalis						1			1				
Piscicola geometra									3				
Oligochaeta		5	2	30		6	2		1				

TABLE 5.4 b: R. AVON - TEWKESBURY

* only one S.Auf.U recovered, calculated totals for 3 S.Auf.U. given.

TAXON	REMOVAL → DATE / IMMERSION → PERIOD (WKS)	6.3	10.4	1980 8.5	5.6	2.7	31.7	28.8	25.9	5.11	2.12	1981 6.1	3.2
		7	5	4	4	4	4	4	4	6	4	6	4
Asellus aquaticus		6	3			5		1		9	4	3	7
Corophium curvispinum		143	107	156	47	450	2604	860	505	238	45	31	100
Crangonyx pseudogracilis			4						4	68	7	9	2
Gammarus pulex		6	2	1	2	1			1	3	4	1	1
G. tigrinus		73	31	4	5	11	2	32	10	12	39	22	49
Isoperla grammatica				1					1				
Taeniopteryx nebulosa											1		10
Baetis rhodani			2	4	4		2						
Caenis moesta			1			21							
Centroptilum luteolum									1				
Ephemerella ignita					189	12							
Leptoceridae							2		1				
Limnephilidae					1								
Plectrocnemia geniculata								3	4	5			
Polycentropus flavomaculatus		3	2	1						1	1	2	
Agrion splendens			2	3	1	5		1	3	3	2		
Dytiscinae (L)												1	
Haliplus spp. (L)											1		
Oulimnius tuberculatus (L)		1								1	1		
Chironomini (excl. *C.rip.*)(L)		7	3	4	56	569	206	35	19	22	6	4	3
Tanytarsini (L)		2	6	44	40	1	4		5				1
Diamesinae (L)		18	6								10	10	1
Orthocladiinae (L)		82	202	1056	860	3	20	16	28	7	1	6	9
Tanypodinae (L)		59	14	24	4	22	12	3	21	80	36	18	5
Chironomidae (P)		2	6	69	4	5	12	1	4				
Simulium spp.		12	14	28						1	1	1	9
Tipula spp.		1	2								2		
Tipulidae										2			
Ancylus fluviatilis									1				
Lymnaea auricularia					1		1						
L. peregra		11	1	5	9	38	90	65	15	5	10	6	1
Physa fontinalis			3	10	18	21	26	16	12	32	12	14	4
Bithyna tentaculata				10	21	56	28	21	8	4	1		
Potamopyrgus jenkinsi		58	10	14	19	62	123	52	23	38	119	68	70
Theodoxus fluviatilis		10	4	13	4	23	26	19	12	9	4	1	
Valvata piscinalis								4		1			
Viviparus viviparus			1			13	13	7	5				
Pisidium spp.					2	16	16	7		1		1	
Unio spp.						1							
Erpobdella octoculata				1			1					2	
Glossiphonia complanata				2						1	1		
G. heteroclita							1						
Helobdella stagnalis						2				1			
Piscicola geometra		2	2		4	2	3	4	2	2	3	5	2
Oligochaeta		31	32	32	3		8	41	8	99	143	237	388
Dendrocoelum lacteum										1		1	
Dugesia polychroa							1	1	2	2		1	
Polycelis tenuis		2		13	2	7	1	2	4	17	9	12	10

TABLE 5.4c: R. SEVERN - SAXONS LODE

REMOVAL DATE →	6.3	10.4	8.5	5.6
↓ TAXON IMMERSION → PERIOD (Wks.)	7*	5	4	4+
Asellus aquaticus	1.5	1	9	
Corophium curvispinum	58.5	55	514	5712
Crangonyx pseudogracilis		12	9	
Gammarus tigrinus	1.5	18	1453	510
Limnephilidae		1	1	6
Polycentropus flavomaculatus	1.5		1	3
Agrion splendens			4	
Oulimnius tuberculatus (L)		1	1	
Sialis luteria		1		
Chironomus riparius (L)			1	
Chironomini (L)			2	42
Tanytarsini (L)			5	3
Diamesinae (L)		10		
Orthocladiinae (L)	66	55	21	141
Tanypodinae (L)		5	11	3
Chironomidae (P)	3	1	1	12
Simulium spp.	6			
Lymnaea peregra	3		1	
Potamopyrgus jenkinsi	1.5			
Pisidium spp.			1	
Erpobdella octoculata			1	
Glossiphonia complanata		1		
Helobdella stagnalis		1	1	
Piscicola geometra	1.5	1		
Oligochaeta	13.5	47	40	
Polycelis tenuis		1		

TABLE 5.4 d : R. SEVERN-HAW BRIDGE

to organic pollution than most other species of Odonata, found at Saxons Lode whereas Coenagrion puella and Aeshna cyanea were also found in the R. Avon. The cleaner Severn may have been reflected by the more frequent recovery of A. splendens (Tables 5.4a - c). The species of Valvata found in the two rivers also differed with V. cristata being recovered from the R. Avon and V. piscinalis from Saxons Lode. Other gastropod differences are discussed in the section 5.4.5.2.

Differences in the abundance of certain taxa between sites also reflected the organic enrichment of the R. Avon. The difference in the relative abundances of members of the Crustacea was the most distinct difference between rivers. Smaller numbers of the pollution tolerant Asellus aquaticus and larger numbers of the relatively intolerant Gammarus spp. were recorded at Saxons Lode (R. Severn) throughout the year. However, the largest numbers of another member of the Gammaridae, Crangonyx pseudogracilis, were recorded at Evesham (R. Avon) (Tables 5.4a - c). Gammaridae/Asellus ratios ranged from 2.4-∞ at Saxons Lode (R. Severn), 0.67-∞ at Tewkesbury (R. Avon), and 0.06-1.67 at Evesham (R. Avon), reflecting the deteriorating water quality between these three sites. There were also distinct differences within the leeches. These were dominated by Piscicola geometra, generally restricted to cleaner waters than most of the other species because they feed on fish, at Saxons Lode whereas E. octoculata, characteristic of organically polluted waters, dominated at Evesham. Finally, more polycentropids were collected from Saxons Lode than the R. Avon and there were some large differences in gastropod populations which are discussed in Section 5.4.5.2.

5.4.3 Pollution and Diversity Indexes

All three pollution indexes calculated only really differentiated the grossly polluted sites from the others (Table 5.3), e.g. within the Yorkshire W.A. the three chemical class 4 sites had B.M.W.P. scores of 9, 14 and 27 compared with a score of 54 at Naburn Weir (R. Ouse) (class 1). There were no clear differences between scores for class 1 and class 2 sites on the whole, e.g. the B.M.W.P. scores on the R. Avon in August 1980 were 53, 62, 87 and 52 at the four sites, while the scores of 67, 65 and 57 on the cleaner R. Severn were not any higher. This lack of difference was to some extent a reflection of the similar

numbers of taxa collected at class 1 and 2 sites, e.g. in the Anglian W.A. class 1 sites had 15, 28 and 30 taxa, while class 2 sites had 22, 28 and 32 taxa. A further reason for the insensitivity of the indexes is that they were not primarily designed for lowland rivers where most of the high scoring taxa are absent, regardless of the degree of pollution. Only the B.M.W.P. Score takes account of lowland river taxa such as the Agriidae and Viviparidae (Department of the Environment, 1980), but this index too is dominated by stoneflies, mayflies and caddises at the high scoring end.

In the year-long study of the R. Avon and R. Severn, the pollution indexes performed slightly better. In the majority of months the Chandler Scores and the B.M.W.P. Scores were greater at Saxons Lode (R. Severn) than Evesham (R. Avon) (Table 5.5). Furthermore, average Chandler Scores over the year at Tewkesbury (R. Avon) were intermediate to those at Saxons Lode and Evesham which were less and more polluted respectively. Chandler Scores ranged from 278 to 670 at Saxons Lode, 234 to 639 at Tewkesbury and 117 to 573 at Evesham, while B.M.W.P. Scores ranged from 51 to 90, 30 to 70 and 20 to 63 at these three sites respectively. The TBI again failed to differentiate clearly between sites (Table 5.5). Values at Haw Bridge (R. Severn) were depressed because of the impoverished fauna (see earlier) (Table 5.5).

Of the three diversity indexes calculated (Table 5.6), the Kempton-Taylor index best reflected water quality. With the exception of Willington (R. Trent) which has improved in water quality since the 1975 survey (STWA, 1979b), the class 4 sites plus Mythe 2 (R. Severn) had the lowest diversities with values of 0.54, 1.14, 2.22 and 3.14 (Table 5.6). In addition the three class 3 sites occupied three of the next four lowest diversities with values of 5.18, 5.25 and 7.13. This index also reflected the improvement in water quality downstream in the R. Avon with the exception of a rise at Gt. Comberton, which had a rich fauna possibly associated with the large growths of vegetation (Appendix Table 8.21), and on the whole gave higher diversities in the R. Severn. Values with increasing water quality were 4.99 → 6.66 → 13.91 → 7.52 in the R. Avon, while values of 7.23, 10.80 and 11.12 were recorded in the R. Severn (Table 5.6).

Pollution → index	TRENT BIOTIC INDEX				CHANDLER SCORE				B.M.W.P. SCORE			
Removal Date ↓ Site →	SX	HAW	EVE	TEWK	SX	HAW	EVE	TEWK	SX	HAW	EVE	TEWK
14.2.80			V*				219*				32*	
6.3.Δ	VI	V*	IV	VI	378	216*	117	262	61	40*	20	49
10.4.Δ	VIII	VI	IV	VII	486	355	159	355	79	46	30	51
8.5.	IX	VII	VII	VI+	457	364	325	234+	75	57	62	30+
5.6.	VIII	V+	VIII	VIII	594	171+	472	639	71	28+	79	67
2.7.	IX	-	VIII	VII	617	-	573	319	84	-	70	39
31.7	VII	-	VIII	VII	528	-	425	407	67	-	63	50
28.8.	VII	-	VIII*	VII	425	-	443*	420	67	-	62*	52
25.9.	IX	-	VI*	VIII	670	-	383*	558	90	-	60*	70
24.10.	-	-	VI*	-	-	-	296*	-	-	-	61*	-
5.11.Δ	VIII	-	-	-	639	-	-	-	86	-	-	-
2.12.	IX	-	V	-	570	-	263	-	90	-	45	-
6.1.81.Δ	VII	-	VII	-	517	-	415	-	70	-	43	-
3.2.	VIII	-	VII	-	384	-	424	-	51	-	51	-

TABLE **5.5** : POLLUTION INDEXES OBTAINED DURING CONTINUOUS SAMPLING OF THE R. SEVERN AND R. AVON.

* only 2 S.Auf.U recovered

\+ only 1 S.Auf.U recovered

Δ variation from 4 wk. immerions period (see raw data).

↓ SITE	DIVERSITY		
	Shannon-Weaver (H')	Kempton-Taylor (Q)	Fisher et al. (α)
SEVERN-TRENT W.A.			
Welford*	1.4556	4.99	3.2
Evesham*	1.8601	6.66	3.3
Gt. Comberton	1.4901	13.91	4.5
Tewkesbury	0.5760	7.52	2.5
Saxons Lode	1.1476	10.80	3.2
Mythe 1	0.8246	11.12	3.2
Mythe 2	0.9954	1.14	1.3
Haw Bridge	0.7753	7.23	2.5
Willington	0.9150	9.30	3.6
Shardlow*	0.6147	7.13	2.2
Nottingham	1.3009	9.44	3.1
ANGLIAN W.A.			
Denver Sluice	1.4183	16.24	2.2
Mullicourt Priory Sluice	1.7061	11.25	5.1
Oundle	1.7762	11.78	6.6
Wansford	1.6340	11.68	5.5
Dog-in-a-Doublet Sluice	1.8785	12.23	3.9
Crowland	1.9434	13.05	5.9
NORTH WEST W.A.			
Warrington	0.8065	5.18	3.1
Hartford Bridge	1.6949	5.80+	2.3
Acton Bridge	0.3982	5.25	0.9
YORKSHIRE W.A.			
Beal Weir	0.0392	2.22	0.8
Methley	1.7973	3.14	1.8
Doncaster	0.0088	0.54	0.3
Naburn Weir	2.3584	8.20	5.0

* only 2 S.Auf.U recovered
\+ data does not conform to an S-shaped curve

TABLE 5.6 : DIVERSITY INDEXES AT LOWLAND RIVER SAMPLING SITES

In contrast, neither Fisher's α nor the Shannon-Weaver diversity reflected differences between class 1 and 2 sites or showed a consistent downstream increase in value in the R. Avon (Table 5.6). In the continuous Avon-Severn sampling, Shannon-Weaver values at Evesham (R. Avon) were higher than those at Saxons Lode (R. Severn) in 7 months out of 12 (Table 5.7). Values ranging from 0.8316 to 2.3565 at Saxons Lode, 0.2251 to 2.0121 at Tewkesbury (R. Avon) and 1.5675 to 2.1659 at Evesham were achieved. The Shannon-Weaver index did differentiate between the heavily polluted class 3 and 4 sites and the class 1 and 2 sites except for Methley (R. Calder) where the value of 1.7973 was greater than at the majority of class 1 sites. A likely reason for the poor performance of this index is its tendency to be depressed by seasonal increases in numbers of certain species (Kempton and Taylor, 1976), e.g. large numbers of Corophium curvispinum occurred at Saxons Lode (R. Severn) throughout the summer (Table 5.4c) when values were always lower than at Evesham (R. Avon) (Table 5.7). The Kempton-Taylor index is not so prone to this as it only takes account of species of intermediate abundance.

Fisher's α gave the worst performance of all the diversity indexes not even consistently differentiating class 3 and 4 sites from class 1 and 2. Beal Weir (R. Aire) and Warrington (R. Mersey) both class 4, had values of 1.8 and 3.1 respectively - not very different from the class 1 values of 2.2 at Denver Sluice (Ely Ouse), 2.5 at Haw Bridge (R. Severn) and 3.2 at Saxons Lode (R. Severn) and Mythe 1 (R. Severn) (Table 5.6). This index was intended for summarising data with very large numbers of species and may not be so applicable to less diverse communities.

In contrast to these results, Learner et al. (1971) and Hellawell (1978) found with the Shannon-Weaver index and Fisher's α to perform reasonably well on data from the R. Cynon and the R. Derwent respectively. All diversity indexes suffer from the drawback that they work on the premise that pollution exerts stress on the community which is reflected in a decrease in diversity, yet organic pollution in particular can be beneficial to some species (Hawkes, 1979). Despite the reasonable performance of the Kempton-Taylor index in this exercise, it is probably unreliable to use diversity to reflect the response of the biota to pollution. There appeared to be quite a lot of region variation in

Removal Date ↓ / Site →	DIVERSITY (H′)			
	SX	HAW	EVE	TEWK.
14.2.80			1.6769*	
6.3.Δ	2.1055	1.1782	1.5858	2.0121
10.4.Δ	1.7170	1.7564	2.0801	1.6538
8.5.	1.0312	0.7753	1.8553	1.3250+
5.6.	1.2798	0.4392+	2.1659	1.3928
2.7.	1.6709	-	2.1641	1.2310
31.7.	0.8316	-	1.5675	0.4970
28.8.	1.1476	-	1.8601*	0.5760
25.9.	1.2814	-	1.6322*	0.2251
24.10.	-	-	1.8502*	-
5.11.Δ	2.0620	-	-	-
2.12.	2.1601	-	1.7513	-
6.1.81.Δ	2.3565	-	1.6616	-
3.2.	1.8902	-	1.7836	-

TABLE 5.7 : SHANNON-WEAVER DIVERSITY INDEX VALUES FOR CONTINUOUS SAMPLING OF THE R. SEVERN AND R. AVON.

* only 2 S.Auf.U. recovered
\+ only 1 S.Auf.U recovered
Δ variation from 4 wks. immersion period (see raw data).

values (Table 5.6) with the Anglian sites having the highest diversities and the sites in the N.W.W.A. having similar values despite having different degrees and types of pollution.

5.4.4 Macrophytes

The macrophytes found at each site are listed with their relative abundance values in Appendix Table 8.21. No values of Spearmanns rank correlation coefficient (r_s) for the relation between macrophyte abundance and the number of both total invertebrate and snail taxa and individuals were significant (Table 5.8). Therefore it appears that macrophyte abundance does not detract from the effects of pollution. However macrophytes might be important at certain sites, e.g. Gt. Comberton had far more invertebrate taxa (28) than other sites on the R. Avon which had much less vegetation.

5.4.5.1 Gastropod Studies - General Lowland River Study

Lymnaea peregra and Bithynia tentaculata showed significant differences in their frequency of occurrence at sites of different chemical class whereas other snail taxa did not (Table 5.9). The χ^2 values of the two former species were significant because they were found at a high porportion of class 1 and 2 sites, but few class 3 and 4 sites. All the other taxa also showed a distinct preference for class 1 and 2 sites but were absent from them more frequently. Boycott (1936) stated that one of the most important characteristics of an ideal molluscan habitat was clean water. However, snails have often been found in heavily polluted situations, e.g. Ortman (1909), Baker (1922), Moore (1922), Gaufin and Tarzwell (1956). Physa spp. in particular tend to re-occur among these.

Only three sites had no gastropods - Mythe 2 (R. Severn), Shardlow (R. Trent) and Acton Bridge (R. Weaver) (Table 5.2). As already mentioned (p.**175**) either the effect of suspended solids and/or a high aluminium level could account for the absence of molluscs from Mythe 2. Mollusc distribution is widely affected by the substratum. Harman (1972) found a good correlation between mollusc diversity and substrate diversity. The majority of gastropod taxa showed a clear difference between the range of suspended solid levels where they occurred and where they were absent and the difference between these

CHEMICAL CLASS ↓ OF SITES	No. Sites	r_s			
		Total taxa	Total Indivs.	No. snail Taxa	No. snails
All sites	24	0.15	-0.01	0.07	0.12
Class 1	7	0.11	0.07	0.09	0.54
Class 2	9	-0.08	-0.09	-0.19	0.11
Class 3	3	-	-	-	-
Class 4	5	0.85	0.15	0.41	0.31

All values not significant.

TABLE 5.8 : VALUES OF SPEARMAN'S RANK CORRELATION COEFFICIENT (r_s) FOR RELATIONSHIPS BETWEEN NUMBERS OF TAXA AND INDIVIDUALS COLLECTED ON 3 S.AUF.U. AND RELATIVE MACROPHYTE ABUNDANCE.

CHEMICAL CLASS →	No. of OCCURRENCES				χ^2
	1	2	3	4*	
No. of sites	7	9	3	5	
Lymnaea peregra	7	8	1	1	12.60**
Physa fontinalis	5	7	1	2	3.30
Planorbis spp.	3	6	0	1	5.43
Bithynia tentaculata	6	9	1	2	9.47*
Potamopyrgus jenkinsi	6	6	1	1	6.21
Theodoxus fluviatilis	3	1	1	0	4.17
Valvata spp.	5	3	0	1	5.96
Viviparus viviparus	2	3	0	0	3.11

TABLE **5.9** : PRESENCE/ABSENCE OF GASTROPODS IN RIVERS OF DIFFERENT CHEMICAL CLASS. Values of χ^2 (with significance levels) are given for differences in occurrence between different chemical classes.

* Mythe 2 was treated as Class 4 for this exercise.

two means was significant for Planorbis spp. and Bithynia tentaculata (Tables 8.23a - h). However this was undoubtedly because the two highest suspended solid levels of 377mgl^{-1} and 495mgl^{-1} occurred at the generally grossly polluted sites of Methley and Doncaster respectively.

Gastropod taxa could well have been absent from Shardlow because of the high temperature (maximum 28^{o}C). Van der Schalie and Berry (1973) reported that lymnaeids, planorbids and Amnicola spp. thrived best at much lower temperatures. Lymnaeids and Amnicola spp. began to die more rapidly above 22^{o}C while planorbids had their reproduction inhibited at 30^{o}C. In contrast physids tolerated temepratures greater than 30^{o}C. Mattice (1975) had similar results with Lymnaea obrussa and Shiff and Garnett (1967) even found that mortality of the tropical Biomphalaria pfefferi was increased at 27^{o}C. Most gastropod taxa were also absent from Nottingham (R. Trent) which had the next highest maximum temperature of 24^{o}C and significant differences in mean temperatures at sites with and without a particular taxon were recorded for four taxa (Tables 8.23a - h).

The final site with no gastropods, Acton Bridge (R. Weaver), recorded the highest values of ammonia and total copper, lead and mercury (Tables 9.6a - f). As reported in the previous section, any one or combination of these toxicants could have been responsible for the absence of gastropods (p.**175 - 176**).

Three other sites had only one or two gastropod taxa - Haw Bridge (R. Severn), Beal Weir (R. Aire) and Doncaster (R. Don) (Tables 5.2 and 5.4d). Haw Bridge was unpolluted and the unstable substratum was probably responsible for the absence of more taxa. The reasons for only two taxa at Beal Weir are unclear. This site had a high nitrite level (2.14mgl^{-1}) and a low dissolved oxygen (minimum 2.8mgl^{-1}) but Methley had higher and lower values of these two variables respectively (Tables 8.6a and c) together with four gastropod taxa. Doncaster had the highest values of fluoride, total chromium, nickel and zinc and γ-BHC along with a high total copper level (Tables 9.6b, d and f). The metal levels probably account for the absence of all gastropod taxa except Physa spp. (See Section 5.4.2.1, p.**172**).

The ranges of pollutants specific gastropod taxa occurred in or were absent from, together with the two medians of these distributions

and t-values for the differences between the two mean values, are given in Appendix Tables 8.23a - h. Differences in ranges of temperature and suspended solids have already been discussed (p.**192**). Differences between the two ranges for chloride also existed with no gastropods present in the highest concentration of 10500mgl^{-1}, yet their absence was probably primarily affected by the high toxicant concentrations at Acton Bridge (R. Weaver) (see physicochemical data section). Hubendick (1958) states that many freshwater snails occur also in brackish water. Only Physa spp. occurred in the highest fluoride concentration (5.00mgl^{-1}) at Doncaster (R. Don). However, high metal concentrations were also present (Table 9.6d). Significant t-values for B. tentaculata with low pH and Valvata spp. with high anionic detergent were also recorded (Tables 8.23d and g) but neither the minimum nor maximum values respectively were distinct from other sites.

A distinct difference in the ranges of ammonia snails occurred in and were absent from existed (Tables 8.23a - h). Only Physa spp. was found in more than 11.4mgl^{-1} N-NH_3 while the maximum recorded was 22.65mgl^{-1}. My own laboratory experiments indicate that P. jenkinsi could not survive in such levels at similar pH's (see Section 7.3.2). However, most sites with high ammonia also had high concentrations of metals. A similar distinct difference in ranges existed with nitrite for the majority of taxa (Tables 8.23a - h). Little work has been done on the effects of nitrite on invertebrates but it is highly toxic to fish (Russo et al., 1981). In contrast, in my own static laboratory experiments, 92.5 - 95mgl^{-1} N-NO_2 had no effect on mortality over 48h. Hynes (1960) says that it probably acts over a long period of time.

There was a small difference in the ranges of both chromium and copper in which gastropod taxa occurred and were absent from, except for Physa spp. (Tables 8.23a - h). Most taxa were found at sites with up to 0.06mgl^{-1} of either chromium or copper but were absent from Doncaster (R. Don) with 0.0079mgl^{-1} chromium and 0.077mgl^{-1} copper and Acton Bridge with 0.08mgl^{-1} copper. Significant t-values for L. peregra and P. jenkinsi with copper were recorded. Levels in the field as low as 0.033mgl^{-1} chromium together with 0.02mgl^{-1} copper have killed or had a sublethal effect on caged P. jenkinsi (Brown, 1980). LC50's on gastropods in chromium as wide apart as 0.8mgl^{-1} over 48h (Cairns et al., 1978) and 17.3mgl^{-1} in 96h (Patrick et al., 1969)

have been reported. Copper appears to be far more toxic, 96h static LC50's reported in Murphy (1978) for gastropods range from $0.013mgl^{-1}$ to $0.9mgl^{-1}$ and the majority of values are below $0.1mgl^{-1}$ (Murphy, 1978; Spear and Pierce, 1979). Overall both field results and previous laboratory work suggest that copper is important in the distribution of molluscs. It is important to point out, however, that all sites with high metal levels had high values for several metals (Table 9.6d).

Most taxa occurred in lead concentrations of up to $0.16mgl^{-1}$ but all taxa were absent from Acton Bridge (R. Weaver) with $0.28mgl^{-1}$ lead (Tables 8.23a - h). This ties in with a study of the Lower Rheidol where molluscs were absent where there was 0.2 - $0.5mgl^{-1}$ dissolved lead (Laurie and Jones, 1938) but high copper and mercury levels were also recorded at Acton Bridge (Table 9.6d). Laboratory studies again reveal wide ranging results: Borgmann *et al.* (1978) found that 0.019 - $0.036mgl^{-1}$ lead reduced long term survival of *Lymnaea palustris* in a continuous-flow system, whereas Extence (1978a) found the static 96h LC50 for *P. jenkinsi* to be over $100mgl^{-1}$ based on initial concentrations.

No taxa were found at Acton Bridge (R. Weaver) with the highest concentration of mercury ($0.034mgl^{-1}$). All other mercury levels were considerably lower (Table 9.6d). A significant t-value for *Physa* spp. was recorded (Table 8.23). Little work has been carried out on mercury toxicity to molluscs. Rehwoldt *et al.* (1973) found a static 96h LC50 of $0.08mgl^{-1}$ for *Amnicola* spp. As the highest levels of copper and lead were also recorded at Doncaster, it is not possible to separate their effects.

Most taxa occurred in nickel concentrations up to $0.07mgl^{-1}$ but all taxa except *Physa* spp. were absent from Doncaster (R. Don) with $0.128mgl^{-1}$ (Tables 8.23)a - h). Extence (1978a) found that nickel levels in excess of $0.1mgl^{-1}$ reduced growth and prevented reproduction in *P. jenkinsi*. Reported 96h LC50's are considerably higher (Rehwoldt *et al.*, 1973; Extence, 1978). High copper and zinc levels also occurred at Doncaster so it is not really possible to conclude anything about the effects of nickel.

The majority of taxa were recorded in 0.15 - 0.17mgl^{-1} zinc but all except Physa spp. were absent from Doncaster (R. Don) with 0.28mgl^{-1}. Once again it is difficult to separate any effect of zinc from other metals but molluscs did not return to the Northwest Miramichi River even after zinc levels had fallen below 0.2mgl^{-1} (Wurtz, 1962) which is below the level recorded at Doncaster. Zinc also eliminated molluscs from the R. Ystwyth (Jones, 1940). Furthermore, in laboratory experiments zinc levels well below 0.28mgl^{-1} have killed snails. The range of static 96h LC50's reported by Murphy (1978) is again large ranging from 0.79 - 1.27mgl^{-1} to 14.0mgl^{-1}. Significant t-values were recorded for L. peregra, P. jenkinsi and Valvata spp., more than for any other metal (Tables 8.23a - h). Overall it seems quite possible that zinc might be important in limiting mollusc distribution.

Clear differences in the ranges of BHC where gastropod taxa were present and absent occurred for all taxa except Physa spp. which was the only taxa to occur at Doncaster (R. Don) with 2884ngl^{-1} γ-BHC (Tables 8.23a - h). However, this site also had high metal and ammonia levels (Tables 9.6c and d). Levels of α-HCH, which is one of the isomers of BHC, required to have a deleterious effect on Lymnaea stagnalis is reported to be considerably higher by Canton and Slooff (1977) who found that 65000ngl^{-1} caused a 50% reduction in overall reproduction. It appears considerably more likely that either the high metal levels and/or the high ammonia account for the absence of most gastropods from Doncaster.

The factor eliminating many species from organically polluted water in upland rivers is low dissolved oxygen (Hynes, 1960; Hawkes, 1979). However, all gastropod taxa in this study except for Valvata spp. were recovered from rivers with low oxygen and molluscs have often been found in rivers with less than 2mgl^{-1} dissolved oxygen (Moore, 1922; Richardson, 1925; Harman and Berg, 1971; Horst, 1971). Therefore, on its own it is not an important factor affecting gastropod distribution.

5.4.5.2 Gastropod Studies - Continuous R. Avon - R. Severn Sampling

Populations and biomasses of gastropods found at the organically

polluted sites of Evesham and Tewkesbury on the R. Avon and Saxons Lode on the R. Severn are shown in Figures 5.5a - c. Raw data is displayed in Tables 5.4a - c and Appendix Table 8.22. Peak numbers of all species were normally achieved in late spring or summer at all sites. Peaks in biomass occurred at similar times except for Physa fontinalis where peaks at all sites were in autumn. Numbers of all species except Potamopyrgus jenkinsi fell considerably prior to winter, rising again in spring. The snails probably migrated into the mud and/or deeper water for this period. This has been reported for Lymnaea palustris by McCraw (1970) and Bithynia tentaculata by Lilly (1953). The occurrence of small individuals of Lymnaea peregra Physa fontinalis, B. tentaculata and Viviparus viviparus in late spring and early summer (Figures 5.6a - f) roughly corresponded to the population peaks and indicates that reproduction occurs in late spring and early summer. L. peregra and B. tentaculata eggs were found on S.Auf.U. from May to July. In contrast both P. jenkinsi and Theodoxus fluviatilis tended to be dominated by medium and large sized individuals throughout the year (Figures 5.6d and e). Overall it would seem that the best time to sample for gastropods is between June and October when fairly high numbers of each species are likely to be present in the right conditions.

With the exception of L. peregra and P. jenkinsi, Tewkesbury (R. Avon) had the lowest populations and biomasses of all snail taxa (Figures 5.5a - c). The reason for this is unclear as there was a stable substratum and vegetation and Tewkesbury is intermediately polluted compared with Evesham (R. Avon) and Saxons Lode (R. Severn).

Populations of L. peregra and P. fontinalis were similar at Saxons Lode (R. Severn) and Evesham (R. Avon) through most of the year (Figure 5.5a). In addition, populations of L. peregra at Tewkesbury (R. Avon) were also similar. However peak numbers of both species were achieved on the organically enriched R. Avon. L. peregra had peak numbers of 172 at Evesham compared with 90 at Saxons Lode, while P. fontinalis had peaks of 39 and 32 respectively. Biomass was similar at all three sites in L. peregra except for one peak of nearly 2g on 3 S.Auf.U. at Tewkesbury (Figure 5.5a). However P. fontinalis consistently had lower biomasses on the R. Avon with a peak of 0.1289g on 3 S.Auf.U. at Evesham compared with 0.4035g at

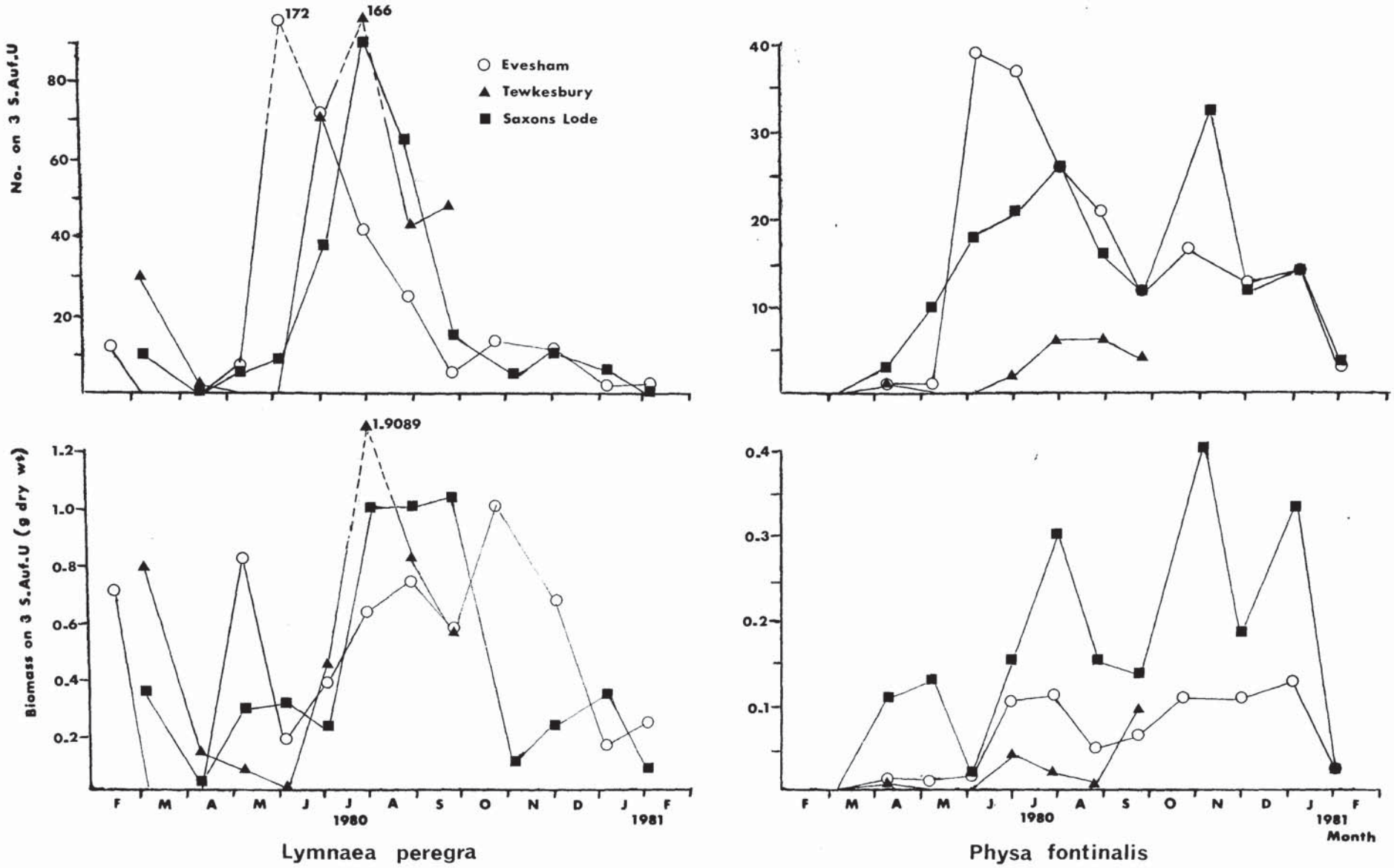
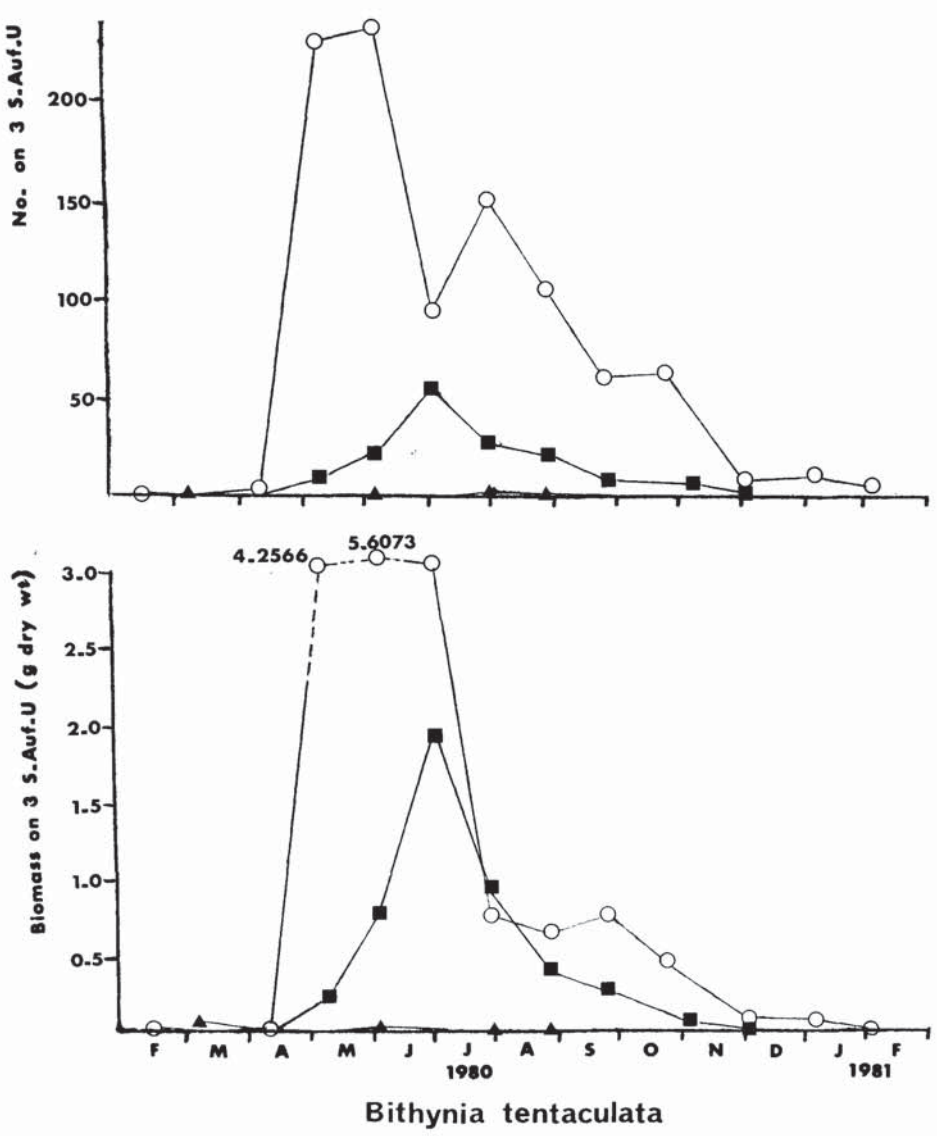
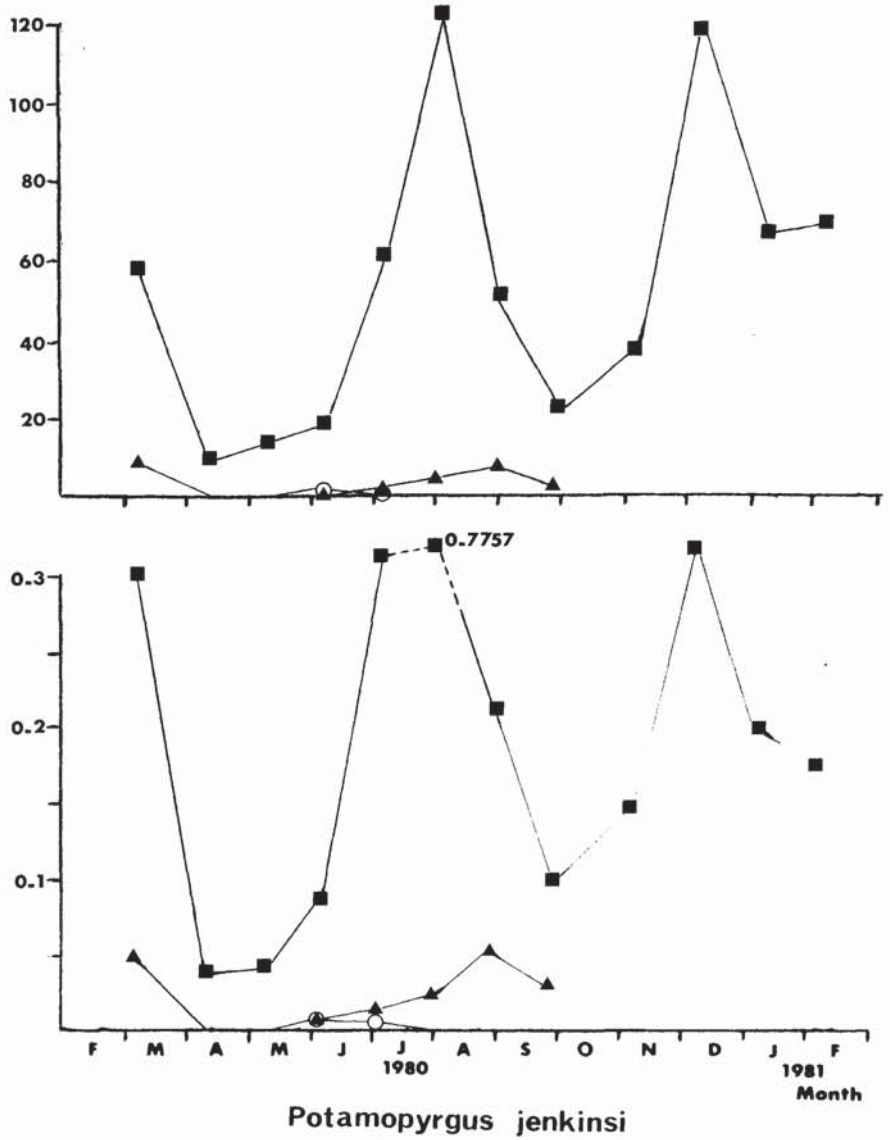


FIGURE 5.5 a

FIGURES 5.5 a - c: NUMBERS AND BIOMASS OF SNAILS COLLECTED ON S. AUF. U. IN CONTINUOUS SAMPLING OF THE R. AVON - R. SEVERN.



Bithynia tentaculata



Potamopyrgus jenkinsi

FIGURE 5.5 b

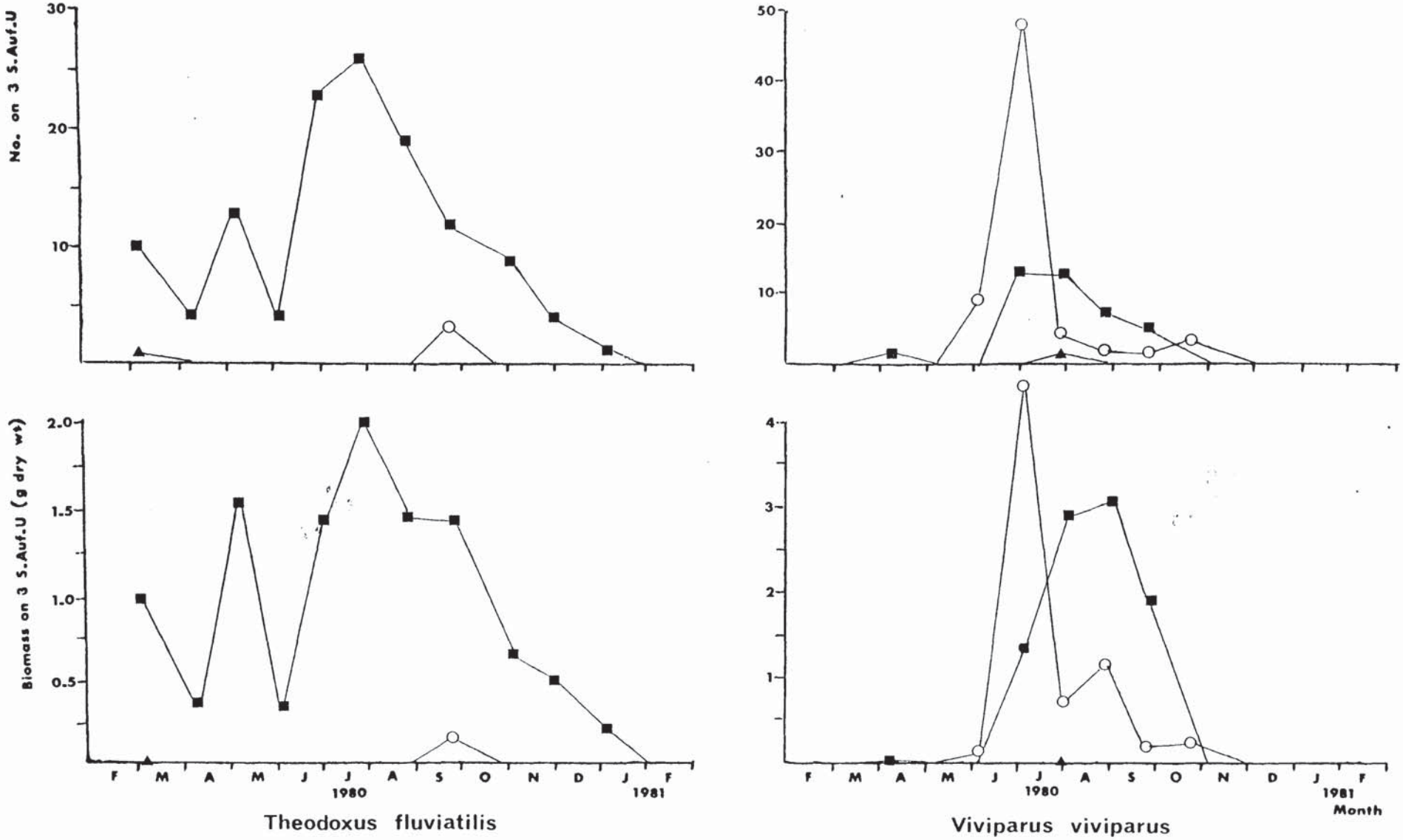

No. on 3 S.Auf.U
30
20
10
Biomass on 3 S.Auf.U (g dry wt)
2.0
1.5
1.0
0.5
F M A M J J A S O N D J F
1980
1981
Theodoxus fluviatilis
50
40
30
20
10
4
3
2
1
F M A M J J A S O N D J F
1980
1981
Month
Viviparus viviparus

FIGURE 5.5 c

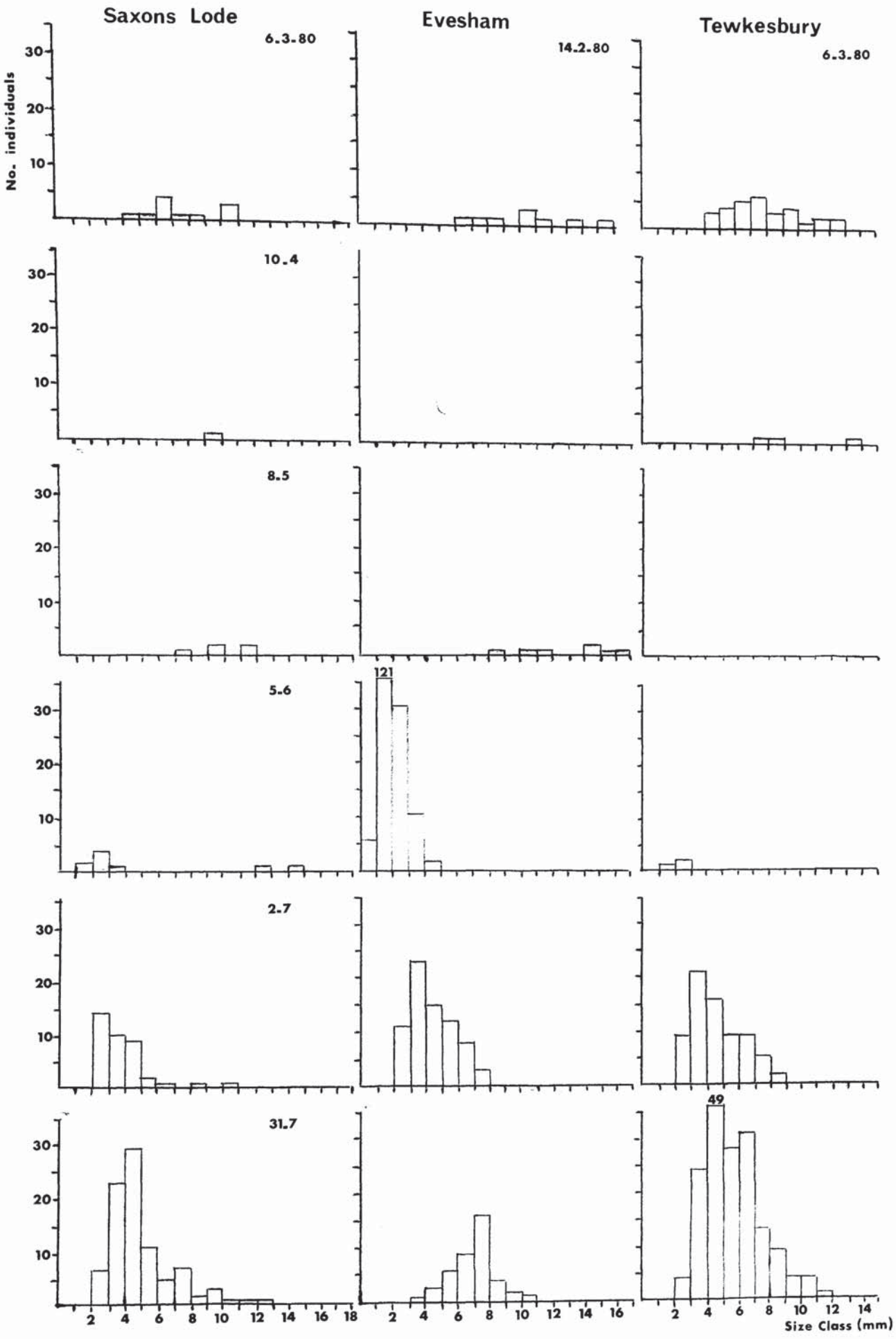


FIGURE **5.6** a: *Lymnaea peregra*

FIGURES **5.6** a-f:SIZE CLASS DISTRIBUTIONS OF SNAILS COLLECTED ON S.AUF.U DURING CONTINUOUS SAMPLING OF THE R. AVON-R.SEVERN

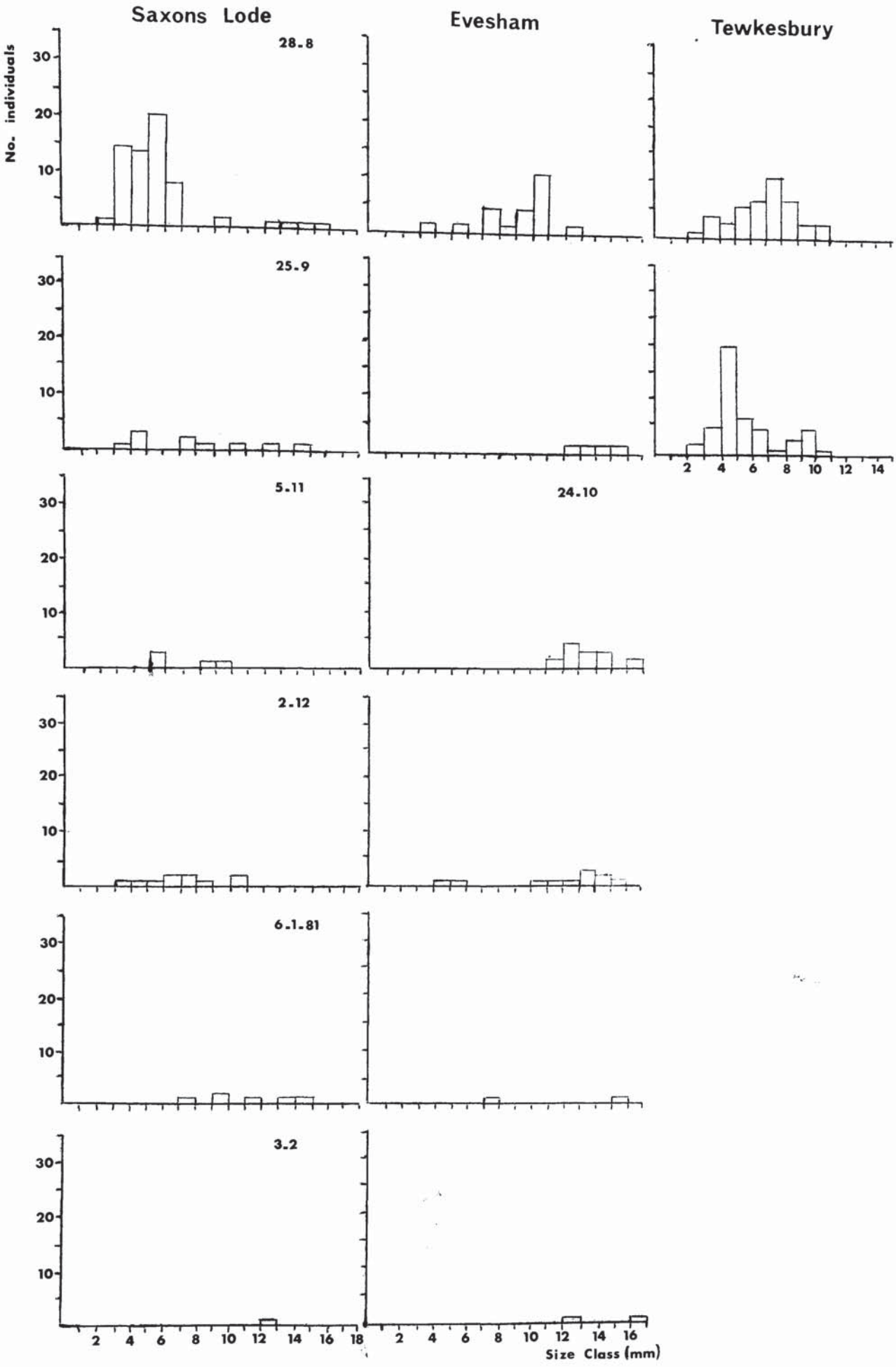


FIGURE 5.6 a continued

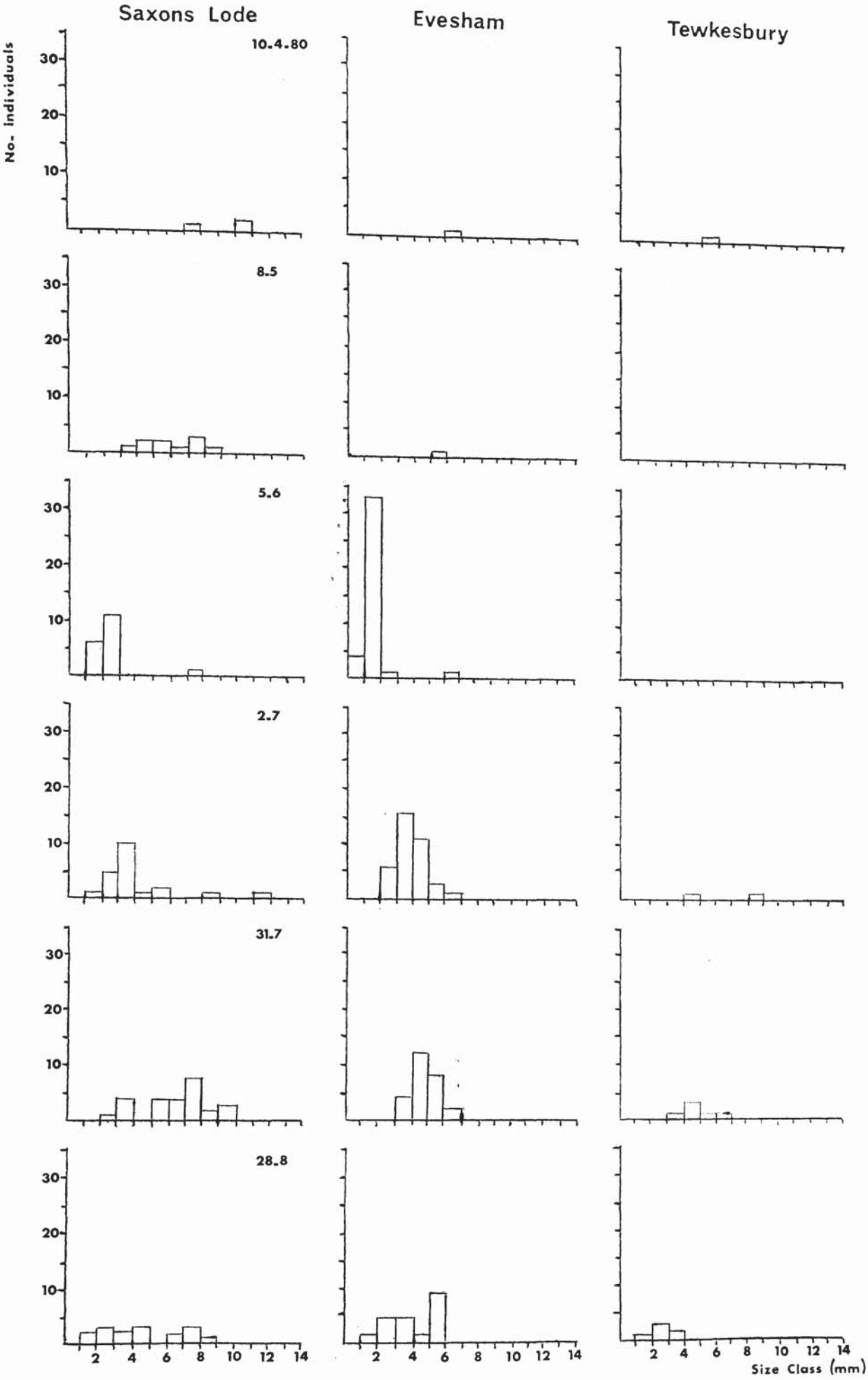


FIGURE 5.6 b: *Physa fontinalis*

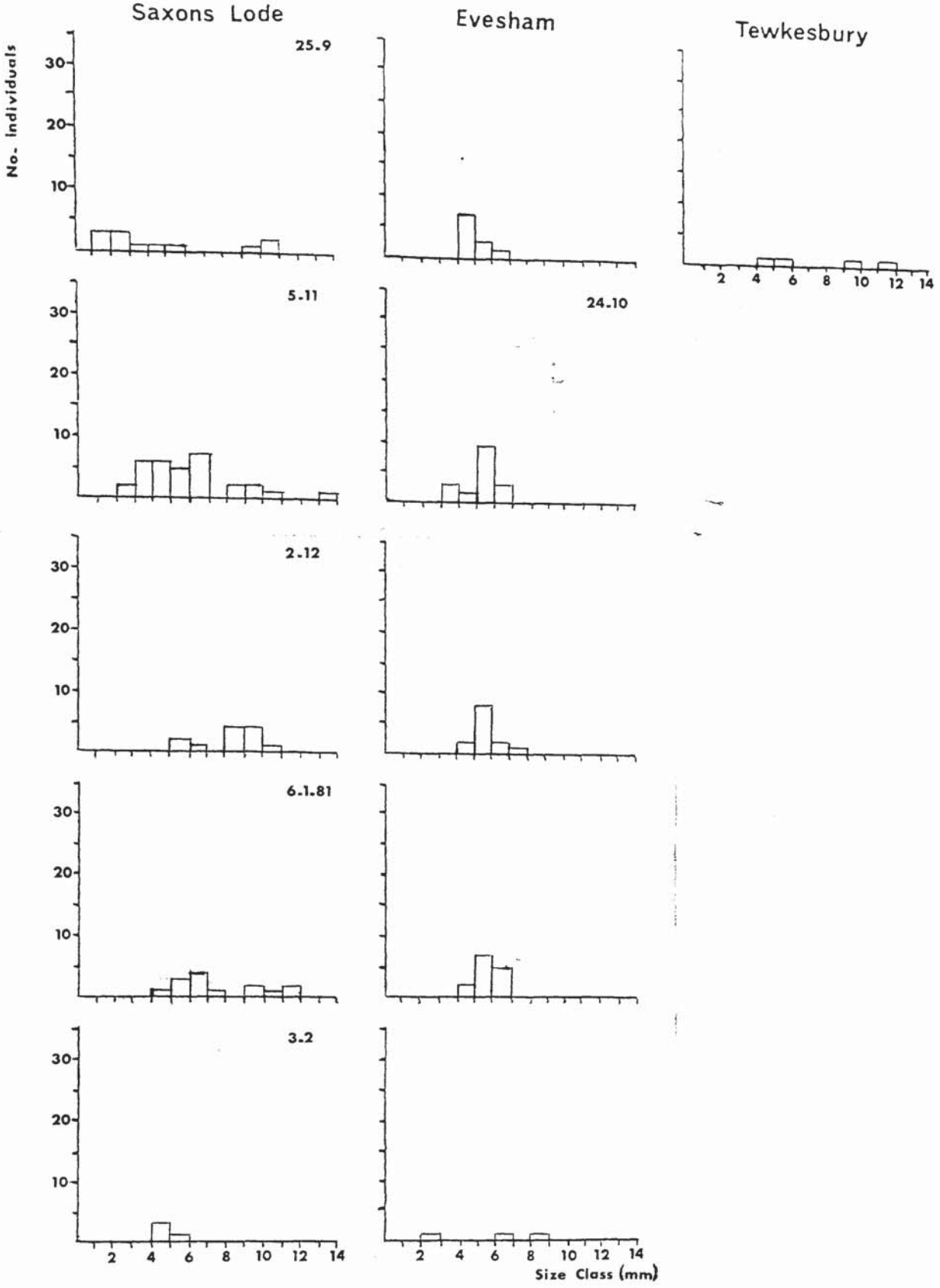


FIGURE 5.6 b continued.

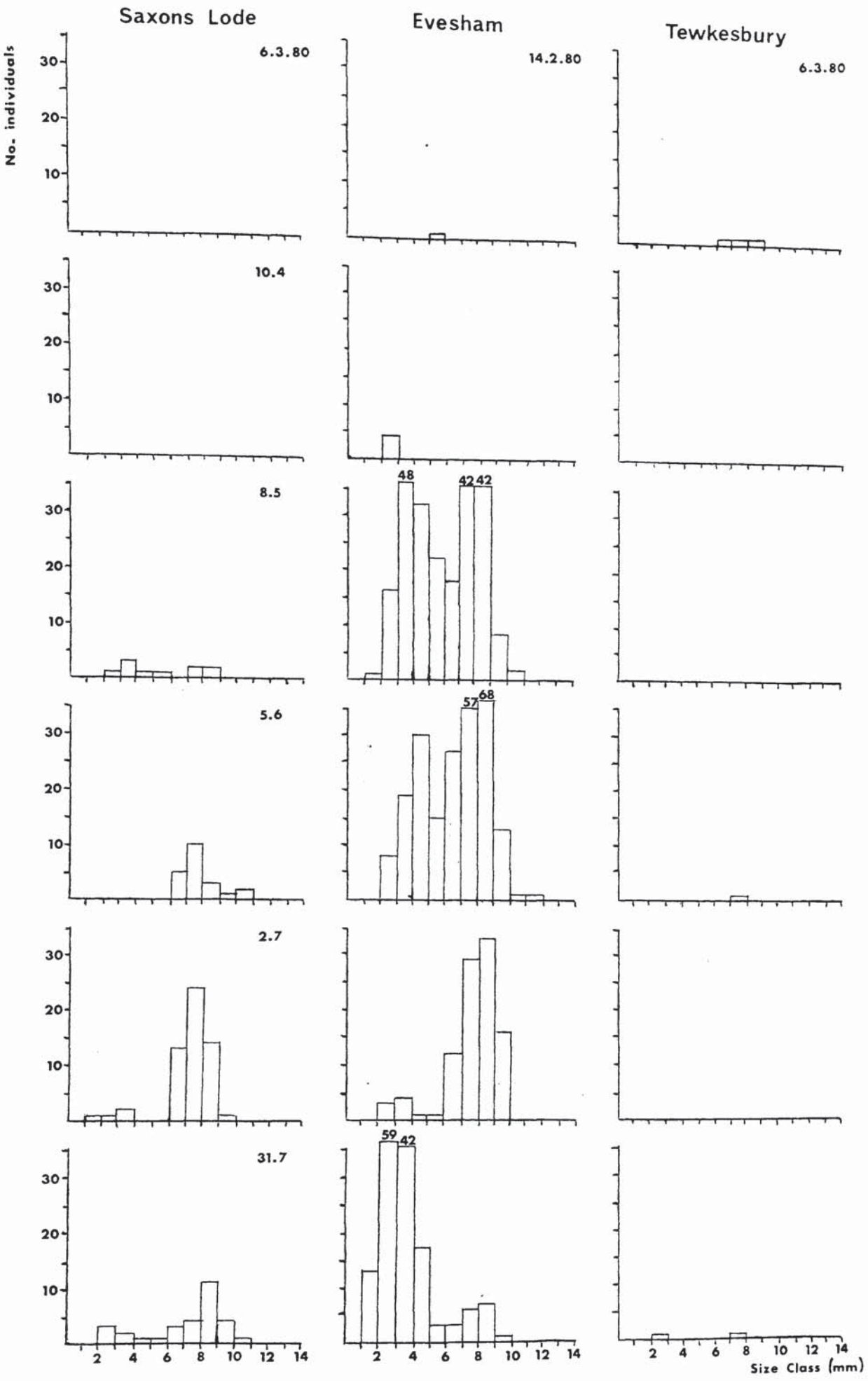


FIGURE 5.6 c : *Bithynia tentaculata*

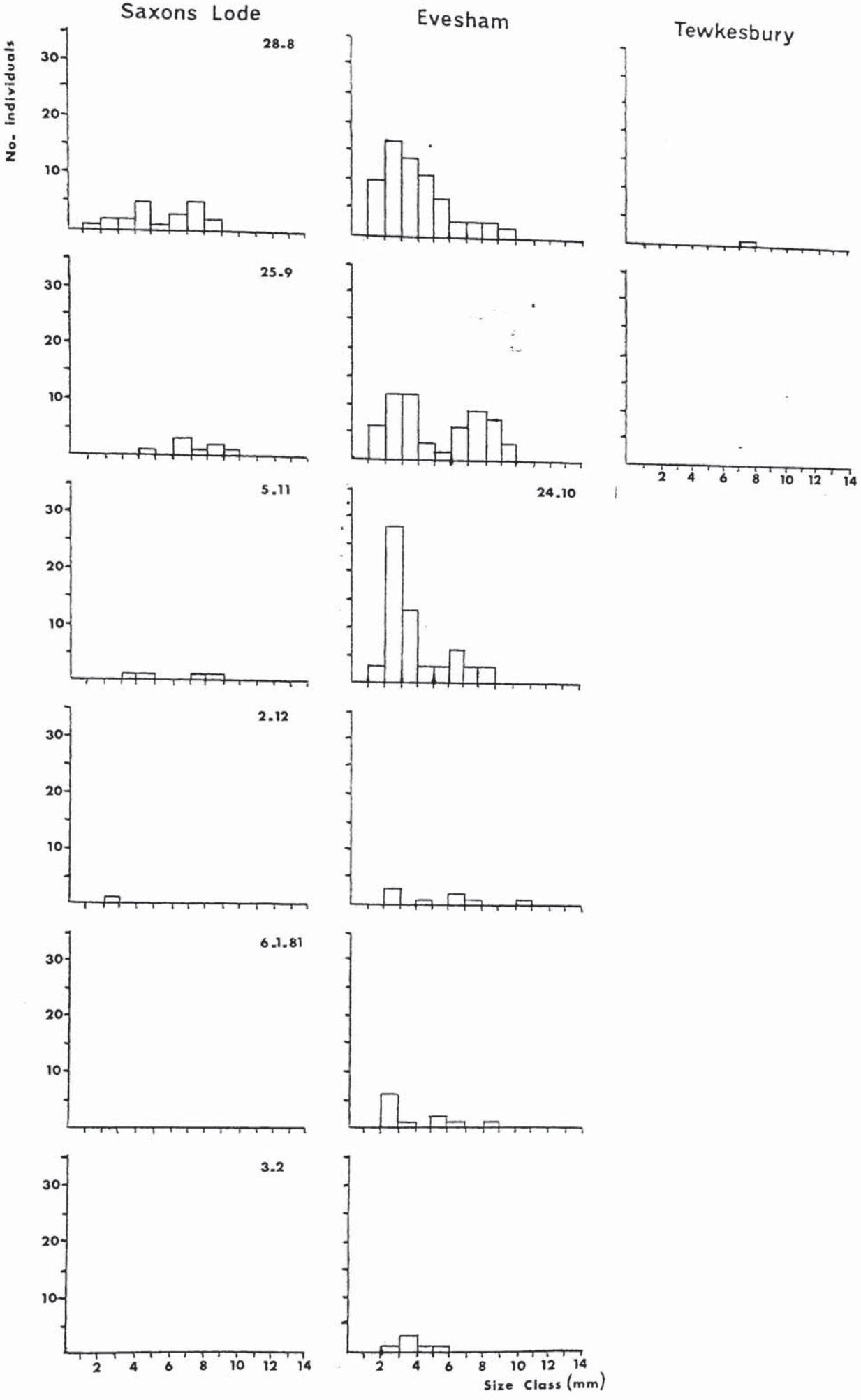


FIGURE 5.6 c continued

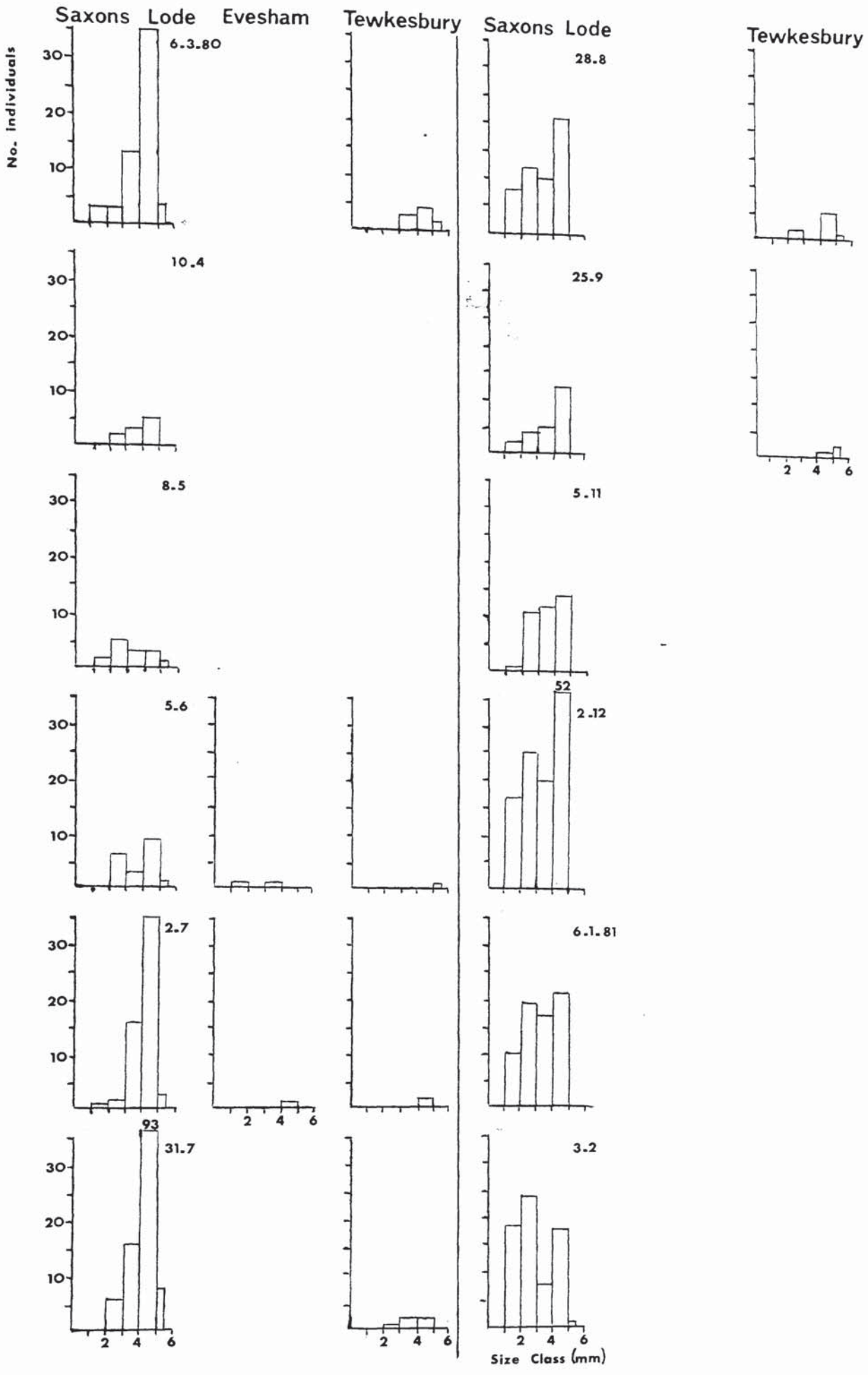


FIGURE: 5.6 d: *Potamopyrgus jenkinsi*

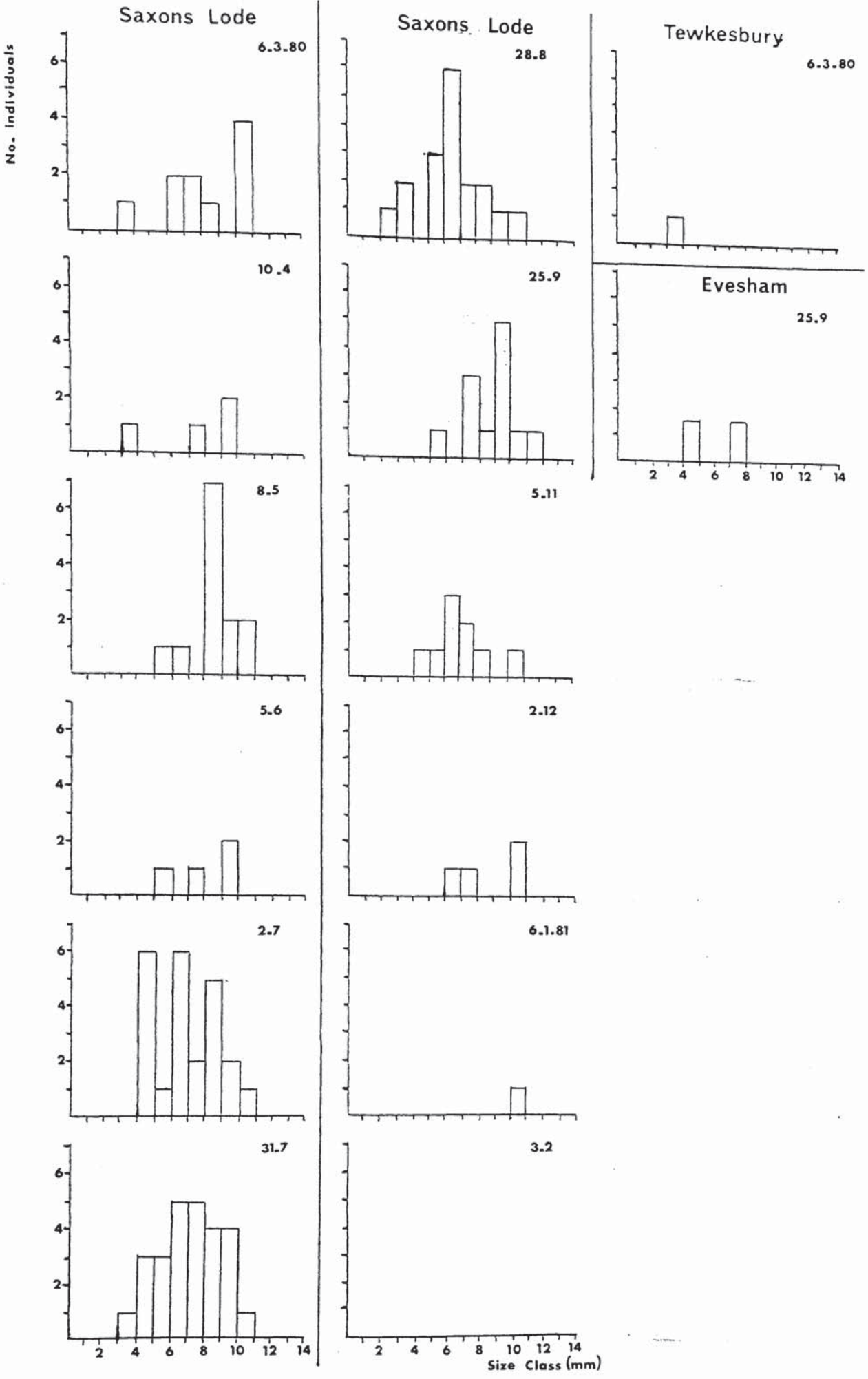


FIGURE 5.6 e : *Theodoxus fluviatilis*

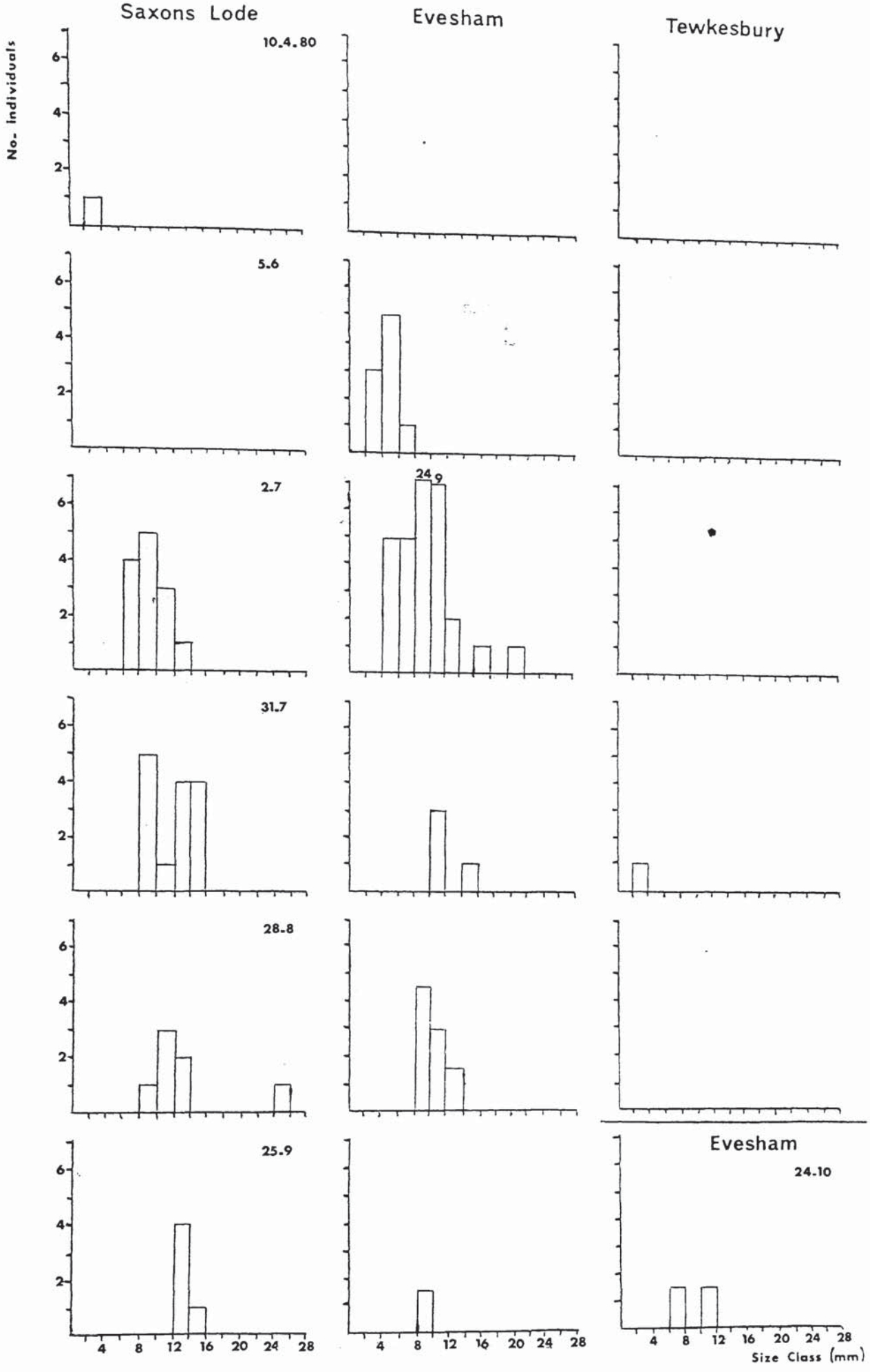


FIGURE 5.6 f: *Viviparus viviparus*

Saxons Lode.

V. viviparus populations and biomasses were higher at Evesham (R. Avon) than Saxons Lode (R. Severn) in June and early July, but lower for nearly all the rest of the year (Figure 5.5c). The maximum number of 47 recorded at Evesham was considerably greater than the peak of 13 at Saxons Lode. Because of the lack of clear differences in abundance between the unpolluted Saxons Lode and the organically polluted Evesham in L. peregra, P. fontinalis and V. viviparus, it can be concluded that they are not useful indicator organisms for mild organic pollution.

B. tentaculata was consistently more abundant, with a corresponding greater biomass, at Evesham (R. Avon) than Saxons Lode (R. Severn) (Figure 5.5b). Peak numbers of 239 were reached at Evesham compared with 56 at Saxons Lode. The greater numbers at the organically polluted site might be a reflection of a greater food supply resulting from organic enrichment. This species feeds on vegetative detritus according to Wesenburg-Lund (1939) and filamentous algae and diatoms according to Fretter and Graham (1962) all of which could be increased in quantity by mild organic pollution.

In complete contrast, P. jenkinsi and T. fluviatilis were considerably more abundant at Saxons Lode than on the R. Avon (Figures 5.5b and c). Peak numbers of 123 for P. jenkinsi at Saxons Lode compared with 2 at Evesham and 26 and 3 for T. fluviatilis at these two sites respectively were reached. Furthermore, both species were recovered on far more occasions from Saxons Lode. Biomass clearly followed the same pattern. Both these species could therefore have value as indicators of organic pollution. This study suggests that P. jenkinsi could be particularly useful since Tewkesbury which was less polluted that Evesham but more polluted than Saxons Lode had intermediate populations of P. jenkinsi throughout the summer (Figure 5.5b).

No consistent clear differences in the size class-distributions occurred between sites except that large numbers of small L. peregra and V. viviparus occurred at Evesham (R. Avon) before Saxons Lode (R. Severn) (figures 5.6a - f). Large numbers of small L. peregra

(<4mm long) appeared at Evesham in early June but at Saxons Lode principally in July. Similarly, small V. viviparus appeared at Evesham in early June and Saxons Lode in late June. These results imply that reproduction begins earlier at Evesham than Saxons Lode. There were not any temperature differences between the two sites that could have been responsible (Table 9.6a).

It was not possible to calculate growth rates as the different cohorts could not be distinguished except in L. peregra where growth had already been studied (see Chapter 4).

5.4 Conclusions and Recommendations

1. S.Auf.U. at six sites had a distinctly poorer fauna than those at other sites. High concentrations of heavy metals and/or ammonia were probably responsible at Acton Bridge (R. Weaver) and Doncaster (R. Don). Beal Weir (R. Aire) and Methley (R. Calder) could have been affected by low dissolved oxygen levels and/or high nitrite levels, while Mythe 2 (R. Severn) suffered from the effects of suspended solids including aluminium compounds. The reasons for a poor fauna at Hartford Bridge (R. Weaver) are unclear.

2. S.Auf.U. from the Anglian W.A. rivers supported the richest fauna. High nutrient levels may have benefited some species.

3. The benthic fauna of both the R. Avon and R. Trent reflected a downstream improvement in water quality whereas sites of chemical classes 1 and 2 on the R. Nene were indistinguishable. The Gammaridae/Asellus ratio was useful in the two former rivers.

4. In the continuous sampling of the R. Avon - R.Severn over one year the S.Auf.U. colonisers reflected the improvement in water quality Evesham (R. Avon)→Tewkesbury (R. Avon)→Saxons Lode (R. Severn). Crustacea were particularly useful indicator taxa .

5. No pollution indexes performed particularly well in the general lowland river survey, they were largely unable to distinguish between class 1 and 2 sites. Their design principally for riffle

species was the most important reason for this. In contrast the Chandler and B.M.W.P. Scores reflected the differences in water quality between Evesham (R. Avon) and Saxons Lode (R. Severn) over most of the year in the continuous sampling programme.

6. The Kempton-Taylor diversity index reflected differences in water quality reasonably well distinguishing between sites of different chemical class and showing the downstream improvement in the R. Avon. However, it showed some regional variation. On the other hand the Shannon-Weaver and Fisher's α indexes performed very poorly.

7. On the basis of the overall poor performance of both pollution and diversity indexes, it is recommended that an abbreviated list of taxa be used in the biological surveillance of lowland rivers. The suggested list is shown in Table 5.10 and the relative abundance scale of Chandler (1970) should be applied to it. This list should be able to reflect organic pollution, heavy metals and the effects of pesticides. In particular, non-chironomid insects should be eliminated by organic pollution and the ratios within the Crustacea, Gastropoda and Hirudinea altered. Molluscs, leeches and worms should be affected by heavy metals and all insects including chironomids by insecticides.

8. No correlation was found between macrophyte abundance and the numbers of total and snail taxa and individuals found on S.Auf.U.

9. Lymnaea peregra and Bithynia tentaculata showed significant differences in their frequency of occurrence at sites of different chemical class. These and all other snail taxa occurred more frequently at class 1 and 2 sites.

10. Three sites had no gastropods. Heavy metals and possibly ammonia were probably responsible at Acton Bridge (R. Weaver), suspended solids including aluminium compounds at Mythe 2 (R. Severn) and high temperatures at Shardlow (R. Trent).

11. Three other sites had only one or two gastropod taxa. The unstable substratum was probably responsible at Haw Bridge (R. Severn) and heavy metals at Doncaster (R. Don), whereas

CRUSTACEA	*Asellus aquaticus* *Corophium curvispinum* *Crangonyx pseudogracilis* *Gammarus spp.*
INSECTA	Baetidae *Caenis spp.* *Ephemerella ignita* Polycentropidae Cased caddises excluding Limnephilidae *Agrion spp.* Coenagriidae *Chironomus riparius* (L) Other Chironomidae (L)
MOLLUSCA	*Lymnaea spp.* *Physa spp.* *Potamopyrgus jenkinsi* *Theodoxus fluviatilis* Other Gastropoda Sphaeriidae
ANNELIDA	Erpobdellidae Piscicolidae *Stylaria spp.* Other Oligochaeta

TABLE **5.10** : RECOMMENDED ABBREVIATED LIST OF TAXA FOR USE IN THE BIOLOGICAL SURVEILLANCE OF LOWLAND RIVERS

the reasons for the absence of more taxa at Beal Weir (R. Aire) are unclear. Nitrite could have had an effect.

12. Heavy metals, in particular copper, lead, mercury and zinc seemed to affect the distribution of gastropods. Temperature probably had an effect at Shardlow and high ammonia levels could have had an effect at several sites.

13. Potamopyrgus jenkinsi and Theodoxus fluviatilis achieved far greater numbers in the R. Severn than the R. Avon in the continuous sampling programme and could be useful indicator species of organic pollution in lowland rivers. B. tentaculata reached larger numbers in the R. Avon while other snail taxa showed no appreciable difference between the rivers. It is suggested that the ratio P. jenkinsi + T. fluviatilis/other snails might be a useful indicator system as it eliminates effects of non-pollution factors such as hardness.

14. Some snail taxa appeared to begin to breed earlier in the R. Avon but no clear differences in life-cycle between this and the R. Severn were found.

6. S. AUF. U AND GRAB SAMPLING OF THE R. CHURNET

6.1. Introduction

The R. Churnet was studied as it had a range of water qualities along its length. Consequently, the viability of S. Auf. U in detecting any resultant biological changes along its length could be assessed. Grab samples were taken so as to compare S. Auf. U results with those of a method sampling the natural substratum.

6.2. Site Description

Six pool sections on the rhithronic R. Churnet were selected for sampling using the S. Auf. U. and/or grabs (fig.6.1). These were chosen so as to correspond to a wide range of chemical water qualities (table 6.1). All the sites were close to riffles (table 6.1) which were without doubt an important source of colonising invertebrates.

6.3. Methods

Three S. Auf. U. were anchored using 7 mm diameter metal rods for 28 days, as recommended by Girton (Department of the Environment, 1979), at all six sites between 12th June and 10th July 1979. Unfortunately, all three samplers from Tittesworth Reservoir, above any source of pollution, were lost. In addition three Ekman grab samples were taken at the beginning of each immersion period from five of the sites to offer a comparison between direct and colonisation sampler sampling. It was not possible to take grab samples from Cheddleton Mill because of a great deal of woody debris in the benthos.

The same physicochemical samples as in the Severn-Avon study were taken at the beginning of the immersion period. Macroinvertebrates were removed, transported, preserved and counted as stated in previous chapters except that no subsamples were taken during counting. The TBI, Chandler Score,B.M.W.P. Score, Shannon-Weaver diversity and Simpson's diversity were calculated for each group of three S. Auf. U and three grab samples.

6.4. Results and Discussion

The physicochemical data are displayed in appendix Table 9.10. It is clear that the river has recovered chemically from the days when copper was recorded at levels of up to 1.0 mgl^{-1} (Pentelow and Butcher, 1938; Butcher, 1946, 1955). The elevated BOD_5 and metal levels at

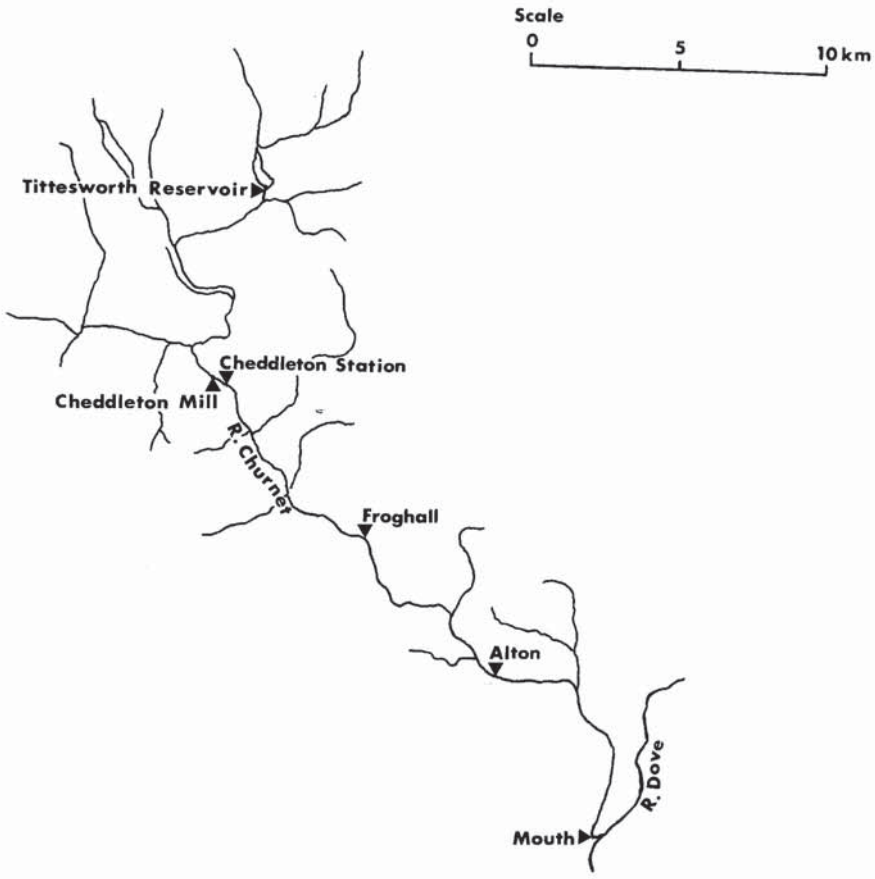


FIGURE **6.1** : R. CHURNET SAMPLING SITES

SITE	GRID. REFERENCE	PROXIMITY OF NEAREST RIFFLES	CHEMICAL CLASS 1978/9
Titt esworth Reservoir	SJ 994 586	10m. upstream and downstream	1A
Cheddleton Mill	SJ 973 526	Weir immediately downstream	3/2
Cheddleton Station	SJ 982 522	50m. downstream	3/2
Froghall	SK 024 474	20m. upstream and downstream	3/2
Alton	SK 071 426	10m. upstream and downstream	2/1B
Mouth	SK 100 376	30m. upstream	2/1B

TABLE **6.1** : R. CHURNET SAMPLING SITES.

Cheddleton Mill reflected the sewage works input above this site.

Both the fauna collected on S. Auf. U and in grab samples reflected the improvement in water quality between Cheddleton and the Churnet Mouth - all 3 pollution indexes and both diversity indexes increased fairly constantly over the 5 sites (table 6.2). The grab samples similarly reflected the deterioration in water quality between Tittesworth Reservoir and downstream of the Leek effluent. Scores obtained for all 3 pollution indexes were clearly higher for the S. Auf. U. samples (Table 6.2). The collection of high scoring taxa such as Ephemerella ignita and Phryganaeidae only on S. Auf. U (Tables 6.3 and 6.4) accounted for much of the difference. In addition, S. Auf. U. collected more individuals of each taxon except for oligochaetes and also chironomids at Alton; cased-caddises, leeches and A. aquaticus were all far more abundant on S. Auf. U. Therefore S. Auf. U has advantages over the Ekman grab in that observable differences in pollution indexes and the basic species - abundance lists between unpolluted and polluted sites are greater.

The principal changes in the fauna going downstream involved A. aquaticus and leeches, which were abundant below the effluent, gradually decreasing in numbers as the water quality improved, and caseless caddises, Atherix sp. and P. jenkinsi which only occurred at the cleanest sites below Leek (tables 6.3. and 6.4). G. pulex, cased - caddises, beetles and chironomids were recorded throughout the course of the river.

6.5. Conclusions

1. The fauna of both S. Auf. U and grab samples reflect the water quality of the river.
2. S. Auf. U. have advantages over grab samples as additional taxa important in biological surveillance can be collected and because more individuals are recorded.

Site	Pollution Index			Diversity Index	
	Trent Biotic	Chandler Score	B.M.W.P.	Simpson's	Shannon-Weaver
Cheddleton Mill	V	273	30	0.2960	0.6536
Cheddleton Stn.	V	284	31	0.1600	0.4011
Froghall	VI	374	39	0.5303	1.2551
Alton	VII	354	42	0.6650	1.5307
Mouth	VII	423	49	0.7969	1.8486

(a). S.AUF.U.

Site	Pollution Index			Diversity Index	
	Trent Biotic	Chandler	B.M.W.P.	Simpson's	Shannon-Weaver
Tittesworth Res.	IV	118	10	0.6417	1.0610
Cheddleton Statn.	IV	162	17	0.0244	0.0796
Froghall	IV	211	18	0.3693	0.8392
Alton	III	69	6	0.4147	0.7864
Mouth	V	281	27	0.9011	1.9459

(b) Ekman Grab.

TABLE 6.2.: POLLUTION AND DIVERSITY INDEXES FOR THE R. CHURNET FOR S.AUF.U IMMERSED 20.8.79 TO 17.9.79 AND GRAB SAMPLES TAKEN 20.8.79.

↓ TAXON SITE →	CHED. MILL	CHED. ST.	FROGH'L	ALTON	MOUTH
Asellus aquaticus	522	1024	62	43	1
Gammarus pulex	28	54		15	
Ephemerella ignita					1
Hydropsyche pellucidula				1	1
Limnephilidae	6			5	1
Phryganeidae			1		
Polycentropus flavomaculatus				4	7
Brychius elevatus(A)				2	1
Dytiscinae (L)	4	6	1		
Haliplus spp. (L)			1		
Haliplus spp. (A)		1	1		
Sialis luteria			3		
Atherix spp.				1	1
Diamesinae (L)			1	4	
Orthocladiinae (L)	1	6	11	2	
Tanypodinae (L)			1		1
Chironomidae (P)	3				
Lymnaea peregra					1
Potamopyrgus jenkinsi					10
Pisidium spp.		1	1	1	
Erpobdella octoculata	60	5	5	1	1
Glossiphonia complanata	4	21	4		
Helobdella stagnalis	2	1			
Oligochaeta	381	664	101	67	204

TABLE **6.3** : NUMBERS OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED ON THREE S.AUF.U. IN THE R. CHURNET 20.8.1979 to 17.9.1979

TAXON ↓ SITE →	RES.	CHED. ST.	FROGHL	ALTON	MOUTH
Asellus aquaticus			7	1	2
Limnephilidae	1	1			1
Sialis luteria			1		1
Atherix spp.					2
Chironomus riparius (L)				7	
Chironomini (L)				26	
Diamesinae (L)	6		3	69	
Orthocladiinae (L)	1		14		
Tanypodinae (L)			4		1
Chironomidae (P)				1	
Dicranota spp.			1		
Potamopyrgus jenkinsi					2
Pisidium spp.		6			1
Erpobdella octoculata		2			
Glossiphonia complanata		1			
Helobdella stagnalis			1		
Oligochaeta	8	805	115	298	4

TABLE 6.4: NUMBERS OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED IN THREE GRAB SAMPLES TAKEN FROM THE R. CHURNET ON 20.8.79.

7. ACUTE TOXICITY TESTS ON POTAMOPYRGUS JENKINSI (SMITH)

7.1 Introduction

It was observed in Chapter 5 that the toxicants most likely affecting gastropod distribution in lowland rivers were ammonia, nitrite, copper and zinc. Consequently these toxicants were initially selected for laboratory studies. The field work carried out on lowland rivers and in the Checkley Channels also suggested that the least tolerant gastropods were Potamopyrgus jenkinsi and Theodoxus fluviatilis since they were absent from the sites with the highest metal levels and were severely reduced in abundance in water containing organic effluent. Therefore it was decided to perform toxicity tests in the laboratory on these two species. However, T. fluviatilis could not be obtained in large numbers from the field and would not breed in the laboratory despite manipulation of temperature and photoperiod. Laboratory tests were, as a result, restricted to P. jenkinsi.

Static range finding toxicity tests were carried out initially on ammonia, nitrite, copper and zinc after which ammonia and copper were selected for further study in a flow-through system because they appeared to be toxic at levels similar to those recorded in the field. A flow-through test system was used since copper levels tend to be depleted in static tests through uptake by the test organisms and chambers (A.P.H.A., 1976; E.P.A., 1978; Murphy, 1978). Toxicity tests were performed on three different ages of snail since previous work had shown juvenile snails to be less tolerant towards the toxicant zinc (Wurtz, 1962). Most toxicity tests on gastropods have been carried out solely on adults. Such a lack of study on different ages and/or life stages is widespread in macroinvertebrate toxicity testing (Buikema and Benfield, 1979).

7.2 Materials and Methods

7.2.1 Experimental Animals

P. jenkinsi were collected from channel A (100% clean river water) of the Checkley Channels (see Chapter 4) using colonisation samplers. The snails were kept in a controlled temperature room at 15 - 20^{o}C under a 12 h light:12 h dark photoperiod. Basic stocks of snails were kept in ca.20 l of pond water from Langley Pool (Grid.ref. SP 153968) in glass tanks while stocks for subsequent experiments were separated into other tanks, containing either ca.6 l, 12 l, or 20 l of Langley Pool water

(Plate 7.1). Tanks were aerated via diffuser blocks and water was changed every four weeks. Snails were regularly fed a mixture of wheatgerm, dried milk, dried powdered grass and calcium chloride in a gelatinous mass of sodium alginate. This recipe was recommended by Young, J.O. (University of Liverpool, pers. comm.).

Three ages of snail were used in the toxicity experiments:-

(i) juvenile snails bred in the laboratory of age 4 - 12 weeks and length 1 - 2 mm.

(ii) prime adult snails bred in the laboratory of minimum length 4 mm and just commencing breeding or breeding rapidly.

(iii) senescent adult snails collected from the field but kept in the laboratory for over 6 months during which breeding had virtually ceased at the time of experimentation. These snails were also of minimum length 4 mm.

7.2.2 Range Finding Tests

These static tests were carried out at 15°C over 24 h in glass jars containing 1 l of Langley Pool water. Groups of 10 adult snails were exposed to 2 - 4 concentrations of toxicant at widely spaced intervals plus a control. Nominal concentrations of toxicant were as follows:-

NH_4Cl	80, 320 mgl^{-1}	total $N\text{-}NH_3$ at pH 7.5
$NaNO_2$	1, 10, 50, 100 mgl^{-1}	$N\text{-}NO_2$
$CuSO_4.5H_2O$	0.1, 1.0, 4.0 mgl^{-1}	total Cu
$ZnSO_4$	0.3, 1.0, 5.0, 20.0 mgl^{-1}	total Zn

Snails were not fed. Mortality and retraction of snails behind their opercula, with the exception of the ammonia range finding test, were recorded using the method described in section 7.2.3.3.

7.2.3 Flow-through Tests

Subsequent to the range finding tests 96 h acute tests on ammonia (from NH_4Cl) and copper (from $CuSO_4.5H_2O$) were performed separately on the three ages of snail described in section 7.2.1. Prior to each experiment snails were acclimated to test conditions in the apparatus shown on the left of plate 7.2. In this system snails were kept for a period of

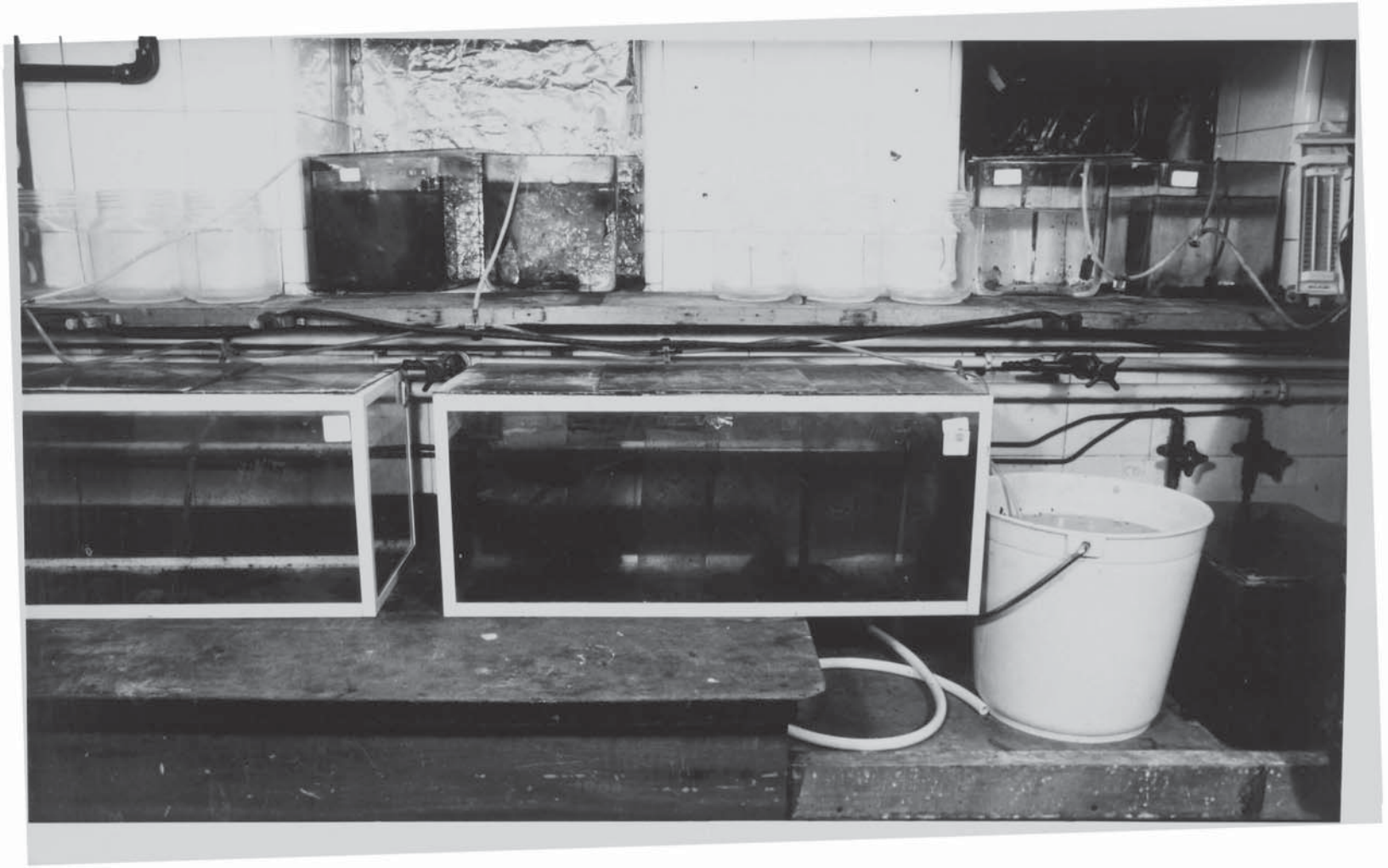
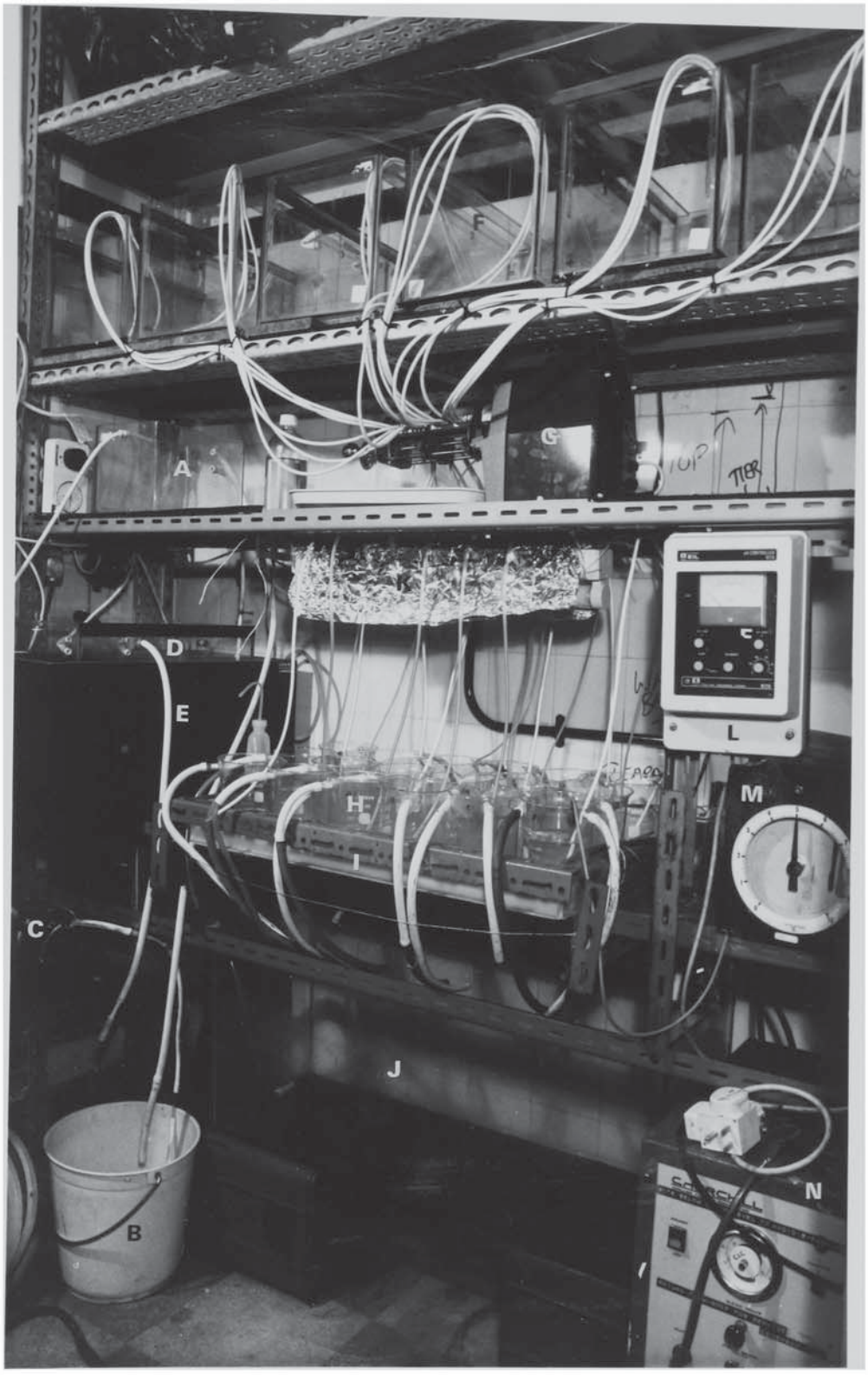


PLATE 7.1 : HOLDING TANKS FOR GASTROPODS



A,B = reservoirs for acclimation system
C = peristaltic pump
D = acclimation tank
E,I = water baths
F = header tank
G = Watson-Marlow peristaltic pump
H = test chamber
J = effluent tank
K = light
L = pH meter
M = continuous recorder
N = Churchill heater/cooler

PLATE 7.2 : TOXICITY TEST SYSTEM TOGETHER WITH ACCLIMATION SYSTEM

60h at 15°C under a 12 h light:12 h dark photoperiod in a tank containing 20 l of Langley Pool water and with a flow regime similar to that of the test chambers except that it was recirculated by a peristaltic pump. Snails were fed during this acclimation period during which negligible mortality occurred.

After the acclimation period three replicates of 10 snails of each age (with one exception where not enough senescent individuals were available) were exposed to five concentrations of toxicant nominally at geometrically increasing concentrations plus a control. These are shown in table 7.1.

7.2.3.1 The Apparatus

Fresh toxicant was mixed in with 20 l or 25 l of Langley Pool water in fresh acid-cleaned glass header tanks (plate 7.2) every 24 h. At the start of each experiment the test chambers were filled from these header tanks. Water was part pumped by a Watson-Marlow Delta pump, part siphoned from the header tanks to the bottom of the test chambers which were 1 l Pyrex beakers with overflows holding ca. 1 l of test solution (plate 7.3). A flow-rate of 4 ml min^{-1} to each test chamber was aimed for since this would produce an exchange rate in accordance with those recommended by Sprague (1969) and EPA (1978). The actual flow rate was estimated by daily measuring the quantity of toxicant solution removed from each header tank.

The test chambers were immersed in a water-bath kept at 15°C by a Churchill heater-cooler unit and were exposed to a 12 h light:12 h dark photoperiod by a strip light directly above them (plate 7.2). Snails were not fed during the test periods.

7.2.3.2 Physicochemical Sampling

As mentioned above, Langley Pool water was used as dilution water. This was collected on either one or two occasions for each experiment, being transported to the laboratory in plastic dustbins just prior to or during it. The water was continuously aerated via diffuser blocks in the laboratory. Physicochemical samples of the dilution water were taken regularly, the same variables as in the R. Avon - R. Severn study (see section 5.3.1) were measured.

SYMBOL FOR NOM. CONC. OF TOXICANT	NOMINAL CONC. OF TOXICANT ($mg\ l^{-1}$)	
	Total $N\text{-}NH_3$	Total Cu
A	Control (0.2)[a]	Control (0.018)[a]
B	18.125	0.04
C	36.25	0.045
D	72.5	0.055
E	145	0.075 or 0.08
F	290	0.115

a = estimated from Langley Pool data (see table 7.3)

TABLE 7.1 : NOMINAL CONCENTRATIONS OF TOTAL AMMONIA (as $N\text{-}NH_3$) AND TOTAL COPPER USED IN FLOW-THROUGH TOXICITY TESTS ON *A. janbimai*

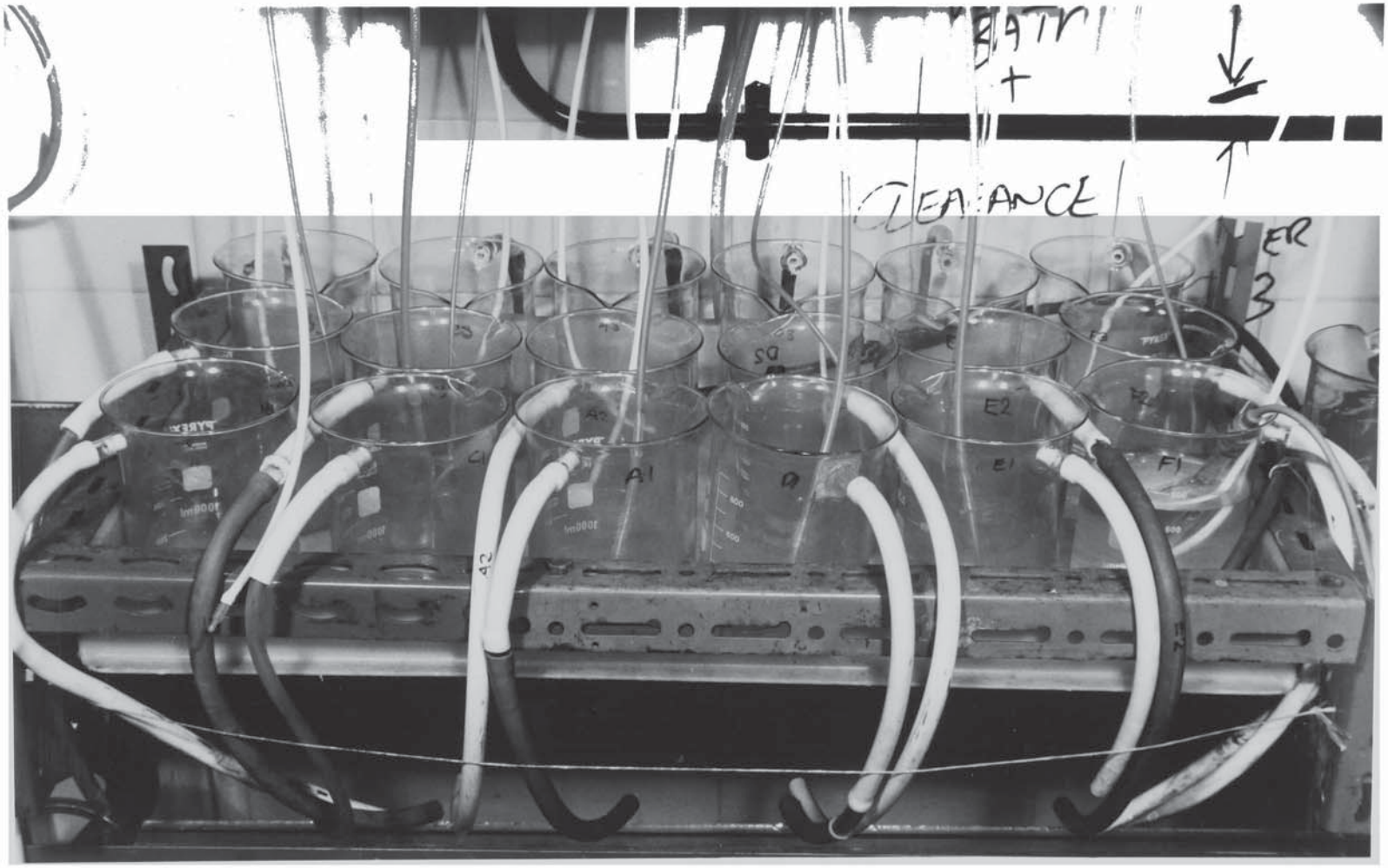


PLATE 7.3 : TOXICITY TEST ANIMAL CHAMBERS

During each experiment chemical samples of the toxicant were taken from each test chamber every 24 h. In early experiments intermediate samples were taken to detect any fluctuation over a 24 h period. Nitrate samples were taken in parallel with this during the ammonia experiments. Ammonia and nitrate levels were measured using a Technicon auto-analyser and copper levels by atomic absorption spectrophotometry. pH was measured in each toxicant concentration at each snail counting point, i.e. 1 h, 2 h, 4 h, 8 h, 24 h, 48 h, 72 h and 96 h, except once when the pH meter broke down. pH in the highest toxicant concentration was measured continuously using a pH meter attached to a Fielden continuous recorder. D.O was measured at the end of the first few experiments using the Winkler method but not subsequently since it seemed always to remain high (see 7.3.2.1).

As it is the unionised form of ammonia that is usually regarded as the toxic form (see section 2.2.7.2) the concentration of this form was calculated from total $N\text{-}NH_3$ levels using the formula

$$f = 1/(10^{pK_a - pH} + 1)$$

where f is the percentage of ammonia in the toxic unionised form. This formula was derived by Emerson et al. (1975).

7.2.3.3 Snail Counting

Snails were observed after 1 h, 2 h, 4 h, 8 h, 24 h, 48 h, 72 h and 96 h. A four-level response was defined:-

(a) Snails apparently unaffected and able to cling on to the sides or bottom of the test chambers.

(b) Snails not holding on to the test chamber but not retracted behind their opercula and responding to prodding with a "seeker".

(c) Snails retracted behind their opercula but either moving out from behind them or responding to prodding within 10 minutes in clean water.

(d) No signs of movement within 10 minutes in clean water. Defined as dead.

Juvenile snails were observed under a low-power binocular microscope.

7.2.3.4 Calculations

96 h LC50's and EC50's were estimated using log-probit paper by the method of A.P.H.A. (1976) for all ammonia experiments and the copper toxicity test on juvenile snails. Atomic absorption spectrophotometry values for copper were not however available for tests on adult snails at the time of writing so LC(I)50's and EC(I)50's using the nomenclature recommended by Lloyd and Tooby (1979) were estimated as above. 95% confidence limits were fitted to all values by the method of Litchfield and Wilcoxon (1949). Tests to see whether differences between ages in 48h and 96h LC50's and EC50's were significantly different at the 5% level were carried out as described in A.P.H.A. (1976). This test states that, when comparing two EC50's,the difference is significant at the 5% level if

$$\frac{\text{Greater EC50}}{\text{Smaller EC50}} > 1.96 \text{ S.E.}$$

7.3 Results and Discussion

7.3.1 Range Finding Tests

Results of the range finding tests are displayed in table 7.2. Both ammonia and copper caused mortality at levels similar to those recorded at lowland river sites in chapter 5. Specifically, 0.68 mgl^{-1} unionised $N\text{-}NH_3$ resulted in 90% mortality in 24h while levels of >2 mgl^{-1} unionised $N\text{-}NH_3$ could have been present at Acton Bridge on the R. Weaver and, 0.1 mgl^{-1} Cu affected all snails exposed to it at least sublethally while up to 0.08 mgl^{-1} total Cu was recorded in the field (table 9.6d). In contrast, nitrite levels as high as 100 mgl^{-1} produced no observable detrimental effects while a maximum of only 2.24 mgl^{-1} was recorded in the field (table 9.6c). Furthermore, 1.0 mgl^{-1} Zn produced no lethal or sublethal effects while the highest concentration recorded in the field was 0.28 mgl^{-1} (table 9.6d). Consequently, as a result of the range finding tests, ammonia and copper were selected for further study in flow-through systems.

7.3.2 Flow-Through Toxicity Tests

7.3.2.1 Physicochemical Data

Physicochemical data for the Langley Pool dilution water is shown in Table 7.3. The water was hard and of alkaline pH. Levels of

$N-NH_3$		$N-NO_2$		Cu		Zn	
Nominal Conc. Toxicant ($mg\ l^{-1}$)	24h* resp	Nominal Conc. Toxicant ($mg\ l^{-1}$)	24h* resp	Nominal Conc. Toxicnt ($mg\ l^{-1}$)	24h* resp	Nominal Conc. Toxicant ($mg\ l^{-1}$)	24h* resp
Control	9a-c 1d	Control	10a	Control	10a	Control	10a
80[p] 0.68[q]	1a-c 9d	1	10a	0.1	7c 3d	0.3	10a
320[p] 2.74[q]	1a-c	10	10a	1.0	2c 8d	1.0	10a
		50	10a	4.0	10d	5.0	8a 1b 1c
		100	10a			20.0	2b 4c 4d

p = total $N-NH_3$

q = unionised $N-NH_3$ (pH = 7.5)

TABLE 7.2 : RESULTS OF STATIC RANGE FINDING TESTS FOR THE EFFECTS OF AMMONIA , NITRITE , COPPER AND ZINC ON *P. jenkinsi* (* responses described in text)

VARIABLE (mg l^{-1} exc. pH)	n	$\bar{x} \pm$ 95% C.L.	S.D.	Min.	Max.
BOD_5	23	3.0 ± 0.65	0.8	0.4	6.25
Chloride	22	36 ± 10	5	27	106
pH	23	8.0 ± 0.2	0.1	7.25	8.7
Alkalinity (as $CaCO_3$)	23	133 ± 10	5	100	205
Total Hardness (as $CaCO_3$)	22	298 ± 15	7	248	382
Calcium Hardness (as $CaCO_3$)	22	192 ± 12	6	138	242
Magnesium Hardness (as $CaCO_3$)	22	106 ± 7	3	73	144
N-NH_3	18	0.2 ± 0.1	0.1	0.1	0.6
N-NO_3	18	7.0 ± 0.9	0.4	3.0	10.2
N-NO_2	18	0.035 ± 0.01	0.005	0.01	0.09
P-PO_4	18	1.0 ± 0.4	0.2	0.1	2.3
Total Fe	18	0.280 ± 0.070	0.033	0.051	0.615
Cd	18	0.002 ± 0.000	0.001	0.002	0.003
Cr	18	0.003 ± 0.000	0.001	0.002	0.004
Cu	18	0.018 ± 0.004	0.002	0.008	0.040
Pb	18	0.019 ± 0.003	0.001	0.010	0.026
Ni	18	0.011 ± 0.002	0.001	0.005	0.015
Zn	18	0.019 ± 0.003	0.002	0.006	0.033

TABLE 7.3 : PHYSICOCHEMICAL DATA FOR LANGLEY POOL DILUTION WATER DECEMBER 1980 - NOVEMBER 1981 .

possible toxicants, i.e. $N\text{-}NH_3$ and metals except for copper, which was high relative to unpolluted rivers, were low.

Volumes of water used per three replicates were found to be 16.49±0.55 l (n=62) and 17.55±0.36 l (n=59) ($\bar{x}$±95% C.L.) in the ammonia and copper toxicity experiments respectively. If one assumes that the flow through each replicate is the same, this corresponds to flow rates of 3.82ml min^{-1} and 4.06ml min^{-1} respectively. Such flow rates would produce ca.90% volume replacement in the test chambers in ca.10h according to the nomogram of Sprague (1969). This flow rate is in accordance with the recommendations of Sprague (1969) and E.P.A. (1978) who state that 90% volume replacement should occur within 8-12h and that at least 5 equivalent volume replacements should occur every 24h respectively.

Ammonia, copper and pH levels recorded during the toxicity tests are displayed in Tables 7.4, 7.5 and 7.6 respectively. Nitrate levels for the ammonia toxicity tests are shown in Table 7.7. It can be seen from Table 7.6 that the addition of ammonium chloride depressed the pH with the result that the proportion of ammonia in the toxic NH_3 form fell. Nevertheless, on the whole a logarithmic series of concentrations was maintained (Table 7.3). Measured D.O. levels in the test chamber were 8.3±0.15mgl^{-1} ($\bar{x}$±95% C.L.) with a minimum of 7.4mgl^{-1} and a maximum of 8.6mgl^{-1}. The minimum is well above the minimum 60% saturation recommended for toxicity tests (E.P.A., 1978).

7.3.2.2 Snail Response Data

Raw data on the effects of the toxicants ammonia and copper on *P. jenkinsi* are shown in Appendix Tables 8.23 and 8.24. Clearly tolerance to both unionised ammonia and copper increases juvenile snails<senescent adults<prime adults (Table 7.8); e.g. LC50's for unionised $N\text{-}NH_3$ were 0.315, 0.49 and 0.85mgl^{-1} in juvenile, senescent and prime adult snails respectively and LC(I)50's for total copper were 0.067, 0.099 and 0.103mgl^{-1} for the same three age groups. EC50's and EC(I)50's on the whole followed a similar pattern except that prime adult snails were more sensitive to copper than senescent ones if ability to remain attached to the walls of the test chamber

↓NOMINAL CONC. TOXICANT / AGE OF SNAIL →	$N\text{-}NH_3$ CONCENTRATION ($mg\ l^{-1}$) ($\bar{x}$ ± 95% C.L. with range in parentheses)		
	Juvenile	Prime	Senescent
Unionised $N\text{-}NH_3$			
A	<0.01 (<0.01)	<0.01 (<0.01 - 0.02)	<0.01[a] (<0.01)[a] 0.01[b] (<0.01 - 0.01)[b]
B	0.23 ± 0.03 (0.18 - 0.50)	0.44 ± 0.05 (0.28 - 0.54)	0.38 ± 0.01[b] (0.32 - 0.39)[b]
C	0.53 ± 0.14 (0.35 - 1.00)	0.81 ± 0.13 (0.47 - 1.12)	0.31 ± 0.09[c] (0.15 - 0.58)[c]
D	0.76 ± 0.04 (0.71 - 1.13)	1.37 ± 0.09 (0.83 - 1.89)	0.49 ± 0.13[a] (0.20 - 0.83)[a]
E	1.17 ± 0.16 (1.02 - 2.08)	1.97 ± 0.35 (1.09 - 2.54)	0.82 ± 0.21[a] (0.39 - 1.40)[a]
F	1.95 ± 0.40 (1.58 - 3.25)	3.07 ± 0.83 (1.61 - 3.93)	1.73 ± 0.32[a] (1.23 - 2.37)[a]
Total $N\text{-}NH_3$			
A	0.1 ± 0.0 (0.1 - 0.2)	0.2 ± 0.1 (0.1 - 0.5)	0.1 ± 0.0[a] (0.1 - 0.3)[a] 0.2 ± 0.1[b] (0.2 - 0.3)[b]
B	16.5 ± 0.1 (16.0 - 17.2)	16.8 ± 0.2 (16.4 - 17.6)	18.5 ± 0.1[b] (18.0 - 19.2)[b]
C	33.3 ± 0.3 (32.0 - 34.4)	35.9 ± 0.4 (34.4 - 37.6)	32.5 ± 0.6[a] (31 - 34)[a]
D	67.7 ± 0.8 (66 - 69)	70.0 ± 0.4 (69 - 71)	66.8 ± 0.7[a] (65 - 69)[a]
E	136.3 ± 1.6 (134 - 138)	132.3 ± 1.4 (128 - 134)	129.8 ± 1.3[a] (126 - 134)[a]
F	266.7 ± 5.4 (260 - 275)	266.7 ± 4.3 (260 - 275)	315.6 ±46.6[a] (270 - 460)*[a]

a = first run , b = second run , * = one abnormal value

TABLE 7.4 : UNIONISED AND TOTAL AMMONIA (AS $N\text{-}NH_3$) CONCENTRATIONS RECORDED DURING TOXICITY TESTS .

↓NOM. TOXICANT CONC. / AGE OF SNAIL →	TOTAL COPPER ($\bar{x} \pm 95\%$ C.L. with range in parentheses) ($mg\ l^{-1}$)
	Juvenile
A	0.0197 ± 0.0018^{a} $(0.0124 - 0.0234)^{a}$ 0.0179 ± 0.0029^{b} $(0.0132 - 0.0294)^{b}$
B	0.0486 ± 0.0036^{a} $(0.0426 - 0.0575)^{a}$
C	0.0495 ± 0.0016^{b} $(0.0458 - 0.0550)^{b}$
D	0.0601 ± 0.0022^{b} $(0.0545 - 0.0656)^{b}$
E	0.0765 ± 0.0070^{a} $(0.0660 - 0.0921)^{a}$
F	0.1042 ± 0.0130^{b} $(0.0994 - 0.1098)^{b}$

a = first run , b = second run

TABLE 7:5 : TOTAL COPPER LEVELS RECORDED DURING THE TOXICITY TESTS.

NOMINAL CONC. TOXICANT / AGE OF SNAIL →	pH ($\bar{x} \pm$ 95% C.L. with range in parentheses)		
	Juvenile	Prime	Senescent
N-NH$_3$			
A	7.85 ± 0.1 (7.7 - 8.0)	8.0 ± 0.05 (7.9 - 8.1)	7.75 ± 0.2[a] (7.4 - 8.05)[a] 8.0 ± 0.1[b] (7.75 - 8.1)[b]
B	7.75 ± 0.15 (7.6 - 8.05)	7.9 ± 0.1 (7.8 - 8.1)	7.85 ± 0.05[b] (7.8 - 7.9)[b]
C	7.75 ± 0.15 (7.6 - 8.05)	7.85 ± 0.1 (7.7 - 8.05)	7.6 ± 0.2[a] (7.25 - 7.85)[a]
D	7.7 ± 0.15 (7.6 - 7.8)	7.8 ± 0.1 (7.65 - 8.0)	7.5 ± 0.2[a] (7.05 - 7.75)[a]
E	7.65 ± 0.25 (7.45 - 7.75)	7.65 ± 0.1 (7.5 - 7.85)	7.45 ± 0.15[a] (7.05 - 7.65)[a,c]
F	7.65 ± 0.25 (7.45 - 7.75)	7.5 ± 0.15 (7.35 - 7.75)	7.2 ± 0.1[a] (7.1 - 7.3)
Cu			
A	8.05 ± 0.0[a] (8.0 - 8.1)[a] 8.0 ± 0.1[b] (7.75 - 8.1)[b]	7.9 ± 0.1 (7.75 - 8.1)	7.85 ± 0.0 (7.8 - 7.9)
B	8.1 ± 0.05[a] (8.05 - 8.2)[a]	8.05 ± 0.0 (8.05 - 8.15)	7.75 ± 0.1 (7.65 - 7.95)
C	7.95 ± 0.05[b] (7.85 - 8.05)[b]	8.05 ± 0.05 (8.05 - 8.15)	7.75 ± 0.1 (7.65 - 7.95)
D	8.0 ± 0.05[b] (7.9 - 8.05)[b]	8.1 ± 0.0 (8.05 - 8.15)	7.75 ± 0.1 (7.65 - 7.95)
E	8.15 ± 0.05[a] (8.1 - 8.2)[a]	8.1 ± 0.0 (8.05 - 8.15)	7.75 ± 0.1 (7.6 - 7.9)
F	8.05 ± 0.05[b] (8.0 - 8.1)[b]	8.1 ± 0.0 (8.05 - 8.1)	7.75 ± 0.1 (7.45 - 7.85)[d]

a = first run
b = second run
c = Min. 6.85 recorded on continuous recorder
d = Max. 8.0 recorded on continuous recorder

TABLE 7.6 : pH LEVELS RECORDED IN THE TOXICITY TESTS.

↓NOMINAL CONC. TOXICANT / AGE OF FISH→	$N\text{-}NO_3^-$ ($\bar{x} \pm 95\%$ C.L. with range in parentheses) ($mg\ l^{-1}$)		
	Juvenile	Brine	Senescent
A	8.6 ± 0.2 (8.0 - 9.0)	7.5 ± 0.8 (5.4 - 9.0)	9.9 ± 0.4[a] (8.8 -11.0)[a] 5.2 ± 0.3[b] (4.55- 6.0)[b]
B	8.8 ± 0.2 (8.2 - 9.4)	7.4 ± 0.8 (5.6 - 9.4)	5.4 ± 0.3[b] (4.4 - 6.0)[b]
C	8.6 ± 0.2 (8.2 - 9.2)	7.2 ± 0.8 (5.2 - 9.2)	9.9 ± 0.3[a] (9.2 -10.4)[a]
D	9.0 ± 0.1 (8.6 - 9.2)	7.5 ± 0.9 (6.0 -10.0)	9.9 ± 0.3[a] (9.0 -10.8)[a]
E	9.0 ± 0.2 (8.6 - 9.2)	6.9 ± 0.9 (5.6 - 9.4)	9.9 ± 0.3[a] (9.0 -10.6)[a]
F	9.0 ± 0.1 (8.8 - 9.2)	6.1 ± 0.4 (5.8 - 6.6)	8.4 ± 0.3[a] (7.8 - 8.8)[a]

a = first run

b = second run

TABLE 7.7 : NITRATE (as $N\text{-}NO_3^-$) LEVELS RECORDED DURING AMMONIA TOXICITY TESTS ON *P. jenkinsi*

AGE OF SNAIL →	96h. VALUE ($mg\ l^{-1}$)' * (95% C.L. given in parentneses)		
	Juvenile	Prime	Senescent
Unionised NH_3			
LC50	0.315 (-)	0.85 (0.73-1.00)	0.49 (0.44-0.55)
LC50 (response c)	0.31 (-)	0.56 (0.49-0.64)	0.37 (0.34-0.40)
Total Cu			
LC50	0.054 (0.050-0.058)	-	-
LC(I)50	0.067 (0.063-0.071)	0.103 (0.092-0.115)	0.099 (0.088-0.111)
LC50 (response b)	0.051 (0.049-0.053)	-	-
LC50 (response c)	0.052 (0.050-0.055)	-	-
LC(I)50 (response b)	0.063 (0.061-0.065)	0.066 (0.064-0.068)	0.081 (0.075-0.087)
LC(I)50 (response c)	0.065 (0.063-0.067)	0.098 (0.084-0.114)	0.081 (0.073-0.090)

TABLE 7.8 : 96h LC50's AND LC50's FOR AMMONIA AND COPPER IN P. jenkinsi

was used as a criterion (Table 7.8). Most of the differences between different ages in 48h and 96h LC50's, LC(I)50's, EC50's and EC(I)50's were significantly different at the 5% level (Table 7.9). Notable exceptions to this were the 48h EC50's towards $N\text{-}NH_3$ for juvenile and senescent snails and, the 96h EC(I)50's (response B) towards copper for juvenile and prime adult snails. This emphasises the general trend that the difference between EC50's and EC(I)50's for different ages was less than the LC50's and LC(I)50's because effective and lethal concentrations were similar in juvenile snails.

Juvenile snails were also observed to be less tolerant than adults by Wurtz (1962) testing the toxicity of zinc to Physa heterostropha and Wier and Walter (1976) testing the toxicity of cadmium to Physa gyrina. It has been observed several times that juvenile invertebrates or earlier instars of insects are less tolerant than older individuals (Dowden and Bennett, 1965; Sanders, 1969, 1972; Arthur, 1975). Levels of copper of a similar order to those found to be toxic in these experiments have also been found to be toxic in static tests on P. jenkinsi by Extence (1978a) and Brown (1980). Extence (1978a) obtained a 96h LC50 for adult snails of $0.07mgl^{-1}$ and Brown (1980) found $0.05mgl^{-1}$ to be lethal. It appears that P. jenkinsi is much less tolerant to copper than most invertebrate taxa (see Murphy, 1978; Spear and Pierce, 1979) and therefore may well have value as a biological indicator of this method. In addition, P. jenkinsi could well have value as an indicator of ammonia. The LC50's of all age groups in these experiments were lower than the levels of undissociated ammonia required to kill 50% of any of the range of insect and crustacean taxa in the tests performed by Davies (1971). He found Gammarus pulex to be the least tolerant organism tested; it required $1.5mgl^{-1}$ unionised $N\text{-}NH_3$ to kill 50% in 96h at $18^{o}C$. The LC50 for prime adult P. jenkinsi, the most tolerant age group was about half of this.

The levels of unionised ammonia found to be toxic in these experiments are less than those that could have been present at Acton Bridge (R. Weaver) and Doncaster (R. Don) where up to $2.22mgl^{-1}$ and $0.39mgl^{-1}$ unionised $N\text{-}NH_3$ could have been present if the maximum total $N\text{-}NH_3$ and pH coincided. Consequently ammonia could account for the absence of P. jenkinsi from these sites. However high metal levels were also present at both these sites (Table 9.6d). In

TOXICANT/AGE GPS.	LC50[a]		LC50[a] (response b)		LC50[a] (response c)	
	x	1.96 S.E.	x	1.96 S.D.	x	1.96 S.E.
$\underline{H\text{-}H_3}$						
48h juvenile v prime	3.48*	1.18	-	-	2.25*	1.20
48h juvenile v senesc.	1.54*	1.18	-	-	1.01	1.14
48h prime v senescent	2.25*	1.22	-	-	2.23*	1.21
96h prime v senescent	1.73*	1.21	-	-	1.51*	1.18
Cu						
96h juvenile v prime	1.54*	1.13	1.05	1.05	1.51*	1.16
96h juvenile v senesc.	1.48*	1.12	1.29*	1.09	1.25*	1.12
96h prime v senescent	1.04	1.17	1.23*	1.09	1.21*	1.20

a = LC(I)50 or EC(I)50 for copper

x = $\frac{\text{greater LC50}}{\text{smaller LC50}}$

TABLE 7.9 : SIGNIFICANT DIFFERENCES BETWEEN LC50's AND LC50's OF DIFFERENT AGES OF P. jenkinsi AT THE 5% LEVEL.

particular, the total copper levels of $0.08mgl^{-1}$ and $0.077mgl^{-1}$ recorded at these two sites respectively were found to be toxic in the laboratory experiments. The level of $0.06mgl^{-1}$ total Cu recorded at Warrington (R. Mersey) is also very close to the 96h LC50 for juvenile P. jenkinsi recorded above, yet this species was recovered from the site (Table 5.2). This illustrates the problem of applying laboratory data to the field, it is usually found that levels found to be toxic in the laboratory are much lower than in the field. The effects of a natural substratum, suspended solids and interactions between toxicants are no doubt involved. It is relevant to discussions of the reasons for the absence of most species of gastropod from Acton Bridge (R. Weaver) and Doncaster (R. Don) that, in a further series of experiments not reported here, copper and ammonia were found to be antagonistic towards one another.

7.4 Conclusions

1. P. jenkinsi was, compared to other inverterbate taxa, found to be relatively intolerant of unionised ammonia and copper. Therefore it has potential as a biological indicator of these toxicants.

2. Tolerance towards both ammonia and copper increased juvenile snails<senescent adults<prime adults. Juvenile snails had LC50's and LC(I)50's about half those of prime adults.

3. If laboratory data can be applied to the situation in the field with any degree of certainty either ammonia or copper could account for the absence of P. jenkinsi from Acton Bridge (R. Weaver) or Doncaster (R. Don).

APPENDIX

ANNEXE 1 Raw Biological Data (tables 8.1 - 8.25).

IMMERSION PERIOD (d) →	7			14			28			42			56			70		
↓TAXON REPLICATE →	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Corophium curvispinum	83	284	105	308	156	292	636	792	756	904	812	828	1152	964	1200	1516	1760	1328
Crangonyx pseudogracilis													1					
Gammarus pulex		1	3		4	2		12	1						2			
G. tigrinus																	1	1
Baetis rhodani					1													
Caenis moesta				1			1											
Hydropsyche pellucidula			1															
Leptoceridae						1												
Polycentropus flavomaculatus									1		1						2	
Agrion splendens								1		2	1			1	2	2	4	2
Chironomini (excl C.r)(L)	4	2	1	18	5	11	17	5	5	9	12	11	11	11	10	17	34	20
Orthocladiinae (L)	1		6	6	2	4	4	6	4	1	3	4		11	4	11		
Tanypodinae (L)	3	1		6	3	3		5	1		2		3	1	5	1	2	
Chironomidae (P)							2			1		1						
Simulium sp.									1									
Lymnaea peregra					2		5	3	5	12	10	15	22	7	14	7	7	9
Bithynia tentaculata				2	2		11	7	15	15	10	7	32	28	43	42	14	30
Potamopyrgus jenkinsi			1	7	32	24	29	42	37	23	8	18	33	55	72	23	2	28
Theodoxus fluviatilis		2		3	3		15	3	11	20	12	13	28	27	30	23	17	34
Viviparus viviparus				4	2	3	3	1		1			7	2		1	2	
Pisidium spp.			1	11			6		8	11			3	3	4	13	2	15
Piscicola geometra		1															2	
Oligochaeta				15	1	1				1	6		3	3				
Polycelis tenuis														1				

TABLE 8.1 : NUMBERS OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED ON SINGLE S.AUF.U. AT SAXONS LODE DURING THE FIRST RUN OF THE IMMERSION PERIOD EXPERIMENT (9TH AUGUST - 18TH OCTOBER 1979)

IMMERSION PERIOD (d) →	7			14			21			28			35			42			49		
TAXON REPLICATE →	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Asellus aquaticus												2	1							1	
Corophium curvispinum	1	2	1	2	3	4	5	4	3	9	6	12	15	83	187	352	608	352	804	832	468
Crangonyx pseudogracilis									1												
Gammarus pulex	1			1	1	1				3	1	5	7	2	2	3	1	1	1		1
G. tigrinus	1	12	2	6	5	4	6	12	5	8	10	5	4	6	41	2	6	24	4	3	23
Isoperla grammatica																1					
Baetis rhodani			3	6	2	4		5	3	1	3	1	4			2	1				
Caenis moesta												1	1			4	8	2	4	2	10
Ephemerella ignita							1	12	4	123	70	115	218	60	59	104	62	57	52	58	24
Heptagenia sulphurea				1					1				1		1						
Limnephilidae													2	1	1	1		1			
Polycentropus flavomaculatus	1				3				2		1				2						
Agrion splendens				1			1	1	2		1	1		1	1		3	2	2		
Brychius elevatus								1													
Haliplus sp.							1														
Chironomini (excl G.r)(L)				1						2	3	1	2	1	1	94	140	220	42	50	388
Tanytarsini (L)				1				3	2	2		17	31	145	282	160	92	56	71	36	
Diamesinae (L)																19	4				
Orthocladiinae (L)	872	412	864	336	616	680	91	58	107	133	204	51	48	37	19	180	68	52	89	20	12
Tanypodinae (L)			1	2			1			4	6	8	9	1	5			8	5	16	4
Chironomidae (P)	1	1		10	13	16	3	5	16	3	4	1	2	1	1	4	1	2	7	3	2
Simulium spp.	3	1	3	5	2	1	1	4	13												
Lymnaea auricularia																				1	
L. peregra							1			3	1			1			1	4	1	87	4
Bithynia tentaculata				2		2			2	5	2	2	7		3	6	10	4	3	12	18
Potamopyrgus jenkinsi			1	2	1	1	2	1			1	3		1	5	12	10	10	3	26	24
Theodoxus fluviatilis	1							1		2	2	1	13	4	3	4	16	16	8	12	26
Valvata piscinalis					1																
Viviparus viviparus									4					1	2	1	6	3	2	1	6
Pisidium spp.												1	1	1							
Piscicola geometra									2		2		1								
Oligochaeta				2			1	1	1	1											
Polycelis tenuis							1	1			1										

TABLE 8.2 : NUMBERS OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED ON SINGLE S.AUF.U. AT SAXONS LODE DURING THE SECOND RUN OF THE IMMERSION PERIOD EXPERIMENT (24TH APRIL - 12TH JUNE 1980)

IMMERSION PERIOD (d) →	7			14			21			28		
TAXON ↓ REPLICATE →	1	2	3	1	2	3	1	2	3	1	2	3
Asellus aquaticus	1		2	2	2		9	9	6	7	1	
Corophium curvispinum	22	25	13	75	24	34	33	16	20	37	58	54
Crangonyx pseudogracilis			4		4		1	1	2	7		
Gammarus pulex					1		2		1			
Baetis rhodani			1	3	2							
Caenis moesta	1	3	8	1	5	11	16	20	11	15	6	9
Limnephilidae		1	1	1			1	2		3	3	3
Polycentropus flavomaculatus	1	1	1	2			5	7	6	8	2	9
Coenagrion puella		3		5	2	6	2	2	3	3	7	5
Potamonectes depressus elegans										1	1	
Tanytarsini (L)	9	6	2	3	9	10	21	3	5	15	22	5
Diamesinae (L)											1	
Orthocladiinae (L)		1		23	6	6	1	13	5	28	14	11
Tanypodinae (L)				2	2	1	1	2	3	1	1	
Chironomidae (P)				2	2		5	2	1	3	3	3
Lymnaea peregra										1		1
Physa fontinalis			2								1	
Bithynia tentaculata	1		4		2		3	2	1			4
Potamopyrgus jenkinsi						1		1		1		
Theodoxus fluviatilis								1			1	2
Viviparus viviparus												1
Pisidium spp.			1			1					2	1
Erpobdella octoculata								1	1			
Helodella stagnalis					1							
Piscicola geometra									1	1	2	
Oligochaeta					2		1			4	9	2
Polycelis tenuis				2			1	1	1		1	1

TABLE 8.3 : NUMBER OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED ON SINGLE S.AUF.U. AT GT. CONBERTON (R. AVON) DURING THE IMMERSION PERIOD EXPERIMENT (24TH APRIL - 22ND MAY 1980).

REMOVAL DATE →	8.5			5.6			2.7		
↓TAXON: REPLICATE →	1	2	3	1	2	3	1	2	3
Asellus aquaticus							1	2	2
Corophium curvispinum	11	35	110	17	10	20	96	94	260
Gammarus pulex	1			1	1				
G. tigrinus		4		1	2	2	1	10	
Isoperla grammatica	1								
Caetis rhodani	3		1	1	1	2			
Caenis moesta							16	5	
Ephemerella ignita				78	61	50	2	1	9
Limnephilidae						1			
Polycentropus flavomaculatus			1						
Agrion splendens	1	1	1			1	2	2	1
Chironomini (L)	[illegible]	[illegible]	4	16	16	24	235	279	35
Tanytarsini (L)		4	40	16	8	16			1
Orthocladiinae (L)	520	284	252	408	256	196			3
Tanypodinae (L)	4		20		4		11	8	3
Chironomidae (P)	33	26	10	1		3	3	1	1
Simulium spp.	14	13	1						
Lymnaea auricularia				1					
L. peregra			5	6	2	1	16	17	5
Physa fontinalis	2	3	5	17		1	7	7	7
Bithynia tentaculata		1	9	7	2	12	18	12	26
Potamopyrgus jenkinsi	4	3	7	2	2	15	20	18	24
Theodoxus fluviatilis		4	9		2	2	7	4	12
Viviparus viviparus							5	2	6
Pisidium spp.						2	9	7	
Unio spp.								1	
Erpobdella octoculata	1								
Glossiphonia complanata	2								
Helobdella stagnalis								2	
Piscicola geometra					1	3	1	1	
Oligochaeta	1	9	22			3			
Polycelis tenuis			13			2	5	2	

TABLE 8.4 : NUMBERS OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED ON SINGLE S.A.U.P.U. INTEGRATED FOR 28 DAYS DURING THE SECOND RUN OF THE IMMERSION PERIOD EXPERIMENT AT SALMONS LODGE.

IMMERSION (days) / BLOCK →	Total Taxa			New Taxa			Recurring Taxa			Eliminated Taxa			Colonisation Rate (taxa d^{-1})			Extinction Rate (taxa d^{-1})		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
(a)																		
7	4	6	7	4	6	7	0	0	0	0	0	0	0.57	0.86	1.00	0.00	0.00	0.00
14	11	12	9	7	7	4	0	0	0	0	1	2	1.00	1.00	0.57	0.00	0.14	0.29
28	10	11	13	1	1	5	0	0	1	4	2	2	0.14	0.14	0.86	0.29	0.29	0.29
42	11	11	7	1	1	0	1	1	0	1	2	6	0.29	0.29	0.00	0.14	0.29	0.86
56	11	13	11	1	2	1	1	1	3	2	1	0	0.29	0.43	0.57	0.29	0.14	0.00
70	11	13	10	0	1	1	2	2	1	2	3	3	0.29	0.43	0.29	0.29	0.43	0.43
(b)																		
7	7	4	7	7	4	7	0	0	0	0	0	0	1.00	0.57	1.00	0.00	0.00	0.00
14	14	9	8	9	5	2	0	0	0	2	0	1	1.29	0.71	0.29	0.29	0.00	0.14
21	12	13	15	4	6	9	0	0	0	6	2	2	0.57	0.86	0.29	0.86	0.29	0.29
28	13	16	16	0	5	4	6	2	4	5	4	7	0.86	1.00	1.14	0.71	0.57	1.00
35	17	15	16	4	3	1	2	1	3	2	5	4	0.86	0.57	0.57	0.29	0.71	0.57
42	16	16	16	3	2	1	1	2	1	5	3	2	0.57	0.57	0.29	0.71	0.43	0.29
49	16	16	14	0	2	1	4	2	0	4	4	3	0.57	0.57	0.14	0.57	0.57	0.43

TABLE 8.5 : COLONISATION AND EXTINCTION OF TAXA WITH IMMERSION PERIOD FOR S.AUF.U. AT SAXONS LODE (a) SUMMER/AUTUMN 1979 AND (b) SPRING/SUMMER 1980

TAXON ↓ / SITE → / REPLICATE →	Upper Bewdley 1	2	3	Tot	Middle Bewdley 1	2	3	Tot	Ribbesford 1	2	3	Tot
Corophium curvispinum		1	4	5	7	1	3	11		4		4
Gammarus pulex	4	6	28	38	8	27	57	171	77	20	3	100
Baetis rhodani	5	8	44	55		6		6	1		2	3
Ephemera danica			1	1					2		1	3
Ephemerella ignita	1		4	5						1		1
Heptagenia sulphurea	1	3	2	6			1	1		1	2	3
Hydropsychidae	1	4	8	13	4	13	17	34	2	8	34	44
Hydroptilidae					1		1	2				
Polycentropus flavomaculatus									1			1
Brychius elevatus (L)			2	2								
Gyrinus spp. (L)											1	1
Hydroporus spp. (L)		1		1								
Limnius volckmari (L)		4	1	5	1		2	3	1			1
Aphelocheirus montandoni					3	1	3	7	1			1
Atherix spp.	1	6	15	22	1	2	10	13	1			1
Chironomini (excl C.rip)(L)			4	4								
Tanytarsini (L)		1		1								
Orthocladiinae (L)	30	25	212	267	31	6	15	52	54	23	82	159
Tanypodinae (L)										1		1
Chironomidae (P)	3		6	9	1			1			2	2
Simulium spp.	1		1	2							1	1
Dicranota spp.	1		1	2	4	1		5	2		5	7
Tipulidae (excl. Dicranota)	1	1	6	8								
Ancylus fluviatilis									1			1
Limnaea peregra		1		1			1	1				
Potamopyrgus jenkinsi					1			1	2			2
Sphaeridae	2	1	1	4	5	7	4	16	5			5
Erpobdella octoculata		1	1	2	2	1	5	8	1		1	2
Glossiphonia complanata					2	1	1	4		1		1
Helobdella stagnalis			3	3		1		1	1	1	1	3
Oligochaeta	22	18	30	70	20	19	39	78	33	5		38
Polycelis tenuis			1	1							1	1

TABLE 8.6 : ABUNDANCE OF DIFFERENT TAXA COLLECTED IN 0.05m^2 CYLINDER SAMPLES IN THE LAST FEW RIFFLES OF THE R. SEVERN AUGUST/ SEPTEMBER 1979

SITE → / TAXON ↓ REPLICATE →	Upper Bewdley				Middle Bewdley				Ribbesford			
	1	2	3	Tot	1	2	3	Tot	1	2	3	Tot
Corophium curvispinum	3	1	2	6	1	5	7	13	3	2	17	22
Gammarus pulex	67	67	39	173	222	420	208	850	40	34	83	157
Isoperla grammatica	1			1								
Baetis rhodani	74	56	22	152	6	7	20	33		17		17
Caenis moesta	1			1								
Leptophlebia dispar	1			1								
Ephemera danica	1		1	2					1			8
Ephemerella ignita	20	15	12	47		1		1			1	1
Heptagenia sulphurea	6	7	3	16	6	1	5	12		1		1
Hydropsychidae	6	7	6	19	50	14	36	100	10	19	6	35
Hydroptilidae						1		1				
Psychomyia pusilla									11	39	6	56
Gyrinus spp. (L)									1			1
Hydroporus spp. (L)			1	1								
Limnius volckmari (L)	9	1	8	18	11	16	11	38	4	12		16
Aphelocheirus montandoni	2			2	7	2	24	33	5	3		8
Atherix spp.	14	2	24	40	13	6	20	39	9	7	6	22
Chironomini (excl C.rip)(L)	8		1	9							1	1
Tanytarsini (L)		1		1					3			3
Orthocladiinae (L)	24	3	1	28	4	13	7	24	57	24	35	116
Tanypodinae (L)					1			1	1			1
Chironomidae (P)					2			2	10	4	1	15
Simulium spp.		1		1	9		2	11				
Dicranota spp.		2		2	1			1	21	2	5	28
Tipulidae (excl. Dicranota)	54	16	4	74								
Diptera (L)									2		2	4
Ancylus fluviatilis	2		4	6	1			1	1	2		3
Lymnaea peregra	7	3	3	13	2		1	3		1		1
Bithynia tentaculata					3		1	4				
Potamopyrgus jenkinsi	1		19	20								
Sphaeridae	2		7	9	57	6	21	64	10	5	5	20
Erpobdella octoculata	5		9	14		3	2	5				
Glossiphonia complanata	1		1	2	1	3	3	7			2	2
Helobdella stagnalis		1	2	3		1		1			2	2
Oligochaeta	51	106	69	226	13	12	24	49	1		31	32
Polycelis tenuis	4			4	2	2	5	9	2		2	4

TABLE 8.7 : ABUNDANCE OF DIFFERENT TAXA COLLECTED IN 30 SEC. MEEL-KICK SAMPLES IN THE LAST FEW RIFFLES OF THE R. SEVERN AUGUST/SEPTEMBER 1979

SITE →	UPPER BEWDLEY				MIDDLE BEWDLEY				RIBBESFORD				STOURPORT				SAXONS LODE			
TAXON REPLICATE	1	2	3	Tot	1	2	3	Tot	1	2	3	Tot	1	2	3	Tot	1	2	3	Tot
Asellus aquaticus					9	37	4	50					2							
Corophium curvispinum	156	10	47	213	53	53	36	284	10	6	74	90	480	1203	576	2259	636	792	756	2184
Gammarus pulex	9	8	27	44	15	2	5	22	30	15	239	284	2	2	18	22		12	1	13
Baetis rhodani			1	1	1			1												
Caenis moesta																	1			1
Cloeon dipterum	1			1																
Ephemera danica														1		1				
Ephemerella ignita			1	1																
Heptagenia sulphurea										1		1								
Hydropsychidae		1	12	13		1		1		1		1								
Leptoceridae	11	2		13		5		5												
Limnephilidae									2			2		3		3				
Polycentropus flavomaculatus		1	2	3			2	2											1	1
Agrion splendens		1	4	5			1	1			2	2	1		2	3		1		1
Brychius elevatus (A)					6			6												
Gyrinus sp. (L)		1		1					1	1		2								
Limnius volckmari (A)					1			1												
Oulimnius tuberculatus (A)											1	1								
Potamonectes depressus elegans (A)	1	3		4							1	1								
Aphelocheirus montandoni			1	1																
Sialis fuluginosa			1	1		3		3												
Atherix sp.	2			2																
Chironomini (excl C.rip) (L)		5	1	6	1			1					1	6		7	17	5	5	27
Tanytarsini (L)		4	2	6					1	1		2			1	1				
Orthocladiinae (L)	4	28	2	34	5	5		10	1	5		6	2	1		3	4	6	4	14
Tanypodinae (L)		1	4	5	1	4	1	6										5	1	6
Chironomidae (P)		3	1	4					1	2		3					2			2
Simulium sp.																			1	1
Lymnaea peregra	2		2	4	3		1	4	6	4		10	3	1		4	5	3	5	13
Segmentina complanata					2	1	1	4												
Bithynia tentaculata	8		1	9	17	9	1	27	3		1	4		1		1	11	7	15	33
Potamopyrgus jenkinsi	14		1	15					1		1	2	6	4	5	15	29	42	37	108
Theodoxus fluviatilis													10	4	8	22	15	3	11	29
Viviparus viviparus			8	8		1		1			1	1	2	4	2	8	3	1		4
Anodonta sp.		1		1										1		1				
Pisidium spp.																	6		8	14
Sphaerium spp.	5	3		8	2	2		4							1	1				
Erpobdella octoculata	3		1	4		4		4		2	1	3								
Glossiphonia complanata		4		4		6	3	9			4	4		1		1				
Helobdella stagnalis		1		1		2		2												
Piscicola geometra													2			2				
Oligochaeta	6	4		10	1	47	2	50	3	5	1	9		1		1			2	2
Tricladida	3	7	5	15	13	106	4	123	8	6	14	28	7	28		35				

TABLE 8.8 : ABUNDANCE OF DIFFERENT TAXA COLLECTED ON 7 AUG.U. BELOW THE LAST FEW RIFFLES OF THE R. SEVERN AND FURTHER DOWNSTREAM

SAMPLING METHOD →	0.05m² Cylinder				30sec. Heel-Kick			
↓TAXON . REPLICATE →	1	2	3	Tot	1	2	3	Tot
Asellus aquaticus	1			1			1	1
Corophium curvispinum	1	1		2		1	1	2
Gammarus pulex	7	33	41	81	6	16	8	30
Baetis rhodani	9	5	8	22	49	14	7	70
Caenis moesta	26	64	29	119	2	54	47	103
Ephemera danica	1	1	1	3	1	3		4
Ephemerella ignita	65	126	116	307	216	181	103	500
Chematopsyche lepida	16	9	5	30		11	1	12
Hydropsyche contubernalis	1	1	4	6	1			1
H. pellucidula	3	3	6	12		3	2	5
Polycentropus flavo-maculatus		1		1				
Psychomyia pusilla	3			3	3	2		5
Elmis aenea (L)		1		1				
Limnius volckmari (L)	2	7		9		3	2	5
Potamonectes depressus elegans (A)		1	1	2				
Aphelocheirus montandoni					5	5	1	11
Atherix spp.						1		
Chironomini (excl C.rip)(L)	10	10	1	21		1	1	2
Tanytarsini (L)	3	1		4			1	1
Orthocladiinae (L)	15	7	13	35	52	3	7	62
Tanypodinae (L)	2	2	2	6				
Chironomidae (P)	1		1	2	3		2	5
Empididae		6	5	11		1		1
Simulium spp.	1			1			1	1
Diptera (L)	1	3	2	6	29	3	7	39
Segmentina complanata			1	1				
Bithynia tentaculata		1		1				
Anodonta spp.		1		1				
Pisidium spp.		4	1	5		1		1
Erpobdella octoculata		1		1				
Glossiphonia complanata						1		1
Oligochaeta	12	18	5	35	1	15	10	26
Dugesia lugubris		1	2	3				
Polycelis tenuis							1	1

TABLE **8.9** : NUMBERS OF INDIVIDUALS OF DIFFERENT TAXA COLLECTED FROM THE LOWLAND RIFFLE OF THE R. SEVERN ON 23.5.80

TAXON \ DISTANCE BELOW LOWERMOST RIFFLE — REPLICATE	100m.				200m.				400m.				800m.				1600m.			
	1	2	3	Tot	1	2	3	Tot	1	2	3	Tot	1	2	3	Tot	1	2	3	Tot
Asellus aquaticus	1		1	2		8	1	9	2	4	1	7		10	2	12	3			3
Gammarus tigrinus	416	896	388	1700	260	268	188	716	1716	600	1924	4240	1000	604	556	2160	210	584	280	1074
Gammarus pulex	7	32	31	70	70	60	152	282	56	14	110	190	1		208	209	9	60	9	78
Baetis rhodani							3				1	1					1			1
Caenis moesta	15	2	2	19	1	4	23	28	1	5	7	13	5	1		6		8		8
Ephemera danica														1		1				
Ephemerella ignita	8	3	4	15	6	12	31	49	6	3	16	25	4	4	21	29	1	1	3	5
Hydropsyche contubernalis					2		4	6			1	1								
H. pellucidula			1	1	2		11	13			3	3						1		1
Leptoceridae						1		1						2	2	4				
Limnephilidae			1	1		1	2	3	1	1	2	4	1	1	3	5		1		1
Polycentropus flavomaculatus	3	3	3	9	5	6	3	14	6		2	8		2	1	3	1	10	4	15
Agrion splendens	17	5	12	34			2	2	8	3	6	17		3	1	4	1	6	2	9
Platycnemis pennipes										1		1								
Gyrinus spp. (L)			1	1			1	1			1	1								
Haliplus spp. (L)					1	2	2	5												
Potamonectes depressus elevatus (A)									1			1	1			1				
Aphelocheirus tantulonii									1			1	1			1				
Chironomini (excl. Orth.) (L)	10	10	23	43	2	1	7	10	7	13	16	36	1	4	1	6		3	2	5
Tanytarsini (L)	17	6	10	33	5	10	8	23	1			1	1	3	3	7	1	1	2	4
Diamesinae (L)			3	3							1	1								
Orthocladiinae (L)	7	3	9	19		4	3	7	3		3	6	1	1	1	3				
Tanypodinae (L)	3	3	5	11	14	23	24	61	1	2	4	7	2	7	1	10		1	3	4
Chironomidae (P)	3		4	7			1	1			1	1		1	1	2		1		1
Diptera (L)	1			1						1		1								
Lymnaea peregra	5	2	3	10			1	1		1	3	4	4	2	6	12	3	5	13	26
Physa fontinalis																	90	51	28	169
Gyraulus complanata			1	1			1	1	1		2	3			2	2				
Bithynia tentaculata	15	7	11	33	8	21	18	47	6	10		16	28	33	4	65	212	7	22	241
Potamopyrgus jenkinsi		2	1	3		1	5	6	1			1	4			4	8			8
Theodoxus fluviatilis										1		1	31	25	6	62	2	2	1	5
Viviparus viviparus	23	22	31	76	83	13	14	110	35	11	13	59	44	70	8	122	30	7	9	46
Sphaeridae	32	10	3	45	20	5	10	35	5	29	7	42	29	41	2	72	22			22
Batracobdella paludosa		1		1						1		1								
Erpobdella octoculata	2	1	4	7	2		2	4	1	3	3	7	3			3				
Glossiphonia complanata	6	4	3	13	1	2		3	1	1		2	1	2	1	4				
Helobdella stagnalis							1	1		2	1	3	1	7		8			1	1
Hemiclepsis marginata										1	1	2			1	1				
Oligochaeta	1		3	4		1	3	4		18		18	135	3	2	140	1	2	1	4
Dendrocoelum lacteum	3	1	8	12	7	7	11	25		7	1	8	11	23		34	11	2		13
Dugesia polychroa	2	1		3			5	5	3	2		5	5	19		24	10		1	11
Polycelis tenuis	17	14	18	49	10	14	16	40	10	6	6	22	18	19	3	40	10	14	6	30

TABLE 8.10 : ABUNDANCE OF DIFFERENT TAXA ON S.AUP.U. BELOW THE LOWERMOST RIFFLE IN THE R. SEVERN ON 8.7.80

SAMPLING DATE	CHAN.	n	REGRESSION LINE	
			L. peregra	P. jenkinsi
26.6.79[a]	A	100	log w=0.0667h+1.0073 (r^2 = 0.98)	
	B	212	log w=0.0910h+0.6535 (r^2 = 0.99)	
	C	256	log w=0.0951h+0.5970 (r^2 = 0.99)	
10.7.79	A	694		log w=0.2864h-0.7210 (r^2 = 1.00)
11.9.79[b]	A	50	log w=0.2480h-0.4927 (r^2 = 0.97)	
	B	93	log w=0.2669h-0.6717 (r^2 = 0.95)	
	C	50	log w=0.2580h-0.7436 (r^2 = 0.95)	
18.9.79	A	386		log w=0.2270h-0.4446 (r^2 = 1.00)

a = old cohort
b = young cohort
n = no. of snails on which regression based

TABLE 8.11 : REGRESSION LINES OF LOG INDIVIDUAL WEIGHT (w) - HEIGHT (h) USED FOR CALCULATING BIOMASS OF SNAILS COLLECTED ON S.AUF.U. IN THE CHECKLEY CHANNELS MAY - JULY 1979

L. peregra were collected in six 0.1m^2 "Aston" cylinder samples from the lower riffle of each channel. Additional snails were collected from channel A by hand. P. jenkinsi were collected in three 0.1m^2 cylinder samples from the upper pool of channel A. Snails were divided into 1mm. size classes for the calculation of regression lines except for L. peregra on 26.6.79 where 2mm. size classes were used.

DATE ↓ REPLICATE →	NUMBER / SAMPLE								
	1			2			3		
COHORT →	1	2	3	1	2	3	1	2	3
Lower Riffle [a]									
17.1.79 [b]		5			2			0	
18.2 [b]		0			0			0	
14.3 [b]		0			0			1	
19.4 [b]		0			2			1	
21.5 [b]		28			1			0	
21.6	6	0	0	0	2	0	5	0	0
24.7	0	0	0	0	0	0	0	1	0
30.8	0	6	0	0	0	0	0	0	0
27.9	0	1	0	0	0	0	0	0	0
6.11	0	0	0	0	0	0	0	0	0
27.11	0	0	0	0	0	0	0	0	0
15.1.80	0	0	0	0	0	0	0	0	0
21.2	0	1	0	0	0	0	0	0	0
17.3	0	0	0	0	0	0	0	0	0
22.4	0	1	0	0	0	0	0	17	0
20.5	0	2	0	0	0	0	0	22	0
23.6	0	7	1	0	0	0	0	1	0
Upper Pool [b]									
9.10.79	0	0	0	0	7	0	0	17	0
4.12	0	18	0	0	15	0	0	0	0
29.1.80	0	5	0	0	5	0	0	3	0
25.3	0	12	0	0	18	0	0	0	0
20.5	0	2	0	0	0	0	0	2	0
23.7	0	0	0	0	3	1	0	2	0
8.9	0	0	1	0	0	28	0	0	0

S.Auf.U.	Upper Pool		Lower Pool	
17.4.79	22	0	2	0
15.5	7	0	0	0
12.6	1	0	0	0
10.7	1	6	0	0
7.8	0	82	0	2
4.9	0	106	0	3
2.10	0	11	0	1
30.10	0	13	0	2
27.11	0	19	0	5
3.1.80	0	26	0	6
29.1	0	271	0	3
26.2	0	47	0	4
25.3	0	61	0	1

TABLE 8.12a : CHANNEL A

TABLES 8.12a-c : NUMBERS OF L. peregra COLLECTED IN CYLINDER SAMPLES (a = 0.05m^2, b = 0.1m^2) AND ON S.AUF.U. IN THE CHECKLEY CHANNELS

DATE ↓ REPLICATE →	NUMBER / SAMPLE								
	1			2			3		
COHORT →	1	2	3	1	2	3	1	2	3
Lower Riffle [a]									
17.1.79 [b]		6			85			8	
18.2 [b]		7			9			9	
14.3 [b]		0			9			5	
19.4 [b]		80			60			32	
21.5 [b]		34			140			6	
21.6	20	29	0	36	28	0	9	35	0
24.7	1	56	0	0	48	0	1	46	0
30.8	0	53	0	0	66	0	0	57	0
27.9	0	23	0	0	9	0	0	15	0
6.11	0	20	0	0	13	0	0	1	0
27.11	0	1	0	0	11	0	0	1	0
15.1.80	0	3	0	0	6	0	0	6	0
21.2	0	1	0	0	5	0	0	1	0
17.3	0	2	0	0	3	0	0	5	0
22.4	0	7	0	0	9	0	0	1	0
20.5	0	0	0	0	2	0	0	0	0
23.6	0	21	15	0	3	2	0	3	1
Upper Pool [b]									
9.10.79	0	8	0	0	1	0	0	1	0
4.12	0	3	0	0	5	0	0	2	0
29.1.80	0	4	0	0	2	0	0	3	0
25.3	0	6	0	0	3	0	0	2	0
20.5	0	17	0	0	95	0	0	9	0
23.7	0	7	31	0	19	1	0	1	39
8.9	0	0	8	0	0	28	0	0	60
S.Auf.U.	Upper Pool			Lower Pool					
17.4.79	17	0		22	0				
15.5	16	0		1	0				
12.6	23	0		9	0				
10.7	0	0		1	0				
7.8	0	38		0	10				
4.9	0	59		0	4				
2.10	0	72		0	6				
30.10	0	218		0	0				
27.11	0	116		0	2				
3.1.80	0	40		0	3				
29.1	0	11		0	1				
26.2	0	60		0	12				
25.3	0	229		0	51				

TABLE 8.12b : CHANNEL B

DATE ↓	REPLICATE →	NUMBER / SAMPLE								
		1			2			3		
	COHORT →	1	2	3	1	2	3	1	2	3
Lower Riffle[a]										
17.1.79[b]			36			40			48	
18.2[b]			6			19			88	
14.3[b]			14			12			62	
19.4[b]			152			136			75	
21.5[b]			149			182			115	
21.6		44	2	0	123	0	0	32	0	0
24.7		7	6	0	5	17	0	17	21	0
30.8		0	23	0	0	2	0	0	17	0
27.9		0	46	0	0	10	0	0	22	0
6.11		0	16	0	0	1	0	0	1	0
27.11		0	28	0	0	23	0	0	16	0
15.1.80		0	5	0	0	3	0	0	4	0
21.2		0	21	0	0	3	0	0	14	0
17.3		0	1	0	0	16	0	0	32	0
22.4		0	3	0	0	11	0	0	1	0
20.5		0	32	0	0	31	0	0	51	0
23.6		0	92	6	0	7	0	0	10	8
Upper Pool[b]										
9.10.79		0	10	0	0	15	0	0	23	0
4.12		0	10	0	0	12	0	0	1	0
29.1.80		0	12	0	0	5	0	0	37	0
25.3		0	23	0	0	4	0	0	0	0
20.5		0	14	0	0	2	0	0	89	0
23.7		0	15	0	0	0	0	0	3	0
8.9		0	0	0	0	0	5	0	0	30
S.Auf.U.		Upper Pool			Lower Pool					
17.4.79		39	0		2	0				
15.5		13	0		2	0				
12.6		17	0		8	0				
10.7		1	2		3	1				
7.8		0	3		0	6				
4.9		0	37		0	1				
2.10		0	44		0	3				
30.10		0	9		0	0				
27.11		0	42		0	0				
3.1.80		0	91		0	35				
29.1		0	22		0	6				
26.2		0	4		0	3				
25.3		0	33		0	3				

TABLE 8.12c : CHANNEL C

CHANNEL →	NUMBER / SAMPLE																		
	A									B									C
REPLICATE →	1			2			3			1			2			3			All
DATE ↓ COHORT →	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	All
Lower Riffle[a]																			
17.1.79[b]		39			19			4			0			0			0		0
18.2[b]		1			22			460			0			0			0		0
14.3[b]		14			0			3			0			0			0		0
19.4[b]		0			0			0			0			0			0		0
21.5[b]		2			2			0			0			0			0		0
21.6	360	0	0	484	0	0	388	0	0	2	0	0	0	0	0	0	0	0	0
24.7	328	0	0	392	0	0	76	0	0	1	0	0	0	0	0	0	0	0	0
30.8	201	0	0	96	0	0	306	0	0	8	0	0	0	0	0	0	0	0	0
27.9	52	0	0	78	0	0	19	0	0	5	0	0	0	0	0	0	0	0	0
6.11	50	30	0	92	196	0	135	112	0	12	0	0	3	0	0	0	0	0	0
27.11	24	27	0	105	352	0	72	144	0	0	0	0	6	0	0	0	0	0	0
15.1.80	92	692	0	280	392	0	32	59	0	1	0	0	0	2	0	0	0	0	0
21.2	18	148	0	92	544	0	21	86	0	0	0	0	0	2	0	0	0	0	0
17.3	19	133	0	28	1952	0	8	250	0	1	1	0	0	1	0	1	1	0	0
22.4	0	387	0	0	724	0	0	311	0	0	1	0	0	1	0	0	1	0	1[c]
20.5	0	586	216	0	29	37	0	460	428	0	4	0	0	3	0	0	0	0	0
23.6	0	234	201	0	335	517	0	233	195	0	27	5	0	10	0	0	0	0	3[d]
Upper Pool[b]																			
9.10.79		316			29			61			0			0			5		0
4.12		79			37			54			0			0			0		0
29.1.80		314			37			224			0			1			0		0
25.3		245			116			200			4			3			1		0
20.5		101			392			145			9			4			0		0
23.7		70			411			199			1			0			4		0
8.9		113			99			88			13			1			1		1[e]
S.Auf.U.	Upper Pool			Lower Pool						Upper Pl			Lower Pl						All
17.4.79		33			1						0			0					0
15.5	0	0		0	0					0	0		0	0					0
12.6	0	0		0	0					0	0		0	0					0
10.7	38	0		31	0					0	0		0	0					0
7.8	176	0		1352	0					1	0		0	0					0
4.9	444	0		152	0					0	0		0	0					0
2.10	71	0		308	0					2	0		0	0					0
30.10	49	0		56	0					4	0		0	0					0
27.11	616	616		60	252					2	1		0	0					0
3.1.80	53	256		118	168					1	0		2	0					0
29.1	896	1384		59	52					5	4		0	0					0
26.2	428	436		29	23					1	0		0	0					0
25.3	68	103		15	19					7	3		0	1					0

c = replicate 2, cohort 2 d = replicate 1, cohort 2 e = replicate 3

TABLE 8.13 : NUMBERS OF P. jenkinsi COLLECTED IN CYLINDER SAMPLES (a = 0.05m^2, b = 0.1m^2) AND ON S.AUF.U. IN THE CHECKLEY CHANNELS

DATE → / REPLICATE → / SUBSTRATE ↓	BIOMASS (dry weight mg)								
	1			2			3		
	1	2	3	1	2	3	1	2	3
Lower Riffle [a]									
21.6.79	326.0	0	0	0	1.2	0	220.5	0	0
24.7	0	0	0	0	0	0	0	2.3	0
30.8	0	12.8	0	0	0	0	0	0	0
27.9	0	1.3	0	0	0	0	0	0	0
6.11	0	0	0	0	0	0	0	0	0
27.11	0	0	0	0	0	0	0	0	0
15.1.80	0	0	0	0	0	0	0	0	0
21.2	0	3.7	0	0	0	0	0	0	0
17.3	0	0	0	0	0	0	0	0	0
22.4	0	53.2	0	0	0	0	0	288.3	0
20.5	0	92.9	0	0	0	0	0	306.8	0
23.6	0	147.3	2.4	0	0	0	0	17.8	0
Upper Pool [b]									
9.10.79	0	112.2	0	0	0	0	0	46.2	0
4.12	0	118.3	0	0	162.3	0	0	0	0
29.1.80	0	68.8	0	0	94.2	0	0	37.7	0
25.3	0	225.0	0	0	356.1	0	0	0	0
20.5	0	78.8	0	0	0	0	0	54.4	0
23.7	0	0	0	0	117.7	0.4	0	65.5	0
8.9	0	0	8.4	0	0	269.4	0	0	0
S.Auf.U.	Upper Pool			Lower Pool					
15.5.79	344.4	0		0	0				
12.6	59.5	0		0	0				
10.7	51.0	0		0	0				
7.8	0	106.4		0	3.7				
4.9	0	331.4		0	42.7				
2.10	0	36.5		0	0.9				
30.10	0	61.3		0	41.1				
27.11	0	205.8		0	168,0				
3.1.80	0	340.1		0	21.3				
29.1	0	4861.0		0	59.4				
26.2	0	711.2		0	128.8				
25.3	0	1346.9		0	56.2				

TABLE **8.14a** : CHANNEL A

TABLES **8.14a-c** : BIOMASS OF *L. peregra* COLLECTED IN CYLINDER SAMPLES ($a = 0.05m^2$, $b = 0.1m^2$) AND ON S.AUF.U. IN THE CHECKLEY CHANNELS

DATE	BIOMASS (dry weight mg)								
REPLICATE →	1			2			3		
↓ COHORT	1	2	3	1	2	3	1	2	3
Lower [a] Baffle									
21.6.79	618.6	15.1	0	1150.5	9.3	0	548.6	13.0	0
24.7	61.8	43.9	0	0	69.2	0	33.0	59.5	0
30.8	0	174.8	0	0	76.3	0	0	48.4	0
27.9	0	57.6	0	0	23.2	0	0	35.6	0
6.11	0	53.1	0	0	47.7	0	0	19.3	0
27.11	0	1.0	0	0	39.2	0	0	1.6	0
15.1.80	0	39.1	0	0	50.2	0	0	62.5	0
21.2	0	11.9	0	0	47.0	0	0	5.2	0
17.3	0	18.6	0	0	39.2	0	0	115.5	0
22.4	0	272.8	0	0	223.5	0	0	8.2	0
20.5	0	0	0	0	22.2	0	0	0	0
23.6	0	396.7	9.2	0	44.3	1.0	0	2.3	0.4
Upper [b] Pool									
9.10.79	0	76.2	0	0	2.5	0	0	22.4	0
4.12	0	36.1	0	0	31.1	0	0	3.6	0
29.1.80	0	56.6	0	0	45.1	0	0	45.3	0
25.3	0	114.3	0	0	92.9	0	0	37.5	0
20.5	0	397.2	0	0	232.0	0	0	193.2	0
23.7	0	207.3	215.1	0	467.1	4.6	0	16.7	94.4
8.9	0	0	111.0	0	0	409.7	0	0	857.8

S.Auf.U.	Upper Pool		Lower Pool	
15.5.79	507.3	0	26.7	0
12.6	976.6	0	312.9	0
10.7	0	0	33.0	0
7.8	0	41.0	0	36.2
4.9	0	199.6	0	19.2
2.10	0	587.6	0	27.1
30.10	0	700.1	0	0
27.11	0	1307.8	0	3.0
3.1.80	0	634.7	0	20.2
29.1	0	174,8	0	19.2
26.2	0	1492.0	0	224.7
25.3	0	6326.8	0	648.0

TABLE 8.14b : CHANNEL B

DATE	BIOMASS (dry weight mg)								
REPLICATE →	1			2			3		
COHORT →	1	2	3	1	2	3	1	2	3
Lower [a] Riffle									
21.6.79	1183.9	1.8	0	4442.0	0	0	682.4	1.6	0
24.7	153.0	11.5	0	119.5	30.9	0	493.7	14.5	0
30.8	0	97.5	0	0	4.3	0	0	34.9	0
27.9	0	114.9	0	0	20.3	0	0	13.3	0
6.11	0	96.6	0	0	4.6	0	0	9.9	0
27.11	0	211.6	0	0	170.9	0	0	59.3	0
15.1.80	0	17.3	0	0	90.5	0	0	19.7	0
21.2	0	321.1	0	0	28.3	0	0	180.5	0
17.3	0	9.0	0	0	200.7	0	0	611.5	0
22.4	0	13.4	0	0	245.3	0	0	13.8	0
20.5	0	816.9	0	0	778.7	0	0	996.2	0
23.6	0	1617.4	14.2	0	136.6	0	0	220.4	5.6
Upper [b] Pool									
9.10.79	0	148.0	0	0	77.6	0	0	47.4	0
4.12	0	185.2	0	0	61.0	0	0	85.3	0
29.1.80	0	197.9	0	0	87.3	0	0	693.3	0
25.3	0	303.0	0	0	34.4	0	0	0	0
20.5	0	169.8	0	0	27.6	0	0	2415.9	0
23.7	0	533.4	0	0	0	0	0	97.6	0
8.9	0	0	0	0	0	21.6	0	0	16.2
S.Auf.U.	Upper Pool			Lower Pool					
15.5.79	359.4	0		50.0	0				
12.6	647.0	0		276.3	0				
10.7	49.1	5.2		97.1	0.4				
7.8	0	1.4		0	15.5				
4.9	0	242.0		0	3.0				
2.10	0	230.8		0	3.1				
30.10	0	65.5		0	0				
27.11	0	290.6		0	0				
3.1.80	0	1747.2		0	1040.3				
29.1	0	201.8		0	175.8				
26.2	0	87.8		0	76.9				
25.3	0	592.1		0	57.0				

TABLE 8.14 c : CHANNEL C

D REPLI-CATE → / T E↓ COHORT →	BIOMASS (dry weight mg)								
	1			2			3		
	1	2	3	1	2	3	1	2	3
Lower [a] Riffle									
21.6.79	371.3	0	0	500.7	0	0	291.4	0	0
24.7	522.8	0	0	615.9	0	0	111.6	0	0
30.8	497.6	0	0	158.1	0	0	532.7	0	0
27.9	123.7	0	0	214.9	0	0	52.9	0	0
6.11	103.0	14.9	0	241.8	88.4	0	282.2	70.4	0
27.11	43.1	13.4	0	281.1	228.4	0	192.6	88.4	0
15.1.80	346.0	954.4	0	1019.6	434.8	0	113.3	68.9	0
21.2	56.8	138.4	0	309.1	905.6	0	66.3	85.8	0
17.3	74.4	205.0	0	113.6	2569.1	0	33.4	280.3	0
22.4	0	677.9	0	0	1814.4	0	0	1189.8	0
20.5	0	776.8	52.0	0	42.3	9.6	0	885.6	149.2
23.6	0	587.1	136.5	0	808.6	251.8	0	599.8	125.0
Upper [b] Pool									
9.10.79		1008.2			112.5			244.1	
4.12		90.4			75.7			156.5	
29.1.80		535.1			41.3			504.9	
25.3		717.1			317.3			636.4	
20.5		184.3			497.6			189.3	
23.7		237.1			1329.5			354.6	
8.9		429.4			378.4			280.1	
S.Auf.U.	Upper Pool			Lower Pool					
15.5.79	0	0		0	0				
12.6	0	0		0	0				
10.7	66.5	0		54.3	0				
7.8	492.4	0		4513.6	0				
4.9	1221.2	0		422.6	0				
2.10	231.0	0		1229.6	0				
30.10	146.5	0		193.3	0				
27.11	2675.2	247.2		220.5	101.1				
3.1.80	219.4	130.8		431.3	72.0				
29.1	3917.6	900.8		205.0	92.5				
26.2	1772.4	88.4		314.0	33.8				
25.3	321.4	199.8		68.6	43.2				

TABLE 8.15a : CHANNEL A

TABLES 8.15 a-b : BIOMASS OF *P. jenkinsi* COLLECTED IN CYLINDER SAMPLES (a = 0.05m^2, b = 0.1m^2) AND ON S.AUF.U. IN THE CHECKLEY CHANNELS

DATE	BIOMASS (dry weight mg)									
CHANNEL →	B									C
REPLICATE →	1			2			3			All
COHORT →	1	2	3	1	2	3	1	2	3	All
Lower Riffle [a]										
21.6.79	5.1	0	0	5.0	0	0	0	0	0	0
24.7	3.3	0	0	0	0	0	0	0	0	0
30.8	19.3	0	0	0	0	0	0	0	0	0
27.9	11.2	0	0	0	0	0	0	0	0	0
6.11	21.1	0	0	8.1	0	0	0	0	0	0
27.11	0	0	0	16.6	0	0	0	0	0	0
15.1.80	2.0	0	0	0	3.3	0	0	0	0	0
21.2	0	0	0	0	5.6	0	0	0	0	0
17.3	6.4	1.6	0	0	5.3	0	3.4	3.1	0	0
22.4	0	3.5	0	0	3.3	0	0	5.8	0	1.7[c]
20.5	0	10.0	0	0	11.0	0	0	0	0	0
23.6	0	61.9	3.1	0	23.1	0	0	0	0	16.3[d]
Upper Pool [b]										
9.10.79		0			0			25.9		0
4.12		0			0			0		0
29.1.80		0			1.8			0		0
25.3		12.4			13.9			3.7		0
20.5		15.0			14.1			0		0
23.7		3.1			0			12.7		0
8.9		62.6			4.6			4.0		3.1[e]
C.Auf.U.	Upper Pool			Lower Pool						All
15.5.79	0	0		0	0					0
12.6	0	0		0	0					0
10.7	0	0		0	0					0
7.8	1.2	0		0	0					0
4.9	0	0		0	0					0
2.10	8.8	0		0	0					0
30.10	13.0	0		0	0					0
27.11	8.6	0.5		0	0					0
3.1.80	5.8	0		7.1	0					0
29.1	34.0	8.9		0	0					0
26.2	3.9	0		0	0					0
25.3	40.1	8.7		0	0.5					0

TABLE 8.15 b : CHANNELS B AND C

c = replicate 2, cohort 2
d = replicate 1, cohort 1
e = replicate 3

CHANNEL	SAMPLING DATE	MACRO-PHYTE Bio-mass	L. peregra Pop.	L. peregra Biomass	P. jenkinsi Pop.	P. jenkinsi Biomass
A	21.8.79	17.73	16	0.0570	946	3.0167
		12.30	34	0.0767	219	0.5822
		23.09	33	0.1102	907	2.3295
	9.10.79	17.30	1	0.0075	93	0.2767
		28.24	4	0.0190	65	0.2223
		39.47	13	0.0666	638	2.5131
	6.11.79	16.26	6	0.0525	1856	2.4184
		9.15	3	0.0597	312	0.8434
		17.20	8	0.0582	388	0.3949
B	6.11.79	7.00	16	0.1493	0	0.0000
		10.76	14	0.1417	4	0.0082
		21.42	139	0.6229	8	0.0276

TABLE 8.16 : VARIATION IN SNAIL POPULATIONS (expressed as No. $(0.1m)^{-2}$) AND BIOMASS (g dry weight $(0.1m)^{-2}$) WITH BIOMASS (g dry weight $(0.1m)^{-2}$) OF MACROPHYTES (Potamogeton crispus in channel A, Elodea canadensis in channel B) IN THE CHECKLEY CHANNELS

CHANNEL→	A		B		C	
↓SITE/DATE	ALGAE DRY WT. (g)	No. *L. peregra*	ALGAE DRY WT. (g)	No. *L. peregra*	ALGAE DRY WT. (g)	No. *L. peregra*
Upper Riffle	0.000	0	5.240	24	1.500	14
14. 6.78	1.300	0	13.467	32	6.910	54
	0.000	0	-	12	18.860	172
	2.595	0	21.250	8	0.000	12
	0.000	0	6.294	20	7.665	8
	2.677	0	13.109	4	7.340	12
Lower Riffle	0.000	0	9.477	0	13.047	44
20. 6.78	0.000	3	3.614	2	3.247	18
	0.000	2	1.400	1	10.185	43
	0.000	5	2.731	2	12.931	71
	0.000	2	7.284	8	16.091	152
	0.000	0	26.590	0	10.265	83

TABLE 8.17: A COMPARISON OF THE AMOUNT OF FILAMENTOUS GREEN ALGAE AND NUMBER OF *L. peregra* IN 0.1 m^2 CYLINDER SAMPLES TAKEN FROM THE CHECKLEY CHANNEL RIFFLES IN JUNE 1978 (DATA -COURTESY OF T. WARDLE).

SPECIES→	MEAN INDIVIDUAL WEIGHT (mg.)																	
	L. peregra									*P. jenkinsi*								
CHANNEL →	A			B			C			A			B			C		
DATE ↓ COHORT→	1	2	3	1	2	3	1	2	3	1	2	3	1	2	2	1	2	3
Lower Riffle																		
21. 6. 79	49.7	1.0		45.2	0.4		31.7	0.9		0.9			2.9					
24. 7		2.3		47.4	1.2		26.4	1.3		1.6			3.3					
30. 8		2.1			1.7			3.3		2.0			2.4					
27. 9		1.3			2.5			3.1		2.6			2.2					
6.11		-			3.5			6.2		2.3	0.5		1.9					
27.11.		-			3.2			6.6		2.6	0.6		2.8					
15. 1.80		-			10.1			10.6		3.7	1.3		1.9	1.6				
21. 2		3.7			9.2			13.9		3.3	1.3		2.8	-				
17. 3		-			17.3			16.8		4.0	1.3		4.9	3.3				
22. 4		19.0			29.7			18.2			2.6			4.2			1.7	
20. 5		16.7			11.1			22.7			1.6	0.3		3.0			-	
23. 6		20.6	2.4		17.5	0.6		18.2	1.4		2.5	0.6		2.3	0.6		5.4	
Upper Pool																		
9.10.79		6.6			10.1			5.7										
4.12.		8.5			7.9			14.4										
29. 1.80		15.4			16.3			18.1										
25. 3		19.4			22.2			12.5										
20. 5		33.6			24.5			24.9										
23. 7		36.6	0.4		25.6	4.6		35.1										
8. 9			9.6			14.4			1.1									
S.Auf.U.																		
14. 5.79	49.1			31.4			27.3											
12. 6	59.5			40.3			36.9											
10. 7	51.0	2.0		33.0			36.6	1.9		1.8								
7. 8		1.3			1.4			1.9		3.3			1.2					
4.9		3.4			3.5			6.4		2.8								
2.10		3.1			7.9			5.0		3.9			4.4					
30.10		6.8			3.2			7.3		3.2			3.3					
27.11.		15.6			11.3			6.9		4.3	0.4		4.3	0.5				
3.1.80		11.3			15.2			22.1		3.8	0.6		4.3	-				
29.1.		18.0			16.2			13.5		4.3	0.7		6.8	2.2				
26.2		16.5			23.8			23.5		4.1	0.8		3.9	-				
25.3		22.6			24.9			18.0		4.7	2.0		5.7	2.3				

TABLE 8.18: MEAN INDIVIDUAL WEIGHTS OF SNAILS IN THE CHECKLEY CHANNELS

DATE ↓ CHANNEL →	NO. OF EGG MASSES / STRIP																	
	A						B						C					
REPLICATE →	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Lower Riffle																		
25.3.80	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
22.4	0	0	0	0	1	0	4	0	0	0	2	3	3	0	0	0	7	4
21.5	0	0	1	0	8	1	5	4	1	8	25	LS	0	1	1	3	2	LS
23.6	0	LS	0	2	14	2	0	LS	0	78	56	0	3	LS	4	0	21	2
23.7	0	4	6	2	LS	4	1	5	0	29	13	1	1	0	6	5	5	2
19.8	0	0	0	0	0	0	1	1	0	0	10	0	0	0	0	0	0	0
8.9	0	0	0	0	0	0	0	0	2	1	11	1	0	0	0	0	0	0
Upper Pool																		
25.3.80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22.4	0	0	1	0	0	0	0	1	0	1	5	1	0	0	0	0	3	0
21.5	0	2	2	0	0	0	10	1	0	LS	13	1	1	0	1	LS	0	LS
23.6	27	49	14	LS	4	0	77	11	LS	42	75	L	5	10	16	15	7	47
23.7	0	0	4	0	LS	1	73	4	10	15	25	7	8	58	56	29	30	25
19.8	0	0	LS	0	0	0	0	0	5	0	4	0	1	0	1	3	2	2
8.9	0	0	0	0	0	0	LS	0	1	2	1	0	0	0	0	0	2	4

LS = lost or silted up

TABLE 8.19 : NUMBERS OF EGG MASSES LAID ON POLYTHENE STRIPS IN THE CHECKLEY CHANNEL BY *L. peregra* DURING 1980 .

DATE ↓ / CHANNEL → / REPLICATE →	NO. OF EGGS / STRIP																	
	A						B						C					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Lower Riffle																		
25.3.80	0	0	0	0	0	0	0	34	0	0	0	0	0	0	0	0	0	0
22.4	0	0	0	0	31	0	193	0	0	0	136	142	85	0	0	0	234	198
21.5	0	0	72	0	425	33	95	109	18	309	756	L	0	109	24	98	46	L
23.6	0	L	0	91	584	68	0	L	0	2161	2069	0	77	L	61	0	613	49
23.7	0	68	88	23	L	74	22	86	0	635	369	16	18	0	96	110	72	27
19.8	0	0	0	0	0	0	14	26	0	0	166	0	0	0	0	0	0	0
8.9	0	0	0	0	0	0	0	0	42	27	142	6	0	0	0	0	0	0
Upper Pool																		
25.3.80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22.4	0	0	28	0	0	0	0	12	0	14	117	41	0	0	0	0	198	0
21.5	0	60	77	0	0	0	445	11	0	L	318	28	51	0	39	L	0	L
23.6	1277	1517	292	L	44	0	2549	423	L	8 6	2198	L	225	444	526	414	232	1154
23.7	0	0	148	0	L	8	2143	62	194	331	623	122	317	1441	895	644	576	475
19.8	0	L	0	0	0	0	0	0	56	0	93	0	10	0	16	55	39	16
8.9	0	0	0	0	0	0	L	0	8	26	11	0	0	0	0	0	40	60

L = lost or silted up

TABLE 8.20 : NUMBERS OF EGGS LAID ON POLYTHENE STRIPS IN THE CHECKLEY CHANNELS BY L. pereger DURING 1980 .

TAXON ↓ / RIVER → / SITE →	RELATIVE ABUNDANCE RATING																											
	AVON				SEVERN				TRENT			ELY OUSE	M.L.M.D.	N E N E			WELLAND	MERSEY		WEAVER		AIRE	CALDER	DERWENT	DON	YORKSHIRE OUSE	
	WELFORD	EVESHAM	GT. COMBERTON	TEWKESBURY	SAXONS LODE	MYTHE 1	MYTHE 2	HAW BRIDGE	WILLINGTON	SHARDLOW	NOTTINGHAM	DENVER	MULLICOURT	OUNDLE	WANSFORD	DOG-IN-A-DOUBLET	CROWLAND	FLIXTON	WARRINGTON	HARTFORD BRIDGE	ACTON BRIDGE	BEAL	METHLEY	BARMBY	DONCASTER	NETHER POPPLETON	KABURN WEIR
SUBMERGED																												
Elodea canadensis														1			1			4								
Myriophyllum spicatum		1					1			2						1				3								
Potamogeton pectinatus		1	2			1					2			1				1	4		1					4		
FLOATING																												
Lemna minor													5						1	3								
Nuphar lutea	3	1	2										2	2														
Polygonum amphibium				1											1				2			1						
EMERGENT																												
Alisma plantago-aquatica																				1								
Iris pseudacorus												2										2						
Juncus effusus												1																
Phalaris arundinacea				3							4	2		2		2												
Phragmites communis			4									4	3		2													
Schoenoplectus lacustris			2	2						2	1																	
Sparganium emersum			1											1	1													
S. erectus		1	4	3					3	5	3								3				1					
ALL SPECIES	3	2	5	3	0	1	1	0	3	5	5	4	5	3	2	2	1	1	4	5	1	2	1	0	0	4	0	

TABLE **8.21**: RELATIVE ABUNDANCE OF MACROPHYTES AT SAMPLING SITES

REMOVAL ↓DATE SITE→	BIOMASS (g. dry wt.)																	
	Lymnaea peregra			*Physa fontinalis*			*Bithynia tentaculata*			*Potamopyrgus jenkinsi*			*Theodoxus fluviatilis*			*Viviparus viviparus*		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
14.2.80	-	0.7095	-	-	0.0	-	-	0.0168	-	-	0.0	-	-	0.0	-	-	0.0	-
6.3	0.3485	0.0	0.8023	0.0	0.0	0.0	0.0	0.0	0.0621	0.3003	0.0	0.0466	0.9576	0.0	0.0042	0.0	0.0.	0.0
10.4	0.0428	0.0	0.1369	0.1095	0.0143	0.0079	0.0	0.0035	0.0	0.0399	0.0	0.0	0.3656	0.0	0.0	0.0093	0.0	0.0
8.5	0.3010	0.8179	0.0715	0.1291	0.0122	0.0	0.2337	4.2566	0.0	0.0433	0.0	0.0	1.5459	0.0	0.0	0.0	0.0	0.0
5.6	0.3143	0.1808	0.0018	0.0266	0.0149	0.0	0.7874	5.6073	0.0391	0.0811	0.0074	0.0078	0.3513	0.0	0.0	0.0	0.1211	0.0
2.7	0.2329	0.3850	0.4457	0.1544	0.1044	0.0438	1.9407	3.0640	0.0	0.3125	0.0061	0.0142	1.4356	0.0	0.0	1.3130	4.3858	0.0
31.7	0.9983	0.6359	1.9089	0.3045	0.1132	0.0223	0.9811	0.7554	0.0254	0.7757	0.0	0.0225	1.9756	0.0	0.0	2.8934	0.7009	0.0037
28.8	1.0074	0.7364	0.8210	0.1557	0.0485	0.0053	0.4210	0.6530	0.0160	0.2114	0.0	0.0516	1.4429	0.0	0.0	3.0816	1.1322	0.0
25.9	1.0294	0.5766	0.5627	0.1407	0.0635	0.0967	0.2702	0.7635	0.0	0.1005	0.0	0.0301	1.4310	0.1353	0.0	1.9053	0.1422	0.0
24.10	-	1.0448	-	-	0.1121	-	-	0.4590	-	-	0.0	-	-	0.0	-	-	0.1878	-
5.11	0.0977	-	-	0.4035	-	-	0.0867	-	-	0.1473	-	-	0.6308	-	-	0.0	-	-
2.12	0.2311	0.6678	-	0.1895	0.1109	-	0.0015	0.0979	-	0.3150	0.0	-	0.4866	0.0	-	0.0	0.0	-
6. 1.81	0.3413	0.1593	-	0.3352	0.1289	-	0.0	0.0755	-	0.2004	0.0	-	0.1970	0.0	-	0.0	0.0	-
3. 2.	0.0781	0.2386		0.0297	0.0312	-	0.0	0.0377	-	0.1767	0.0	-	0.0	0.0	-	0.0	0.0	-

TABLE **8.22** : BIOMASS OF SNAILS COLLECTED ON 3 S.AUF.U FROM (a) SAXONS LODE ON THE R. SEVERN AND (b) EVESHAM AND (c) TEWKESBURY ON THE R. AVON.

TABLES **8.23** a - **h**: PRESENCE/ABSENCE OF GASTROPODS IN DIFFERENT POLLUTANTS WITH ONE-TAILED t-TESTS (WITH SIGNIFICANCE LEVELS) ON DIFFERENCES IN PHYSCICOCHEMICAL VALUES BETWEEN SITES WITH AND WITHOUT GASTROPODS. (Maximum annual values used except for
a where annual minima used and
b where minima and maxima used).

(Where chemical values beyond the limit of detection exist values of t for minimum and maximum possible differences between sites with and without gastropods are given).

Variable (mg l^{-1} except where otherwise stated) ↓	No. occ	No. abs.	Range occurrence	Range absence	Median occ.	Median abs.	t
Temp. ^{o}C	17	6	17.5 - 22.5	20 - 28.5	20	20	3.34**
Suspended Solids	17	6	46 -377	50 - 495	142	115	0.68
D.O. [a]	17	7	1.5 - 8.6	2.8 - 7.6	6.6	6.0	-0.71
Chloride	17	7	36 -488	139 -10500	99	149	1.64
Fluoride	12	3	0.1 - 0.95	0.32- 5.00	0.33	0.56	2.35*
pH [b]	17	7	6.7 - 9.2	6.9 - 8.5	7.3/8.7	7.2/7.9	-0.98/-3.22
Anionic Detergent	14	6	0.09 - 0.98	0.14 - 0.87	0.2	0.21	0.15/0.22
$N\text{-}NH_3$	17	7	0.4 - 11.4	0.3 - 22.65	1.2	1.6	2.02*
$N\text{-}NO_3$	15	4	3.9 - 43.8	5.2 - 9.20	10.4	8.49	- 1.01
$N\text{-}NO_2$	13	3	0.03 - 2.24	1.20- 2.14	0.14	1.89	3.81***
Total Cd	14	7	<.001- .01	.001- <.01	<.01	< .01	-
Total Cr	14	7	<.01 - .06	.003 - .079	<.03	.02	1.66/2.25*
Total Cu	14	7	<.01 - .06	.001 - .08	.025	.06	2.61**
Total Pb	14	7	< .01- .16	.01 - .28	.042	.038	0.83/0.95
" Mg ($\mu g\ l^{-1}$)	6	3	<1.05 - 1.1+	<1.05 -34.1+	<1.05	1.96	1.59/1.66
" Ni	14	7	.007 - .07	.01 - .128	.03	.038	1.89*/2.07*
" Zn	14	7	.03 - .15	.035 - .28	.06	.09	1.76*
α-BHC ($ng\ l^{-1}$)	5	2	5 - 111	29 - 79	7.2	54	0.61
γ-BHC ($ng\ l^{-1}$)	12	3	28 - 281	279-2884	96	640	3.19**
Dieldrin ($ng\ l^{-1}$)	12	3	2-2500	< 2 -163	<50	< 10	0.52/0.55
Heptachlor ($ng\ l^{-1}$)	5	1	< 2 - 14	<10	< 2	< 10	-

TABLE 8.23a: *Lymnaea peregra*

Variable (mg l^{-1} except where otherwise stated) ↓	No. occ	No. abs.	Range occurrence	Range absence	Median occ.	Median abs.	t
Temp. ^{o}C	16	7	17.5 - 22.5	18 - 28.5	20	21.5	**1.79***
Suspended Solids	16	7	46 -495	50 -209	142	132	**-0.86**
D.O. [a]	16	8	1.5 - 8.6	2.8 - 7.75	6.6	6.0	**0.75**
Chloride	16	8	36 - 488	75 -10500	99	146	**1.40**
Fluoride	12	3	0.1 - 5.00	0.3 - 0.56	0.36	0.41	**-0.36**
pH [b]	16	8	6.7 - 9.2	6.9 - 8.9	7.3/8.7	7.2/8.0	**0.62 / -0.75**
Anionic Detergent	13	7	< 0.14- 0.98	0.09 - 0.87	0.24	0.20	**-1.65**
$N\text{-}NH_3$	16	8	0.24- 14.70	0.3 - 22.65	1.2	1.3	**0.34**
$N\text{-}NO_3$	15	4	3.9 - 43.8	5.2 - 20.5	9.4	8.6	**- 0.29**
$N\text{-}NO_2$	14	2	0.03- 2.24	0.10 - 1.20	0.16	0.54	**0.01**
Total Cd	13	8	< .001- .01	<.01 - <.01	< .005	< .01	-
Total Cr	13	8	< .01 - .079	<.01 - .04	.023	.02	**-0.93/-0.76**
Total Cu	13	8	< .02 - .077	<.01 - .08	.033	.04	**0.32/ 0.44**
Total Pb	13	8	< .04 - .16	<.01 - .28	.042	.038	**0.29/ 0.55**
"Hg ($\mu g\ l^{-1}$)	8	1	<1.05 - 1.96	0.94 - 34.1+	<1.05	17.5	-
" Ni	13	8	< .03 - .128	<.03 - .08	.021-.025	.035	**-0.16/ 0.26**
" Zn	13	8	.03 - .28	.035 - .17	.055	.09	**0.04**
α-BHC ($ng\ l^{-1}$)	6	1	5 -111	79	17.9	79	-
γ-BHC ($ng\ l^{-1}$)	10	5	59 -2884	28 - 640	105	140	**-0.58**
Dieldrin ($ng\ l^{-1}$)	10	5	< 2 -2500	<10 - 163	<3.8	<50	**-0.99/-0.91**
Heptachlor ($ng\ l^{-1}$)	4	2	< 2 -14.0	<10 - 13.0	<2	6.5-11.0	**0.36/ 0.46**

TABLE 8.23 b: *Physa spp.*

Variable (mg l^{-1} except where otherwise stated) ↓	No. occ	No. abs.	Range occurrence	Range absence	Median occ.	Median abs.	t
Temp. ^{o}C	10	13	17.5- 24	19 - 28.5	20	21	1.74*
Suspended Solids	10	13	72 -207	46 -495	98	172	1.80*
D.O. [a]	10	14	1.5- 8.6	2.7 - 7.1	6.75	5.95	- 1.02
Chloride	10	14	56 -244	36 -10500	109	125	0.89
Fluoride	5	10	0.28- 0.95	0.1 - 5.00	0.50	0.31	0.33
pH [b]	10	14	6.8- 9.0	6.7 - 9.2	7.5/8.7	7.1/ 8.35	2.87**/ 0.73
Anionic Detergent	9	11	0.09- 0.98	< 0.14- 0.87	0.21	0.20	-0.24/0.15
$N\text{-}NH_3$	10	14	0.57- 11.4	0.3 - 22.65	1.33	1.25	0.88
$N\text{-}NO_3$	6	13	3.9- 43.8	5.2 - 13.00	14.75	8.38	- 2.64
$N\text{-}NO_2$	6	10	0.03- 0.38	0.0095- 2.24	0.15	0.39	1.81*
Total Cd	8	13	< .001- .01	< .001- .01	< .01	< .01	-
Total Cr	8	13	< .01- .06	< .03 - .079	.02	.02	0.09/1.12
Total Cu	8	13	< .01- .06	<.02 - .08	.043	.035	0.11/0.26
Total Pb	8	13	< .01- .16	<.04 - .28	.044	.04	-0.61/-0.18
" Mg ($\mu g\ l^{-1}$)	3	6	<1.05- 1.1+	<1.05 -34.1+	<1.05	1.02- 1.05	0.67/0.78
" Ni	8	13	.010- .07	< .03 - .128	.035	.03	0.77/0.80
" Zn	8	13	.038- .17	.03 - .28	.07	.09	0.40
α-BHC (ng l^{-1})	2	5	6.9 - 28.6	5 - 111	17.8	29	0.80
γ-BHC (ng l^{-1})	6	9	28 -640	40 -2884	146.5	100	0.54
Dieldrin (ng l^{-1})	6	9	< 4 -<50	< 2 -2500	< 4.2	<50	1.11/1.18
Heptachlor (ng l^{-1})	5	1	< 2 - 14.0	<2 -	< 10	<2	-

TABLE 8.23 c: *Planorbis spp.*

Variable ($mg\ l^{-1}$ except where otherwise stated)	No. occ	No. abs.	Range occurrence	Range absence	Median occ.	Median abs.	t
Temp. ^{o}C	18	5	17.5- 24	21 - 28.5	20	22	3.00**
Suspended Solids	18	5	46 -209	50 -495	105	195	2.65**
D.O.[a]	18	6	1.5- 8.6	2.7 - 6.2	6.6	5.5	-1.37
Chloride	18	6	36 -488	76 -10500	100	242	1.88*
Fluoride	12	3	0.1- 0.95	0.24- 5.00	0.365	0.3	2.07*
pH[b]	18	6	6.7- 9.2	6.9 - 8.9	7.3/8.7	7.0/8.0	1.92*/ -1.57
Anionic Detergent	15	5	< 0.14- 0.98	0.14- 0.74	0.20	0.20	0.19/ 0.25
$N\text{-}NH_3$	18	6	0.24- 11.4	0.3- 22.65	1.2	3.2	2.45*
$N\text{-}NO_3$	15	4	3.9 - 43.8	5.2 - 8.6	10.4	7.78	1.06
$N\text{-}NO_2$	14	3	0.03 - 2.14	1.20- 2.24	0.15	1.89	4.05***
Total Cd	15	6	<.001- .01	≤.01	< .01	.001- .004	-
Total Cr	15	6	<.01- .06	.003-.079	.02	.027	0.78/ 1.64
Total Cu	15	6	<.01- .06	.001-.08	.025	.04	1.24/ 1.36
Total Pb	15	6	<.01- .16	.01 -.28	.039	.041	0.80/ 0.95
" Mg ($\mu g\ l^{-1}$)	6	3	<1.05- 1.1+	.78-34.1+	.47-1.0	1.96	1.52/ 1.58
" Ni	15	6	< .03- .07	<.03-.128	.025	.032	0.89/ 1.28
" Zn	16	6	.03- .17	.035-.28	.06	.11	1.94*
α-BHC ($ng\ l^{-1}$)	5	2	5 - 79	29 -111	7.2	65	1.39
γ-BHC ($ng\ l^{-1}$)	12	3	28 -640	40 -2884	105	275	2.82*
Dieldrin ($ng\ l^{-1}$)	12	3	< 4 -2500	<2 - 898	<10	<50	-0.15/ 0.20
Heptachlor ($ng\ l^{-1}$)	6	0	< 2 -14.0	-	< 2	-	-

TABLE 8.23d: *Bithynia tentaculata*

Variable ($mg\ l^{-1}$ except where otherwise stated) ↓	No. occ	No. abs.	Range occurrence	Range absence	Median occ.	Median abs.	t
Temp. ^{o}C	14	9	17.5 - 24	19 - 28.5	20.25	21	1.21
Suspended Solids	14	9	72 -377	46 -495	125	135	0.41
D.O.[a]	14	10	1.5 - 8.6	2.8 - 7.1	6.6	6.0	- 0.72
Chloride	14	10	36 -308	76 -10500	97.5	162	1.27
Fluoride	10	5	0.1 - 0.95	0.3 - 5.00	0.325	0.36	1.38
pH[b]	14	10	6.7 - 9.0	6.9 - 9.2	7.3/8.7	7.15/ 8.25	0.37/-0.94
Anionic Detergent	12	8	0.09- 0.98	<0.14 - 0.87	0.19	0.205	0.07/0.15
$N\text{-}NH_3$	14	10	0.24- 11.4	0.3 - 22.65	0.895	1.45	1.55
$N\text{-}NO_3$	12	7	3.9 - 43.8	5.2 - 13.00	10.28	8.6	- 1.15
$N\text{-}NO_2$	11	5	0.03- 2.24	0.24 - 2.14	0.11	1.20	2.30*
Total Cd	12	9	< .001- .01	<.001 - <.01	<.01	<.01	-
Total Cr	12	9	< .01 - .06	<.03 - .079	.175- .02	.024	0.65/1.81*
Total Cu	12	9	<.01 - .06	.011- .08	.025	.045	2.10*/ 2.15*
Total Pb	12	9	< .01 - .16	.01 - .28	.042	.038	1.20/0.50
" Mg ($\mu g\ l^{-1}$)	5	4	<1.05 - 1.1+	<1.05 -34.1+	.78- 1.0	1.45- 1.48	1.13/1.23
" Ni	12	9	.007- .07	.01 - .128	.025	.035	1.10/1.51
" Zn	12	9	.03- .17	.035- .28	.07	.09	0.73
α-BHC ($ng\ l^{-1}$)	4	3	5 - 111	7.2 - 79	17.25	29	0.02
γ-BHC ($ng\ l^{-1}$)	10	5	28- 640	40 -2884	120	110	1.28
Dieldrin ($ng\ l^{-1}$)	10	5	2- 2500	<2 -163	< 50	<50	-0.86/-0.79
Heptachlor ($ng\ l^{-1}$)	5	1	<2- 14.0	< 2	< 6	< 2	-

TABLE 8.23e: *Potamopyrgus jenkinsi*

Variable (mg l^{-1} except where otherwise stated) ↓	No. occ	No. abs.	Range occurrence	Range absence	Median occ.	Median abs.	t
Temp. ^{o}C	5	18	17.5 - 2.15	18 - 28.5	20	20.75	1.00
Suspended Solids	5	18	72 - 190	46 -495	102	138.5	0.69
D.O. [a]	5	19	1.5 - 8.6	2.7 - 7.9	6.6	6.0	- 0.13
Chloride	5	19	84 - 242	36 -10500	99	146	0.56
Fluoride	3	12	0.1 - 0.37	0.24- 5.0	0.2	0.34	0.72
pH [b]	5	19	6.8 - 9.0	6.7 - 9.2	7.1/ 8.7	7.3/ 8.5	0.54/-0.54
Anionic Detergent	4	17	0.13 - 0.98	<0.14- 0.87	0.24	0.20	+0.60/-0.56
$N\text{-}NH_3$	5	19	0.24 - 11.4	0.3 - 22.65	0.50	1.3	0.18
$N\text{-}NO_3$	4	15	3.9 - 15.0	5.2 - 43.8	7.4	10.4	0.89
$N\text{-}NO_2$	3	13	0.10 - 0.38	0.03- 2.24	0.25	0.16	0.88
Total Cd	4	17	<.001 - .01	<.001 - < .01	<.01	< .01	-
Total Cr	4	17	< .03 - .06	< .01- .079	.012- .022	.02	-0.93/0.27
Total Cu	4	17	< .02 - .06	< .01- .08	.006- .011	.04	1.36/1.71
Total Pb	4	17	< .04 - .16	< .01- .28	.042	.038	-0.24/0.05
" Mg ($\mu g\ l^{-1}$)	2	7	<1.05 - 1.1+	<1.05 - 34.1+	.55- 1.05	.94- 1.0	0.48/0.61
" Ni	4	17	< .03 - .07	.007- .128	.005- .02	.033	0.52/1.16
" Zn	4	17	.03 - .15	.035- .28	.059	.08	0.63
α-BHC ($ng\ l^{-1}$)	1	6	6.9	5 - 111	6.9	28.8	-
γ-BHC ($ng\ l^{-1}$)	2	13	80 - 91	28 - 2884	85.5	110	0.54
Dieldrin ($ng\ l^{-1}$)	2	13	< 4 - 2500	< 2 - 898	1250- 1252	4.4-9	-2.82/2.80
Heptachlor ($ng\ l^{-1}$)	1	5	< 2	< 2 - 14.0	< 2	< 10	-

TABLE 8.23f: *Theodoxus fluviatilis*

Variable ($mg\ l^{-1}$ except where otherwise stated) ↓	No. occ	No. abs.	Range occurrence	Range absence	Median occ.	Median abs.	t
Temp. ^{o}C	9	14	19 - 21	17.5 - 28.5	20	21.25	1.25
Suspended Solids	9	14	70 -207	46 -495	142	122	0.75
D.O.[a]	9	15	4.4 - 8.6	1.5 - 7.9	6.8	6.0	- 1.35
Chloride	9	15	36 - 244	76 -10500	92	149	0.86
Fluoride	8	7	0.2 - 0.95	0.1 - 5.00	0.365	0.32	0.92
pH[b]	9	15	6.7 - 9.2	6.8 - 8.9	7.4/ 8.7	7.1/ 8.0	-1.31/-2.29
Anionic Detergent	9	12	<0.14- 0.35	0.13- 0.98	0.18	0.325	2.21*/2.32*
$N\text{-}NH_3$	9	15	0.41- 1.85	0.24- 22.65	1.2	1.3	1.61
$N\text{-}NO_3$	8	11	6.2 - 43.8	3.9 - 12.8	13.25	8.38	- 2.27
$N\text{-}NO_2$	8	8	0.03- 0.25	0.095 - 2.24	0.105	0.87	2.95**
Total Cd	9	12	<.001- <.01	<.01 - <.01	<.01	<.01	-
Total Cr	9	12	<.01 - .024	<.03 - .079	.015- .02	.025	1.21/2.65**
Total Cu	9	12	<.01 - .06	<.02 - .08	.02	.04	1.16/1.36
Total Pb	9	12	< .01- .09	<.04 - .28	.03	.065	1.46/1.81*
" Mg ($\mu g\ l^{-1}$)	4	5	<1.05- 1.10	.78 - 34.1+	<1.05	1.1+	0.90/1.00
" Ni	9	12	< .03- .06	<.03 - .128	.011 - .02	.038	1.41/1.95*
" Zn	9	12	.038 - .10	.03 - .28	.06	.09	2.10*
α-BHC ($ng\ l^{-1}$)	4	3	5 -28.6	29 -111	7.05	79	2.90*
γ-BHC ($ng\ l^{-1}$)	8	7	28- 281	40 -2884	85.5	275	1.43
Dieldrin ($ng\ l^{-1}$)	8	7	< 4-2500	<2 - 898	2.85- 3.35	<50	-0.66/-0.25
Heptachlor ($ng\ l^{-1}$)	5	1	< 2-14.0	<10	<2	<10	-

TABLE 8.23 g: *Valvata spp.*

Variable (mg l^{-1} except where otherwise stated)	No. occ	No. abs.	Range occurrence	Range absence	Median occ.	Median abs.	t
Temp. ^{o}C	5	18	19 - 21.5	17.5 - 28.5	20.5	20.5	0.53
Suspended Solids	5	18	70 - 197	46 - 495	172	122	0.25
D.O. [a]	5	19	4.5 - 7.1	1.5 - 8.6	6.8	6.0	-0.66
Chloride	5	19	90 -244	36 -10500	100	139	0.54
Fluoride	5	10	0.1 - 0.95	0.24- 5.0	0.36	0.345	0.62
pH [b]	5	19	6.8 - 9.2	6.7 - 9.0	7.3/ 8.8	7.3/ 8.2	-0.21/ - 2.09
Anionic Detergent	5	15	<0.14- 0.35	0.09- 0.98	0.16	0.21	1.43/ 1.60
$N\text{-}NH_3$	5	19	0.50- 1.55	0.24- 22.65	1.2	1.3	1.14
$N\text{-}NO_3$	5	14	5.2 - 43.8	3.9 - 20.5	10.95	8.49	**-1.32**
$N\text{-}NO_2$	4	12	0.03- 0.25	0.095- 2.24	0.105	0.31	1.47
Total Cd	5	16	<.001- <.01	<.001- .01	< .01	< .01	-
Total Cr	5	16	< .01- .024	<.01 - .079	<.03	.022	0.82/2.46*
Total Cu	5	16	< .02- .06	<.01 - .08	.020	.04	0.96/1.24
Total Pb	5	16	< .04- .09	<.01 - .28	.03- .039	.047	**0.68/1.18**
" Hg ($\mu g\ l^{-1}$)	1	8	< 1.05	<1.05- 34.1+	<1.05	1.02- 1.05	-
" Ni	5	16	< .03 - .06	< .03- .128	<.03	.034	**0.77/1.35**
" Zn	5	16	.03 - .08	.035- .28	.06	.09	1.54
α-BHC ($ng\ l^{-1}$)	1	6	7.2	5-111	7.2	28.8	-
γ-BHC ($ng\ l^{-1}$)	4	11	68 -281	28 - 2884	95	140	**0.68**
Dieldrin ($ng\ l^{-1}$)	4	11	< 4 -2500	< 2 - 898	2.2- 27.2	<10	**-1.44/ -1.38**
Heptachlor ($ng\ l^{-1}$)	2	4	< 2 - 14	< 2 - 13	7 - 8	< 6	**-0.68 -0.51**

TABLE 8.23h: *Viviparus viviparus*

t(h) NOM CONC (mgl⁻¹)	RESPONSE (defined in text)																	
	Control			18.125			36.25			72.5			145			290		
REP.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
0	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a
1	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	8^a_b	9^a_b	7^a_b	9^a_b	8^a_b	4^a_b	3^a_b	8^a_b
													3c	1c	2c	4c	6c	2c
											2d	1d				2d	1d	
2	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	9^a_b	10^a_b	10^a_b	7^a_b	5^a_b	6^a_b	4^a_b	4^a_b	4^a_b		2^a_b	3^a_b
										1c	1c	2c	3c	2c	4c	7c	4c	4c
							1d			2d	2d	1d	3d	4d	2d	1d	3d	3d
4	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	9^a_b	9^a_b	8^a_b	2^a_b	2^a_b	4^a_b	1^a_b	2^a_b	2^a_b	1^a_b		
										5c	4c	2c	3c	2c	3c	4c	6c	6c
								1d	1d	1d		2d	4d	2d	3d	2d		1d
									1*									
8	10^a_b	10^a_b	9^a_b	10^a_b	10^a_b	10^a_b	8^a_b	9^a_b	7^a_b	5^a_b	2^a_b	2^a_b		1^a_b				
							1c			2c	3c	2c	1c	2c				2c
			1d						1d		1d	2d	2d	1d	5d	5d	6d	4d
24	10^a_b	10^a_b	9^a_b	10^a_b	10^a_b	10^a_b	9^a_b	7^a_b	4^a_b	3^a_b	1^a_b	2^a_b						
								1c		1c								
								1d	2d	3d	4d	2d	1d	3d				2d
									1*									
48	10^a_b	10^a_b	9^a_b	10^a_b	10^a_b	10^a_b	4^a_b	3^a_b	1^a_b									
							3c	2c	2c									
							2d	3d	1d	4d	1d	2d						
72	10^a_b	10^a_b	9^a_b	10^a_b	10^a_b	7^a_b	2^a_b	1^a_b										
						3c	3c	1c	1c									
							2d	3d	2d									
96	10^a_b	10^a_b	2^a_b	6^a_b	9^a_b	6^a_b		1^a_b										
					1c													
				2d		2d	5d	1d	1d									
%Survival	96.7			86.7			3.3			0.0			0.0			0.0		

* = damaged during handling

TABLE 8.24a: THE EFFECT OF AMMONIA ON THE SURVIVAL AND BEHAVIOUR OF JUVENILES *P. jenkinsi*.

↓t(h) NOM. CONC. (mgl⁻¹) →	RESPONSE (defined in text)																	
	Control			18.125			36.25			72.5			145			290		
REP. →	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
0	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a
1	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	9^a_b 1c	10^a_b	10^a_b	9^a_b 1c	10^a_b	8^a_b 1c 1d	8^a_b 2c	8^a_b 1c 1d
2	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	9^a_b 1c	10^a_b	8^a_b 1c 1d	8^a_b 1c 1d	10^a_b	7^a_b 2d	8^a_b 2c	8^a_b 1c
4	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	8^a_b 1c 1d	9^a_b 1c	10^a_b	7^a_b 2c	5^a_b 2c 2d	9^a_b 1d	4^a_b 3d	5^a_b 5d	5^a_b 4d
8	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	7^a_b 2c	10^a_b	9^a_b 1c	5^a_b 2c 2d	4^a_b 2d 1*	5^a_b 1c 3d	1^a_b 2c 1d	1^a_b 3c 1*	2^a_b 1c 2d
24	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	9^a_b 1c	10^a_b	10^a_b	3^a_b 5c 1d	9^a_b 1d	4^a_b 5c 1d	2^a_b 5c	$2c$ 2d	1^a_b 4c 1d	2c 1d	1c 3d	2c 1d
48	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	6^a_b 3c 1d	7^a_b 3c	9^a_b 1d	5^a_b 2c 1d	3^a_b 4c 2d	1^a_b 7c	4c 3d	1c 1d	2c 3d			
72	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	6^a_b 2c 1d	6^a_b 3c 1d	6^a_b 3c	2^a_b 5d	2^a_b 5d	2^a_b 2c 4d						
96	10^a_b	10^a_b	10^a_b	8^a_b 1c 1d	7^a_b 3c	7^a_b 3c	4^a_b 2c 2d	1^a_b 8c	5c 4d	2d	2d	1c 3d						
%ur-vival	100			96.7			66.7			3.3			0.0			0.0		

TABLE 8.24b: THE EFFECT OF AMMONIA ON THE SURVIVAL AND BEHAVIOUR OF EARLY ADULT *P. jenkinsi*.

↓t(h) NOM. CONC. (mg l⁻¹) →	RESPONSE (defined in text)																	
	Control pg			18.125			36.25			72.5			145			290		
REP. →	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
0	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a
1	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	9^a_b 1d	10^a_b	9^a_b 1c	3c 7d	2^a_b 8d	1^a_b 8c 1d
2	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	9^a_b 1c	10^a_b	10^a_b	7^a_b 2c	8^a_b 2c	10^a_b	3d	1^a_b 1c	7^a_b 1c 1d
4	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	7^a_b 1c 1d	9^a_b 1c	8^a_b 1c 1d		1^a_b 1d	6^a_b 1c 1d
8	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	9^a_b 1c	10^a_b	6^a_b 2c 2*	6^a_b 2d	8^a_b 1c 1d	8^a_b 1d		1c	3^a_b 2c 2d
24	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	10^a_b	9^a_b 1d	9^a_b 1*	3^a_b 6c 1d	4^a_b 6c	2^a_b 5c 1d	1^a_b 4c 1d	1^a_b 6c 2d	6c 2d		1c	5d
48	10^a_b	10^a_b	10^a_b	9^a_b 1d	9^a_b 1c	10^a_b	9^a_b 1d	9^a_b	9^a_b	3^a_b 5c 1d	3^a_b 4c 3d	1^a_b 6c	2c 3d	1^a_b 4c 2d	4c 2d		1d	
72	10^a_b	10^a_b	10^a_b	8^a_b 1c	10^a_b	9^a_b 1c	8^a_b 1c	9^a_b	7^a_b 1c 1d	2^a_b 4c 2d	3^a_b 3c 1d	3^a_b 2c 1d 1*	2d	3c 2d	2c 2d			
96	10^a_b	10^a_b	10^a_b	7^a_b 1c 1d	8^a_b 2d	6^a_b 2c 2d	6^a_b 2c 1d	8^a_b 1d	4^a_b 2c 2d	1^a_b 5d	1^a_b 3c 2d	1^a_b 2c 2d		3d	1c 1d			
%sur-vival	100			83.3			75.9			29.6			3.3			0.0		

TABLE 8.24c: THE EFFECT OF AMMONIA ON THE SURVIVAL AND BEHAVIOUR OF JUVENILE *P. jenkinsi*.

Δt(h) / NOM. CONC. (mgl⁻¹) / REP.	RESPONSE (defined in text)																	
	Control			0.04			0.045			0.055			0.08			0.115		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
0	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a
1	10a	10a	10a	10a	8a 1b 1c	9a 1b	6a 3b 1d	8a 2b	8a 1b 1d	8a 1b 1c 1d	8a 2d	7a 3b	8a 1b 1d	9a 1d	9a 1d	4a 3b 1c 2d	7a 2b 1d	8a 1b 1d
2	10a	10a	10a	10a	7a 1b 2c	10a	5a 4b	8a 2c	7a 1b 1c	8a 1b 1* 1d	7a 1b	8a 1c 1d	8a 1d	9a	4a 2b 1c 1d	4c 4d	1a 3b 2c 3d	1a 3b 2c 3d
4	10a	10a	10a	10a	4a 5b 1c	10a	1a 7b 1* 1d	5a 2b 1c 2d	5b 2c 2d	3a 3b 1c 2d	1b 4c 3d	1a 2b 1c 5d	1a 1b 5c 1d	5a 2c 2d	1a 2b 3c 1d	1b 1c 2d	2c 4d	1a 1c 4d
8	10a	10a	10a	10a	4a 6b	10a	1a 6b 1d	1a 7b	7b	1a 6b 1d	4b 1c	3b 1d	4b 1c 2d	2b 1c 4d	1c 4d 1*	1c 1d	2d	2d
24	10a	10a[p] 9a[q] 1b[q]	10a	10a	9a 1b	8a 2b	3a 4b	5a 2b 1c	3a 2b 1c 1d	2a 4b 1d	5b	2b 1c	1c 4d	1c 2d	1d	1d		
48	10a	10a	10a	9a 1c	10a	7a 3b	4a 1b 1c 1d	7a 1b	6a	6b	3a 2b	2b 1d	1d	1d				
72	10a	10a	10a	8a 1b 1c	9a 1b	9a 1c	3a 3b	7a 1d	6a	4b 1c 1d	2a 2b 1d	1c 1d						
96	10a	10a	10a	8a 2b	6a 4b	9a 1b	3a 3b	7a	6a	2b 2c 1d	2a 2c	1b						
%survival	100			100			65.5			31.0			0.0			0.0		

* = damaged during handling , p = first run , q = second run

TABLE 8.25a: THE EFFECT OF COPPER ON THE SURVIVAL AND BEHAVIOUR OF JUVENILE *P. jenkinsi*.

t(h) / CONC (mgl⁻¹) / REP.	RESPONSE (defined in text)																	
	Control			0.04			0.045			0.055			0.075			0.115		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
0	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a
1	10a	9a 1b	6a 4b	9a 1b	9a 1b	7a 3b	8a 1b 1c	5a 4b 1c	5a 5b	6a 4b	6a 4b	5a 5b	6a 4b	5a 5b	7a 3b	6a 3b 1c	5a 4b 1c	2a 6b 2d
2	10a	8a 2b	7a 3b	10a	9a 1b	8a 2b	8a 1b 1c	5a 4b 1c	5a 4b 1d	6a 4b	7a 3b	6a 4b	1a 4b 2c 3d	3a 5b 1c 1d	4a 3b 2c 1d	1a 3b 4c 2d	2a 3b 5c	1a 4b 3c
4	10a	10a	10a	9a 1b	9a 1b	10a	7a 3b	3a 6b 1d	4a 4b 1c	6a 4b	5a 2b 2c 1d	5a 4b 1c	2a 4b 1c	2a 6b 1c	3a 5b 1c	2a 2b 3c 1d	2a 4b 1c 3d	5b 1c 2d
8	10a	9a 1b	10a	9a 1b	9a 1b	10a	7a 3b	3a 6b	4a 4b 1c	4a 5b 1c	4a 4b 1c	3a 7b	2a 2b 2c 1*	6b 3c	3a 6b	3a 2b 2c	2a 3b 2c	1a 1b 4c
24	10a	10a	10a	9a 1b	9a 1b	10a	6a 4b	5a 4b	3a 6b	5a 5b	3a 6b	4a 6b	1a 4b 1c	8b 1c	9b	1b 6c	1a 1b 4c 1d	2b 3c 1d
48	10a	10a	10a	9a 1b	9a 1b	10a	6a 4b	5a 4b	5a 4b	5a 5b	2a 7b	4a 6b	1a 3b 2c	7b 2c	8b 1c	2a 3b 2c	5b 1c	4b 1c
72	10a	10a	10a	9a 1b	10a	9a 1b	6a 4b	5a 4b	5a 3b 1c	4a 5b 1c	1a 7b 1c	3a 7b	5b 1d	7b 1c 1d	8b 1c	5b 1c 1d	3b 1c 2d	4b 1d
96	10a	10a	10a	10a	9a 1b	9a 1b	7a 3b	5a 4b	5a 4b	1a 7b 2c	2a 6b 1c	3a 6b 1d	.5b	8b	5b 4d	2b 1c 3d	1c 3d	2b 2d
%survival	100			100			93.3			93.3			62.1			20.0		

TABLE 8.25b: THE EFFECT OF COPPER ON THE SURVIVAL AND BEHAVIOUR OF FOUR ADULT *E. jenkinsi*.

↓t(h)	RESPONSE (defined in text)																	
→CON. CONC. (mgl⁻¹)	Control			0.04			0.045			0.055			0.075			0.115		
REP. →	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
0	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	10a	5a	5a	5a
1	10a	10a	10a	10a	10a	10a	10a	10a	8a 2*	10a	10a	10a	10a	10a	10a	3a 1b 1d	4a 1d	3a 1c 1d
2	10a	10a	9a 1b	10a	10a	10a	10a	10a	8a	10a	10a	8a 2*	10a	10a	10a	2a 2b	3b 1c	1a 2b 1c
4	10a	10a	10a	10a	10a	10a	10a	10a	8a	10a	10a	8a	10a	10a	10a	2a 2b	2c 2d	2c 2d
8	10a	10a	10a	10a	9a 1b	10a	9a 1b	10a	8a	10a	10a	8a	9a 1b	9a 1b	10a	2a 1c 1d	2c	2c
24	10a	10a	9a 1b	10a	9a 1b	10a	8a 2b	10a	8a	8a 2b	9a 1b	7a 1b	3a 7b	3a 7b	3a 5b 2c	3b	2b	1c 1d
48	10a	10a	10a	10a	10a	10a	10a	10a	8a	6a 4b	7a 3b	6a 1c 1*	1a 4b 3c 2d	3a 4b 2c 1d	9b 1d	1c 2d	1b 1d	1c
72	10a	10a	10a	10a	10	10a	10a	10a	8a	7a 2b 1d	9a 1d	4a 3b	2b 5c 1d	2a 5c 2d	7b 2c	1d	1c	1c
96	10a	9a	10a	10a	10a	10a	10a	10a	8a	6a 2b 1d	9a	5a 2b	5b 1c 1d	1a 2b 2c 2d	5b 2c 1d 1*		1b	1c
%-survival	100			100			100			88.9			62.1			8.0		

TABLE 8.25c: THE EFFECT OF COPPER ON THE SURVIVAL AND BEHAVIOUR OF GLENESCENT P. jenkinsi.

APPENDIX

ANNEXE 2 Physicochemical Data (tables **9.1 - 9.11**).

VARIABLE (mgl^{-1} unless otherwise stated) ↓ SITE →	SAXONS LODE (RUN 1)			SAXONS LODE (RUN 2)		GT. COMBERTN	
DATE →	9.8. 79	6.9. 79	4.10. 79	24.4. 80	22.5. 80	22.4. 80	22.5. 80
Temperature(°C)	18	17.5	15	-	17	-	14
D.O.	8.35	8.7	8.4	14.3	12.0	13.6	8.55
BOD_5	3.3	2.25	2.65	6.0	5.35	11.75	6.65
Chloride	85	69	73	63	92	71	92
pH	7.95	8.0	7.55	8.1	8.3	8.2	8.15
Alkalinity (as $CaCO_3$)	160	138	75	155	165	220	205
Total Hardness (as $CaCO_3$)	252	218	174	238	279	445	488
Calcium Hardness (as $CaCO_3$)	175	148	124	170	240	306	331
Magnesium Hardness (as $CaCO_3$)	77	70	50	68	39	139	157
$N-NH_3$	0.2	0.55	1.4	0.4	0.3	0.2	0.2
$N-NO_3$	4.1	5.3	4.15	6.0	6.0	8.9	8.6
$P-PO_4$	1.1	1.1	1.3	1.1	0.7	2.0	1.9

TABLE 9.1 : PHYSICOCHEMICAL DATA FOR THE IMMERSION PERIOD EXPERIMENTS

VARIABLE (mg.l^{-1} unless otherwise stated)	SITE → / DATE →	Upper Lewd.	Middle Be d.	Ri be-	Stour-port	Ba. ons Lane
		9.8	16.8	16.8	16.8	9.8
Temperature (°C)		17	19	19	19	18
D.O.		8.75	8.3	8.5	8.25	8.35
BOD_5		2.5	0.3	2.65	2.55	3.3
Chloride		45	39	39	39	65
pH		7.8	7.55	7.55	7.55	7.95
Alkalinity (as $CaCO_3$)		130	110	108	108	160
Total Hardness (as $CaCO_3$)		197	167	162	172	252
Calcium Hardness (as $CaCO_3$)		150	118	116	126	175
Magnesium Hardness (as $CaCO_3$)		47	49	44	46	77
$N-NH_3$		0.15	0.3	0.2	0.6	0.2
$N-NO_3$		3.5	3.15	3.15	5.1	4.1
$P-PO_4$		0.5	0.5	0.9	0.9	1.1

TABLE **9.2** : PHYSICOCHEMICAL DATA FOR THE RHITHRON - POTAMON TRANSITION STUDY

VARIABLE (mgl^{-1} unless otherwise stated)	DISTANCE BELOW LOWERMOST RIFFLE				
	100m	200m	400m	800m	1600m
Temperature(°C)	14	14	14	14	13
D.O.	9.4	9.35	9.25	8.9	8.55
BOD_5	2.9	3.15	3.75	3.05	3.8
Chloride	58	57	58	58	57
pH	7.8	7.8	7.8	7.8	7.8
Alkalinity (as $CaCO_3$)	145	145	150	150	150
Total Hardness (as $CaCO_3$)	242	240	241	242	241
Calcium Hardness (as $CaCO_3$)	185	186	184	184	185
Magnesium Hardness (as $CaCO_3$)	57	54	57	58	56
$N-NH_3$	0.2	0.2	0.1	0.2	0.1
$N-NO_3$	5.2	5.4	5.2	5.4	5.2
$N-NO_2$	0.015	0.005	0.01	0.005	0.005
$P-PO_4$	0.1	0.1	0.2	0.2	0.4

TABLE 9.3 : PHYSICOCHEMICAL DATA FOR SAMPLING SITES BELOW THE LOWERMOST RIFFLE IN THE R. SEVERN ON 23.5.80

VARIABLE· CHANNEL→ (mgl^{-1} unless otherwise stated) PERCENTILE→		A			B			C		
		5	50	95	5	50	95	5	50	95
Temperature (°C)	a	-	3.0	5.5	-	3.5	6.0	-	4.5	6.5
	b	6.5	9.0	12.0	7.5	10.5	12.7	9.5	12.0	13.5
	c	3.0	4.4	5.9	4.0	5.4	6.9	4.3	5.5	6.8
Suspended Solids	a	-	8	92	-	10	90	-	12	59
	b	1	5	15	2	8	19	3	11	29
	c	3	9	89	1	12	49	2	14	31
D.O.	a	-	13.3	15.8	-	12.5	14.4	-	11.9	13.4
	b	9.7	11.0	12.5	8.9	10.0	11.5	7.0	8.5	10.0
	c	10.2	12.1	13.3	8.2	11.5	12.6	8.2	10.4	11.8
Chloride	a	-	61	240	-	72	250	-	108	265
	b	33	42	50	63	77	102	83	100	124
Conductivity (µS	a	-	365	600	-	425	730	-	555	736
	b	340	460	670	460	600	760	580	690	905
	c	275	440	500	370	550	655	400	625	780
pH	a	-	7.7	8.0	-	7.3	7.5	-	7.3	7.6
	b	7.9	8.1	8.3	7.4	7.6	7.8	7.2	7.4	7.8
	c	7.6	7.9	8.0	7.3	7.7	7.8	7.1	7.2	7.5
Alkalinity (as $CaCO_3$)	a	-	150	170	-	150	175	-	175	200
	b	150	165	175	145	165	180	140	160	195
	c	90	130	150	90	150	180	110	160	190
Total Hardness (as $CaCO_3$)	a	-	320	365	-	320	380	-	365	390
	b	245	315	340	300	340	375	310	350	395
	c	64	250	270	64	249	296	60	260	308
Calcium Hardness	a	-	240	260	-	240	265	-	270	550
Magnesium Hardns.	a	-	90	115	-	90	125	-	90	130
$N-NH_3$	a	-	0.7	1.4	-	1.8	2.5	-	2.3	3.8
	b	0.5	1.0	2.5	1.0	1.5	6.5	1.0	2.0	7.5
	c	0.3	0.5	1.2	0.5	1.4	2.9	0.8	1.7	4.1
$N-NO_3$	a	-	4.3	5.2	-	5.1	7.2	-	8.0	10.4
	b	2.5	3.5	4.15	6.4	9.45	11.35	10.1	13.5	14.7
	c	3.0	3.4	4.4	4.0	5.9	7.0	5.0	6.9	8.1
$P-PO_4$	a	-	0.3	0.4	-	2.5	3.1	-	4.3	5.1
	b	0.1	0.4	1.5	2.1	2.9	3.9	3.1	4.6	5.3
Filtrable Cadmium	a	-	.002	.002	-	.004	.005	-	.006	.009
	b	.001	.002	.003	.003	.004	.006	.004	.006	.010
	c	.001	.002	.004	.003	.006	.009	.004	.007	.014
Chromium	a	-	.01	.01	-	.01	.04	-	.02	.12
	b	.001	.003	.005	.005	.010	.032	.008	.016	.078
	c	.001	.003	.005	.005	.013	.045	.007	.019	.086
Copper	a	-	.002	.008	-	.012	.026	-	.018	.030
	b	.001	.003	.008	.011	.016	.025	.020	.024	.038
	c	.002	.005	.011	.005	.014	.030	.012	.018	.032
Lead	a	-	.01	.015	-	.02	.03	-	.02	.03
	b	.005	.015	.02	.015	.025	.035	.02	.035	.05
	c	.005	.021	.035	.020	.048	.108	.036	.060	.105
Nickel	a	-	.01	.015	-	.015	.02	-	.02	.03
	b	.004	.007	.011	.007	.014	.023	.012	.020	.035
	c	.005	.010	.016	.008	.012	.020	.010	.014	.019
Zinc	a	-	.06	.10	-	.11	.15	-	.13	.17
	b	.003	.003	.015	.012	.060	.090	.030	.100	.148
	c	.015	.030	.058	.066	.100	.162	.100	.138	.190

TABLE 9.4 : PHYSICOCHEMICAL DATA FOR THE CHECKLEY CHANNELS, (a). JANUARY - MARCH 1979, (b). AUGUST - NOVEMBER 1979, (c). FEBRUARY - MARCH 1980. (Data courtesy of the research team at Checkley Applied Hydrobiology Field Station)

↓VARIABLE (mg l^{-1} unless otherwise stated) SITE →	Tean 1						Tean 2	Tean 3					
	n	$\bar{x}$	S.D.	S.E.	Min.	Max.		n	$\bar{x}$	S.D.	S.E.	Min.	Max
Temperature (°C)	12	8.5	3.5	1	4	14	-	12	9.5	4.5	1	3.5	16
D.O.	12	10.35	1.25	0.35	8.3	12.0	9.1	11	9.05	1.3	0.4	6.2	11.1
BOD_5 (unsupp.)	10	3.3	2.4	0.75	1.3	8.1	8.7	10	3.5	1.3	0.4	0.5	5.05
Chloride	10	47	22	7	31	101	65	10	85	111	35	33	400
pH	6	7.25	0.2	0.1	7.0	7.5	7.45	6	7.3	0.1	0.05	7.1	7.4
Alkalinity (as $CaCO_3$)	10	131	29	9	75	170	153	11	170	51	15	90	250
Total Hardness (as $CaCO_3$)	12	211	32	9	164	267	244	12	265	44	13	200	354
Calcium Hardness (as $CaCO_3$)	12	157	26	8	123	192	166	12	184	27	8	143	240
Magnesium Hardness (as $CaCO_3$)	12	55	13	4	39	83	78	12	82	20	6	50	124
$N-NH_3$	12	0.4	0.3	0.1	0.1	1.1	0.8	11	0.6	0.4	0.1	0.2	1.5
$N-NO_3$	12	3.0	1.25	0.35	0.5	4.0	7.15	11	6.0	2.95	0.9	0.6	11.0
$P-PO_4$	12	0.6	0.3	0.1	<0.1	1.1	3.9	11	2.7	1.4	0.4	0.5	4.4

TABLE 9.5 : PHYSICOCHEMICAL DATA FOR THE R. TEAN AUGUST 1979 - JULY 1980.
(Tean 1 & 3 data courtesy H. Hirst)

Variable → / Site No. ↓	TEMPERATURE (^{o}C)					SUSPENDED SOLIDS (mg l^{-1})					D.O. (mg l^{-1})					D.O. (% Sat.)					5 DAY BOD (ATU) (mg l^{-1})				
	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.
1a	26	9.9	1.0	2	18.5	24	25	6	4	116	25	10.4	0.4	7.6	13.6	25	91	2	76	112	24	3.3	0.3	1.5	7.4
1b	12	9.5	1.6	2.5	17.5	12	31	8	8	100	12	10.9	0.5	7.9	13.6	12	95	3	82	121	12	4.1	0.6	2.4	8.5
2	26	10.3	1.0	2	19	24	35	9	5	197	24	10.7	0.4	7.1	13.6	24	95	2	77	118	24	3.8	0.5	1.8	>10
3	12	10.1	1.6	2	17.5	12	22	8	4	102	11	11.3	0.8	6.6	14.2	11	97	5	69	126	12	2.9	0.6	1.0	8.4
4	46	10.6	0.8	2.5	21	47	26	4	5	148	44	10.8	0.3	6.6	13.9	44	96	2	71	128	47	2.9	0.2	1.2	6.9
5	47	10.1	0.8	2.5	25	49	34	6	8	172	48	10.4	0.2	6.8	13.1	47	92	2	73	138	49	3.0	0.2	1.4	7.7
6	23	10.5	1.2	2	21.5	24	34	9	6	190	23	10.3	0.5	5.8	13.3	23	90	3	61	120	24	2.6	0.3	1.2	6.1
8	48	10.5	0.8	2	21	48	41	6	9	195	48	10.5	0.3	6.0	13.8	49	93	2	66	134	48	2.8	0.2	1.1	9.4
9	23	11.5	1.0	3.5	20	24	24	5	6	91	22	9.2	0.3	6.3	11.4	21	84	2	64	110	21	4.1	0.2	2.3	5.8
10	49	18.5	0.8	8	28.5	25	22	3	7	50	25	8.9	0.3	6.0	11.2	24	88	3	63	126	25	3.5	0.2	1.8	5.8
11	49	13.4	0.8	5.5	24	49	24	2	7	94	49	10.0	0.2	7.6	12.2	49	95	1	80	122	49	3.9	0.2	2.0	11.3
12	52	11.2	0.8	1	20	52	13	4	2	207	52	9.5	0.3	4.4	15.3	52	88	4	48	164	49	2.6	0.1	1.1	6.2
13	46	10.1	0.9	1	20.5	47	18	2	3	90	47	9.5	0.4	4.5	17.0	46	86	4	37	190	45	3.0	0.3	1.3	10.1
14	6	11.7	2.2	7	19	6	29	15	10	102	6	10.9	0.7	7.9	12.8	6	99	7	85	130					
15	55	11.1	0.8	1	20	55	19	2	< 5	72	55	10.7	0.2	8.6	13.6	55	97	2	74	139	23	3.3	0.3	0.7	7.9
16	39	10.2	0.9	3	20	39	23	3	< 7	70	39	10.9	0.3	7.0	17.0	39	97	3	74	176	23	4.3	0.7	0.7	13.8
17	29	11.5	1.1	4	21	29	27-28	7	< 5	161	27	11.9	0.6	6.9	23.3	27	110	8	73	256	25	2.2	0.4	0.5	10.4
19	46	4.1	2.4	1	20	49	25	3	8	91	49	6.2	0.3	1.5	11.4	47	54	2	16	86	48	6.6	0.3	3.0	13.0
20	10	9.6	1.8	2.5	20	11	24	3	9	46	11	9.1	0.7	4.8	12.1	11	76	4	50	94	11	3.6	0.4	1.8	6.4
21	12	10.8	1.9	1	22	18	54	9	5	135	12	8.8	0.7	5.0	12.7	12	80	4	59	97	12	2.9	0.4	1.1	5.4
22	41	13.1	0.8	5	22	41	29	6	4	209	41	7.9	0.3	2.8	11.1	40	76	2	31	96	39	6.1	0.4	2.3	13.0
23	41	12.8	0.3	5	22.5	41	37	10	6	377	40	7.5	0.4	2.7	13.8	38	72	3	30	112	39	5.7	0.6	1.3	18.3
25	43	11.7	0.8	3	21.5	44	48	13	4	495	44	8.6	0.3	3.6	14.1	41	80	2	32	114	38	4.9	0.4	1.1	14.6
27	43	11.0	0.8	2	20	42	30	4	5	142	43	10.0	0.2	5.9	13.5	43	93	1	62	118	37	2.4	0.1	0.9	4.7

TABLE **9.6** a: PHYSICAL AND OXYGEN RELATED DATA

TABLES **9.6** a - f : WATER AUTHORITY PHYSICOCHEMICAL DATA FOR LOWLAND RIVER SAMPLING SITES

Variable / Site # No	Cl^- (mg l^{-1})					F^- (mg l^{-1})					COND. (micsm)					pH					ALK (mg l^{-1} $CaCO_3$)					HARD. (mg l^{-1} $CaCO_3$)					ANIONIC DET. (mg l^{-1})				
	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.
1a	24	81	4	34	120						24	914	31	620	1240	24	7.9	0.1	7.6	8.6	20	171	6	115	200	20	389	14	290	470	11	.18	.04	<.05	.45
1b	12	80	8	30	130						12	916	56	560	1290	12	8.0	0.1	7.6	8.8	7	176	6	150	190	7	396	21	320	470					
2	24	63	4	31	100	12	.3	.0	.27	.4	24	879	35	570	1300	24	8.0	0.1	7.4	8.9	25	180	5	120	230	25	410	12	270	510	15	.19	<.05		.35
3	12	64	4	42	82						12	903	37	595	1050	12	8.0	0.1	7.5	8.7	8	179	8	155	210	8	423	18	310	465					
4	47	63	3	32	96	10	.3	.0	.2	.42	47	902	21	570	1250	47	8.0	0.0	7.3	8.9	39	192	4	150	240	39	421	10	270	530	14	.20	<.04	<.05	.60
5	49	48	3	16	99	12	.1	.0	.1	.2	48	475	22	250	920	49	7.7	0.1	6.8	8.8	40	117	6	< 50	190	39	202	8	105	280	14	.07	<.01	<.02	.20
6	24	47	4	16	100	1	.1	-	.1	.1	24	484	42	220	1150	24	7.7	0.1	7.1	8.5	20	118	9	63	195	20	212	11	130	300	7	.08	<.01	<.05	.13
8	48	53	4	17	175	12	.2	.0	.1	.3	48	566	22	270	880	48	7.8	0.1	7.0	8.9	39	131	6	7.4	210	39	255	9	145	360	14	.09	<.01	<.02	.20
9	21	83	5	37	139						21	838	28	510	1020	21	7.6	0.0	7.3	7.8	15	153	5	105	178	15	344	14	203	420	7	.10	.02	.05	.21
10	25	84	5	42	149						25	834	25	530	1060	25	7.6	0.0	6.9	7.8	18	150	5	106	175	18	340	12	216	420	7	.09	.02	.05	.20
11	48	89	3	39	146	12	.4	.0	.27	.56	48	871	21	520	1090	48	7.6	0.0	7.3	7.9	40	157	3	113	187	40	349	8	222	445	23	.09	.00	.03	.18
12	52	58-59	1	43	75	11	.32	.08	.23	.50	52	858	21	670	1330	52	8.1	0.0	7.5	8.7	51	219	3	125	260	2	385	10	374	395	52	.03-.04	.00	.02	.09
13	47	160-164	≥ 6	54	244	11	.59	.06	.38	.95	47	1955	75	200	2950	47	8.0	0.0	7.3	8.7	46	196	4	104	245	2	925	75	850	1000	47	.05	.00	.02	.16
14	6	57	6	45	83						6	832	25	775	920	6	8.2	0.2	7.8	8.9	6	193	10	160	220									
15	55	65	2	26	92	12	.30	.01	.22	.37	55	919	17	620	1130	55	8.1	0.0	7.7	9.0	55	200	2	140	245	12	386	13	285	437	5	.09-.17	≥.03	<.14	.28
16	39	62	3	31	90	12	.30	.01	.22	.36	39	920	19	650	1180	39	8.1	0.1	7.8	9.2	39	201	3	140	225	12	392	14	307	481	5	<.14	.00	<.14	<.14
17	29	45	1	26	56	12	.24	.01	.20	.28	29	812	17	590	955	29	8.3	0.1	7.7	9.0	29	191	5	105	225	12	385	11	279	438	4	.05-.15	≥.01	<.14	.18
19	48	116	6	32	242						49	887	36	390	1450	49	7.1	0.0	6.8	7.6	46	124	4	65	180						34	.38	.04	.05	.98
20	11	221	35	92	488						11	1325	144	810	2300	11	7.5	0.1	7.1	7.9	10	164	5	150	205									
21*	18	3162	750	350	10500						18	9541	779	2900	27500	18	8.0	0.1	7.2	8.5	18	141	6	106	185						33	.05-.06	.00	<.05	.14
22	42	108	6	37	201	20	.21	.01	.11	.32	39	954	47	464	1536	40	7.3	0.0	7.1	7.6	21	87	7	1	133	22	232	11	138	314	18	.51	.05	.21	.87
23	42	108	7	32	308	20	.18	.01	.09	.24	39	899	47	461	1503	40	7.2	0.0	6.9	7.5	21	66	5	29	105	22	195	10	110	278	19	.41	.03	.22	.74
25	45	185	11	48	320	21	2.29	.35	.13	5.00	44	1380	56	499	1846	44	7.5	0.0	7.3	8.0	23	121	7	56	164	23	327	16	148	426	22	.34	.02	.20	.51
27	46	24	1	11	36	19	.17	.01	.12	.26	47	473	18	243	679	47	7.5	0.1	6.7	8.2	47	125	5	59	184	46	202	8	60	290	21	.06	.00	.0-	.15

TABLE 9.6 b: CHLORIDE, FLUORIDE, CONDUCTIVITY, pH, ALKALINITY, TOTAL HARDNESS AND ANIONIC DETERGENT DATA.

* detergent sample taken from Frodsham.

Variable → / Site + No	N - NH_3					TON					N - NO_3					N-NO_2					P-PO_4					SO_4					TOTAL Fe					TOTAL Mn				
	n	$\bar{x}$	S.E.	Min	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.
1a	25	.51	.12	.02	2.9	25	10.1	0.4	4.0	14.2	1	11.0	-	11.0	11.0						12	1.7	0.2	.73	2.9															
1b	12	.22	.05	<.05	.60	12	9.3	0.7	3.4	13.0																													
2	25	.25	.05	<.05	1.2	25	9.1	0.4	3.4	13.5	1	10.95	-	10.95	10.95						24	1.2	<0.1	.3	2.7	12	186	<15	91	265	7	.54	.22	<.04	1.6	7	.04	.00	.03	.08
3	12	.10	.02	.02	.24	12	9.4	0.4	6.2	12.0																													
4	47	.15	.02	<.01	1.2	47	9.1	0.2	3.8	11.6											23	1.2	<0.1	.34	2.4	7	179	<19	85	250	5	.86	.59	.20	3.23	5	.04	.01	.02	.10
5	49	.18	.01	.02	.50	49	4.8	0.2	2.0	7.8											22	0.4	<0.1	.05	.85	11	60	< 7	37	97	7	.58	.25	.16	2.1	7	.07	.02	.03	.20
6	24	.15	.02	<.05	.50	24	4.9	0.2	2.7	6.5											12	0.4	<0.1	.09	.85	1	73	-	73	73										
8	47	.14	.01	<.01	.40	48	5.6	0.2	<.05	7.3	1	6.55	-	6.55	6.55						25	0.5	<0.1	.10	1.2	12	91	< 9	53	144	8	.59	.28	<.04	2.5	8	.06	.02	<.01	.20
9	23	.51	.07	.1	1.6	23	8.2	0.3	5.5	10.7											8	1.4	0.2	.40	2.3															
10	57	.25	.03	<.1	1.3	57	8.5	0.2	5.6	11.1											12	1.4	0.2	.40	2.16															
11	49	.28	.03	<.1	1.1	49	7.9	0.1	6.1	10.3											26	1.4	0.1	.28	2.05	12	177	11	109	227	12	.55	.05	.26	.96	12	.12	.01	.06	.25
12	52	.19-.20	≥ .02	<.05	.61						52	9.29	.56	3.4	20.5	3	.05	≥.02	<.02	.10	50	0.5	≥0.0	<.02	1.16	52	142	11	53	368	15	.35	.07	.01	.99	11	.11	.03	.01	.32
13	47	.45-.46	≥ .06	<.05	1.55						47	12.43	1.30	2.2	43.8	2	.02-.03	≥.00	<.02	.03	46	0.4	≥0.1	<.02	1.38	47	677	40	298	1105	13	.48	.13	.06	1.93	9	.24	.06	.04	.51
14	6	.24-.25	≥ .10	<.05	.68						6	10.29	.83	7.3	12.8	6	.11	.01	.07	.16	6	1.2	0.3	.38	2.57	6	150	7	126	177										
15	55	.48-.49	≥ .07	<.05	1.85						55	10.26	.22	6.77	15.00	55	.12	.01	.04	.25	55	1.1	0.1	.15	2.46	55	179	4	106	224	12	1.32	.53	.41	5.92	12	.02-.03	≥.00	< .02	.06
16	39	.33-.34	≥ .05	<.05	1.3						39	10.15	.28	6.80	13.00	39	.09	.01	.03	.24	27	0.9	0.1	.19	1.98	34	181	5	115	234	12	1.33	.52	.19	5.20	12	.04	.00	.03	.07
17	29	.12-.15	≥ .03	<.05	.57						29	7.57	.51	3.92	13.50	29	.08	.01	.04	.14	27	0.3	0.0	.01	.71	29	164	4	102	201	12	1.70	1.04	.13	12.80	11	.03-.04	≥.01	< .02	.10
19	49	5.81	.39	.8	11.4						49	2.11	.12	< .15	3.9	49	.17	.01	.06	.38	48	0.7	0.1	.1	2.2						45	1.17	.08	.50	2.80	45	.28	.01	.20	.42
20	11	1.49	.17	1.0	2.7						11	7.79	.41	5.95	10.4	11	.25	.04	.08	.54	11	0.6	0.1	.2	1.4															
21*	18	6.50	1.29	1.3	22.65						18	6.99	.24	4.95	8.6	18	.29	.07	.08	1.20	12	0.3	0.1	<.1	.7						42	.61	.11	.05	3.61	43	.12	.01	.03	.22
22	42	2.34	.18	.25	4.53						38	5.15	.20	2.93	9.20	40	.38	.06	.08	2.14	21	0.6	0.1	<.01	1.74	22	172	13	92	296	20	1.18	.14	.55	2.58					
23	41	3.11	.22	.57	6.15						39	4.38	.15	3.05	7.17	40	.39	.06	.06	2.24	21	0.3	0.1	.03	.88	22	165	14	67	300	20	1.27	.09	.52	2.05					
25	44	5.82	.47	.88	14.70						42	5.79	.15	3.55	8.38	43	.48	.06	.05	1.89	22	0.4	0.1	.04	.98	23	248	16	87	373	22	2.43	.76	.63	16.50					
27	46	< .15	≥ .01	<.05	.41						46	3.75	.18	1.3	7.4	46	.05	.00	.02	.10	47	0.3	0.0	.09	.89	20	55	4	29	98	21	1.07	.25	.17	4.95					

TABLE 9.6 c: NITROGENOUS COMPOUNDS, ORTHOPHOSPHATE, SULPHATE, IRON AND MANGANESE (mg l^{-1})

* Metal samples taken from Frodsham

Variable / Site No.	Cd					Cr					Cu					Pb					Hg ($\mu g\ l^{-1}$)					Ni					Zn				
	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.
1a	12	<.01	.00	<.01	<.01	12	<.03	.00	<.03	<.03	12	<.02	.00	<.02	.02	12	<.04	.00	<.04	.08						12	.01-03	.00	<.03	.05	12	.05	.00	.03	.08
1b																																		
2	24	<.01	.00	<.01	<.01	24	<.03	.00	<.03	<.03	24	.01-.02	.00	<.02	.06	24	<.04	.00	<.01	.09						24	.01-03	.00	<.03	.06	24	.04	.00	<.01	.06
3																																		
4	23	<.01	.00	<.01	<.01	23	<.03	.00	<.03	.03	23	.01-.02	.00	<.02	.03	23	.01-.04	.00	<.04	.09						23	.01-.03	.00	<.03	.06	23	.03	.00	.01	.05
5	24	<.01	.00	<.01	<.01	23	<.03	.00	<.03	<.03	23	< .02	.00	<.02	<.02	23	< .04	.00	<.04	.04						23	<.03	.00	<.08	<.03	23	.04	.00	.01	.08
6	12	<.01	.00	<.01	<.01	12	<.03	.00	<.03	<.03	12	< .02	.00	<.02	<.02	12	< .04	.00	<.04	<.04						12	<.03	.00	<.03	<.03	12	.02	.00	<.01	.03
8	25	<.01	.00	<.01	<.01	25	<.03	.00	<.03	<.03	25	< .02	.00	<.02	.04	25	< .04	.00	<.04	.05						25	<.03	.00	<.03	<.03	25	.04	.00	<.01	.13
9	10	<.01	.00	<.005	<.01	10	.01	.00	<.01	.02	10	.03	.00	.02	.06	10	.01	.00	<.01	.01						10	.04	.00	.01	.06	10	.06	.00	.04	.08
10	14	<.01	.00	<.005	<.01	14	.01	.00	<.01	.02	14	.03	.00	.01	.04	14	.01	.00	<.01	.01						14	.03	.00	.01	.08	14	.06	.00	.05	.09
11	28	<.01	.00	<.005	<.01	28	.01	.00	<.01	.02	28	.02	.00	.01	.06	28	.02	.00	<.01	.10						28	.02	.00	.01	.04	28	.08	.00	.08	.17
12	13	<.01	.00	<.01	<.01	13	<.01	.00	<.01	<.01	13	<.01	.00	<.01	<.01	13	<.01	.00	<.01	<.01						13	.01	.00	.01	.02	13	.02	.00	<.01	.04
13	11	<.01	.00	<.01	<.01	11	<.01	.00	<.01	<.01	11	<.01	.00	<.01	.04	11	<.01	.00	<.01	.03						11	.01-.02	.00	<.01	.03	11	.02	.00	.01	.06
4																																		
15	12	<.001	.00	<.00	<.001	12	.012	.00	.005	.023	12	.003-.007	.00	.006	.011	12	.010-.038	.00	<.037	.044	3	<1.05	.00	<1.05	<1.05	12	.004-.007	.00	<.006	.010	12	.009-.023	.00	<.020	.038
16	12	<.001	.00	<.001	<.001	12	.009	.00	.008	.024	12	.003-.008	.00	<.006	.020	12	<.040	.00	<.037	<.040	4	<1.05	.00	<1.05	<1.05	12	.003-.007	.00	<.006	.010	12	.015-.025	.00	.020	.042
17	12	<.001	.00	<.001	<.001	12	.004	.00	<.002	.023	12	.006-.016	.00	<.006	.045	12	<.040	.00	<.037	<.040	4	<1.05	.00	<1.05	<1.05	12	.003-.007	.00	<.006	.011	12	.010-.023	.00	<.020	.038
19	46	<.01	.00	<.01	.01	45	<.02	.00	<.02	.06	46	<.02	.00	<.02	.06	46	<.05	.00	<.05	.16	45	.12-.17	.03	< .1	1.1+	46	<.03	.00	<.03	.07	45	.05	.00	.01	.15
20																																		
21*	43	<.01	.00	<.01	<.01	43	<.02	.00	<.02	.04	43	<.02	.00	<.02	.08	43	.07-.09	.00	<.05	.28	43	10.15	1.18	.9	34.1+	43	<.03	.00	<.03	.03	43	.02	.00	<.01	.09
22	20	<.001	.00	<.001	.003	20	.017	.00	.001	.036	20	.022	.00	.09	.045	20	.014	.00	.003	.088	18	<.44	≥.05	.28	.94	20	.018	.00	.005	.035	20	.04	.00	<.01	.09
23	20	<.001	.00	<.001	.002	20	.018	.00	.006	.034	20	.016	.00	.008	.035	20	.013	.00	.004	.031	18	<.33	≥.04	<.10	.78	20	.016	.00	.005	.033	20	.05	.00	<.02	.13
25	22	<.001	.00	<.001	.003	22	.015	.00	.002	.079	22	.017	.00	.002	.077	22	.017	.00	.002	.087	19	<.52	≥.10	<.28	1.96	22	.061	.00	.021	.128	22	.07	.00	.01	.28
27	20	<.001	.00	<.001	.002	21	<.003	.00	<.002	.015	21	.007	.00	<.002	.018	21	.019	.00	.005	.084	5	<.34	≥.06	<.08	1.10	21	<.004	.00	<.004	.007	21	.03	.00	<.01	.10

TABLE 9.6 d: TOTAL HEAVY METALS ($mg\ l^{-1}$)

* Samples taken from Frodsham

Variable → / Site ↓No.	Cd					Cr					Cu					Pb					Ni					Zn				
	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.	n	$\bar{x}$	S.E.	Min.	Max.
1a	12	<.01	.00	<.01	<.01	12	<.03	.00	<.03	<.03	12	<.02	.00	<.02	<.02	12	<.04	.00	<.04	<.04	12	.01-.03	.00	.03	.05	12	.03	.00	.02	.05
2	24	<.01	.00	.0006	<.01	24	<.03	.00	<.01	<.03	24	<.02	.00	<.01	.04	24	<.04	.00	< .01	<.04	24	.01-.03	,00	<.03	.05	24	.02	.00	< .01	.03
3																														
4	23	<.01	.00	<.01	<.01	23	<.03	.00	<.03	<.03	23	<.02	.00	<.02	.02	23	<.04	.00	< .04	<.04	23	<.03	.00	<.03	<.03	23	.02	.00	.01	.04
5	24	<.01	.00	<.01	<.01	23	<.08	.00	<.03	<.08	23	<.02	.00	<.02	<.02	23	<.04	.00	< .04	<.04	23	<.03	.00	<.03	<.03	23	.02	.00	< .01	.04
6	12	<.01	.00	<.01	<.01	12	<.03	.00	<.03	<.03	12	<.02	.00	<.01	<.02	12	<.04	.00	< .04	<.04	12	<.03	.00	<.03	<.03	23	.02	.00	< .01	.04
8	25	<.01	.00	<.01	<.01	25	<.03	.00	<.03	<.03	25	<.02	.00	<.01	<.02	25	<.04	.00	< .04	<.04	25	<.03	.00	<.03	<.03	12	.02	.00	< .01	.03
9	8	<.01	.00	<.005	<.01	8	.01	.00	<.01	.02	8	.02	.00	.02	.04	8	<01	.00	< .01	.01	8	.03	.00	.01	.05	8	.04	.00	.03	.07
10	12	<.01	.00	<.005	<.01	12	.01	.00	<.01	.02	12	.02	.00	.01	.03	12	<01	.00	< .01	.01	12	.03	.00	.01	.07	12	.03	.00	.02	.05
11	27	<.01	.00	<.005	<.01	27	.01	.00	<.01	.02	27	.02	.00	.01	.05	27	<01	.00	< .01	.02	27	.02	.00	.01	.04	27	.05	.00	.01	.11
12																														
13																														
14																														
15																														
16																														
17																														
19																														
20																														
21																														
22	20	<.001	.00	<.001	.001	20	.007	.00	<.002	.015	20	.014	.00	.002	.029	20	.004	.00	<.001	.014	20	.013	.00	<.004	.080	20	.04	.00	<.01	.08
23	20	<.001	.00	<.001	.001	20	.008	.00	<.002	.020	20	.010	.00	<.002	.023	20	.005	.00	<.001	.013	20	.011	.00	<.004	.023	20	.04	.00	<.01	.08
25	21	<.001	.00	<.001	.002	21	.003-.004	.00	<.002	.037	21	.008	.00	<.002	.028	21	.004	.00	<.001	.014	21	.052	.00	<.013	.120	21	.04	.00	<.01	.09
27	21	<.001	.00	<.001	.001	21	<.002	.00	<.002	<.002	21	.005	.00	<.002	.014	21	.005	.00	<.001	.019	21	<.004	.00	<.004	.006	21	.02	.00	<.01	.05

TABLE 9.6 e: HEAVY METALS AS FILTRATE ($mg\ l^{-1}$)

Variable → / Site ↓ No	α-BHC (HCH)					γ-BHC (HCH)					ALDRIN					DIELDRIN					ENDRIN					pp-DDE					pp-DDT					HEPTACHLOR				
	n	x̄	S.E.	Min.	Max.	n	x̄	S.E.	Min.	Max.	n	x̄	S.E.	Min.	Max.	n	x̄	S.E.	Min.	Max.	n	x̄	S.E.	Min.	Max.	n	x̄	S.E.	Min.	Max.	n	x̄	S.E.	Min.	Max.	n	x̄	S.E.	Min.	Max.
1a						8	50	<10	<10	140	9	<20	-	<10	<20	9	<50	-	<10	< 50	9	<100	-	<10	<100						9	<100		< 50	<100					
1b																																								
2						9	50	<10	20	110	9	<20	-	< 10	< 20	9	< 50		< 10	< 50	9	<100	-	<10	<100						9	<100		< 50	<100					
3																																								
4						9	40	<20	<10	100	9	<20	-	< 10	< 20	9	< 50	-	< 10	<50	9	<100	-	<10	<100						9	<100		< 50	<100					
5						6	30	<10	10	80	6	<20	-	< 10	< 20	6	400-450	-	< 20	2500	6	<100	-	<100	<100						6	<100		<100	<100					
6																																								
8						8	20	<10	<10	40	7	<20	-	< 10	< 20	8	< 50	-	< 10	< 50	8	<100	-	<100	<100						8	<100		<100	<100					
9																																								
10																																								
11						12	100	<40	<10	640	12	<10	-	< 10	<10	12	<10	-	< 10	< 10	12	< 10	-	<10	< 10	12	<10	-	<10	<10	12	< 10	-	< 10	< 10	12	<10	-	<10	<10
12						3	21	5	11	28	3	<0.7	-	<0.5	<1.1	3	2.3	0.7	1.4	3.7	2	< 15	-	<10	< 20	3	< 0.5	-	< 0.4	< 0.5	3	< 1.8	-	< 1	< 3.3	3	10.7	1.3	8.4	13.0
13						3	121	82	11	281	3	0.4-0.7	≈0.2	<0.5	1.1	3	2.2	1.1	1.0	4.4	2	< 13	-	< 5	< 20	3	0.5	≈0.2	< 0.1	0.7	3	< 1.8	-	< 1	< 3.3	3	11.2	1.9	7.7	14.0
14																																								
15	3	4.2	1.4	2.1	6.9	3	37	27	8	91	3	< 2	-	< 2	<2	3	< 4	-	< 4	<4	3	< 7	-	< 7	< 7	3	< 5	-	< 5	<5	3	< 23	-	< 23	< 23	3	< 2	-	<2	< 2
16	3	5.0	1.3	2.7	7.2	3	28	20	6	68	3	< 2	-	< 2	<2	3	< 4	-	< 4	<4	3	< 7	-	< 7	< 7	3	< 5	-	< 5	<5	3	< 23	-	< 23	< 23	3	< 2	-	<2	< 2
17	3	11.9	8.4	2.4	28.6	3	56	49	6	153	3	< 2	-	< 2	<2	3	< 4	-	< 4	<4	3	< 7	-	< 7	< 7	3	< 5	-	< 4	<5	3	< 23	-	< 23	< 23	3	< 2	-	<2	< 2
19																																								
21																																								
22	11	<14	>7	<1	79	19	168	14	75	279	8	< 1	0	< 1	1	17	103	9	53	163	8	< 10	-	<10	< 10						7	< 5	-	< 5	< 5					
23	16	38	>9	<1	111	19	160	16	18	275	8	< 1	-	< 1	<1	18	241	47	17.5	898	8	< 10	-	<10	< 10						8	< 5	-	< 5	< 5					
25	9	< 5	>3	<1	29	20	165	> 143	<5	2883	8	< 1	-	< 1	<1	8	< 2	-	<2	< 2	8	< 10	-	<10	< 10						8	< 5	-	< 5	< 5					
27	10	< 2	0	<1	5	17	16	3	3	59	8	< 1	-	< 1	<1	9	< 2	0	<2	2	8	< 10	-	<10	< 10						8	< 5	-	< 5	< 5					

TABLE 9.6 f: PESTICIDES ($ng\,l^{-1}$)

SITE →	EVESHAM						TEWKESBURY						SAXONS LODE						HAW BRIDGE					
↓ VARIABLES	n	$\bar{x}$	S.E.	S.D.	Min.	Max.	n	$\bar{x}$	S.E.	S.D.	Min.	Max	n	$\bar{x}$	S.E.	S.D.	Min.	Max.	n	$\bar{x}$	S.E.	S.D.	Min.	Max
Dissolved Oxygen ($mg\ l^{-1}$)	12	10.4	0.57	1.99	6.9	14.2	12	10.7	0.61	2.10	7.3	14.6	12	10.8	0.71	2.46	6.4	15.5	4	12.4	0.85	1.70	11.3	14.9
5-Day BOD ($mg\ l^{-1}$)	10	5.25	0.74	2.34	2.6	8.05	10	3.25	0.52	1.64	1.9	7.5	10	3.05	0.45	1.41	1.9	6.25	3	4.3	1.33	2.31	2.65	6.95
Chloride ($mg\ l^{-1}$)	12	68	4.47	15.47	45	92	12	61	4.36	15.10	37	89	12	52	5.93	20.53	28	91	4	56	7.70	15.39	42	71
pH	12	7.6	0.08	0.26	7.1	8.05	12	7.65	0.09	0.33	7.05	8.4	12	7.5	0.12	0.43	7.1	8.3	4	7.85	0.16	0.33	7.5	8.3
Alkalinity ($mg\ l^{-1}\ CaCO_3$)	12	195	6.48	22.45	155	225	12	205	6.80	23.56	120	230	12	115	8.73	30.25	75	170	4	145	11.97	23.94	120	175
Total Hardness ($mg\ l^{-1}\ CaCO_3$)	12	416	14.61	50.63	300	464	12	415	15.39	53.33	295	478	12	183	13.00	45.0	125	266	4	252	19.47	38.94	207	302
Calcium Hardness ($mg\ l^{-1}\ CaCO_3$)	12	301	10.49	36.32	227	350	12	304	11.40	39.48	214	352	12	135	9.60	33.24	96	195	4	184	16.06	32.12	148	226
Magnesium Hardness ($mg\ l^{-1}\ CaCo_3$)	12	115	6.05	20.94	73	154	12	112	4.54	15.73	81	134	12	49	3.91	13.54	29	71	4	68	4.14	8.29	59	76
Ammoniacal Nitrogen ($mg\ l^{-1}$)	12	0.5	0.09	0.33	0.1	1.4	12	0.3	0.03	0.10	0.1	0.4	12	0.4	0.05	0.17	0.1	0.8	4	0.4	0.09	0.17	0.2	0.6
Nitrogenous Nitrate ($mg\ l^{-1}$)	12	8.2	0.43	1.50	4.8	10.4	12	7.8	0.41	1.42	4.55	9.6	12	4.5	0.36	1.23	3.0	6.2	4	6.3	0.30	0.61	5.4	6.8
Nitrogenous Nitrite ($mg\ l^{-1}$)	7	0.09	0.01	0.03	0.025	0.11	7	0.06	0.01	0.03	0.015	0.095	7	0.045	0.01	0.03	0.025	0.10	0	-	-	-	-	-
Orthophosphate (as P)($mg\ l^{-1}$)	12	2.1	0.12	0.44	1.5	2.9	12	2.0	0.17	0.60	1.2	3.2	12	0.9	0.16	0.55	0.4	2.3	4	0.8	0.19	0.37	0.4	1.3

TABLE **9.7** : CHEMICAL DATA (EXCLUDING METALS) FOR MONTHLY SAMPLING SITES ON THE R. AVON AND R. SEVERN

↓ VARIABLE / SITE →	MYTHE 1	MYTHE 2
Dissolved Oxygen ($mg\ l^{-1}$)	9.6 5.3	9.2[a] 6.2[b]
5-day BOD ($mg\ l^{-1}$)	5.4 2.4	3.8 1.0
Chloride ($mg\ l^{-1}$)	76 55	76 57
p H	8.15 7.0	8.0 6.95
Alkalinity ($mg\ l^{-1}\ CaCO_3$)	155 120	213 110
Total Hardness ($mg\ l^{-1}\ CaCO_3$)	270 205	272 205
Calcium Hardness ($mg\ l^{-1}\ CaCO_3$)	199 152	198 153
Magnesium Hardness ($mg\ l^{-1}\ CaCO_3$)	71 53	74 52
$N\text{-}NH_3$ ($mg\ l^{-1}$)	0.1 0.4	0.1 0.3
$N\text{-}NO_3$ ($mg\ l^{-1}$)	5.2 4.75	5.2 4.6
$N\text{-}NO_2$ ($mg\ l^{-1}$)	- 0.105	- 0.065
$P\text{-}PO_4$ ($mg\ l^{-1}$)	0.3 1.3	0.8 1.9

TABLE 9.8 : CHEMICAL DATA (EXCLUDING METALS) FOR MYTHE 1 AND 2

a sample taken 6.6.80

b sample taken 31.7.80

↓ DATE	SITE↓	METAL CONCENTRATION (mg l^{-1})						
		IRON	CADMIUM	CHROMIUM	COPPER	LEAD	NICKEL	ZINC
2. 7.80	SAXONS LODE	.34	.001	.002	.006	.015	.005	.02
	MYTHE 1	.33	.001	.002	.008	.01	.01	.02
	MYTHE 2	.50	.002	.003	.011	.01	.01	.035
	EVESHAM	.51	.002	**.006**	.013	.03	.04	.045
	GT. COMBERTON	.255	**.0025**	**.005**	.012	.03	.035	.025
	TEWKESBURY	.38	.003	**.006**	.012	.03	.025	.025
28. 8.	SAXONS LODE	.34	.001	**.003**	**.008**	.02	.01	.015
	MYTHE 1	.62	.001	**.002**	**.007**	.015	.01	.01
	MYTHE 2	.69	.001	**.003**	**.007**	.03	.01	.02
	WELFORD	.285	**.0015**	**.005**	**.01**	.02	.03	.03
	EVESHAM	.49	**.0015**	**.007**	.012	.025	.025	.03
	GT. COMBERTON	.425	**.0015**	**.007**	.011	.025	.02	.02
	TEWKESBURY	.37	.002	**.004**	.01	.025	.02	.015
5. 11.	SAXONS LODE	.672	.001	**.002**	**.001**	.01	.01	<.01
	EVESHAM	.525	**.0035**	**.006**	**.007**	.025	.025	.015
	TEWKESBURY	.32	**.0015**	**.004**	**.003**	.02	.02	**.005**

TABLE 9.9 : TOTAL HEAVY METAL CONCENTRATIONS IN WATER SAMPLES FROM THE R. SEVERN AND R. AVON DURING 1980

↓SITE	VARIABLE (mg l^{-1} exc. pH)			
	Suspended Solid	pH	Total Al	Filtrable Al
Mythe 1 (upstream of effluent)	130	7.55	1.46	<0.01
10m below effluent discharge	535	7.5	4.93	<0.01
20m " " "	910	7.5	5.06	<0.01
40m " " "	200	7.55	1.30	<0.01
ca. 80m " " "	265	7.6	1.32	<0.01
ca. 160m " " "	490	7.6	3.10	<0.01

TABLE 9.10 : THE EFFECTS OF WATERWORKS DISCHARGES ON CERTAIN PHYSICOCHEMICAL VARIABLES AT MYTHE ON THE R. SEVERN ON 10.9.81

VARIABLE / SITE → (mg l^{-1} unless otherwise stated)	Tittes-worth Res.	Cheddle-ton Mill	Cheddle-ton Sta.	Frog-hall	Alton	Mouth
Temperature (°C)	10.5	15	14.5	15	15	15
O.C.	8.35	7.0	8.05	9.35	9.35	9.0
BOD_5 (unsuppressed)	0.15	3.5	1.65	1.7	1.35	1.0
Chloride	22	33	32	30	31	33
pH	7.3	7.1	7.25	7.55	7.55	7.7
Alkalinity (as $CaCO_3$)	50	80	80	80	65	65
Total Hardness (as $CaCO_3$)	98	131	132	136	135	166
Calcium Hardness (as $CaCO_3$)	60	98	108	109	139	136
Magnesium Hardness (as $CaCO_3$)	38	33	24	27	26	30
$N-NH_3$	0.2	0.8	0.35	0.35	0.25	0.2
$N-NO_3$						
$P-PO_4$	0.1	0.4	0.1	0.2	0.2	0.1
Total Fe	0.323	0.783	0.592	0.600	0.535	0.503
Cd	0.001	0.003	0.003	0.003	0.003	0.003
Cr	0.001	0.002	0.002	0.002	0.002	0.003
Cu	0.008	0.045	0.033	0.030	0.021	0.018
Pb	0.005	0.012	0.013	0.010	0.013	0.013
Ni	0.008	0.013	0.017	0.009	0.015	0.017
Zn	0.006	0.026	0.023	0.014	0.016	0.035

TABLE 9.11 : PHYSICOCHEMICAL DATA FOR THE R. CHURNET (20.8.79 EXCEPT METALS - 17.9.81)

APPENDIX

ANNEXE 3 Analysis of Variance and Covariance Tables together with Points of Best Fit

(Tables 10.1 - 10.6)

Analysis of variance and covariance tables display source of variation, degrees of freedom (df), sum of squares (SS) and mean squares (MS).

Points of best fit tables are displayed where one or more of the F-ratios in the above anovar tables are significant at the 5% level. Standard errors and 95% confidence limits are shown beside each point of best fit. Where the raw data was transformed before statistical analysis tables displaying points of best fit are shown for both log data and derived data.

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	5	76.9441	15.3888	4.80897
LINEAR EFF.	1	31.5106	31.5106	9.84698
QUAD EFF.	1	11.6367	11.6367	3.63644
CUBIC EFF.	1	14.6665	14.6665	4.58325
RESIDUAL	2	19.1303		
BLOCKS	2	8.11108	4.05554	1.26735
ERROR	10	32.0002	3.20002	
TOTAL	17	108.944		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
7	8.3242	.694403	9.87133	6.77707
14	8.73973	.594651	10.0646	7.41484
28	9.57078	.44905	10.5713	8.57029
42	10.4018	.435839	11.3729	9.43077
56	11.2329	.564395	12.4903	9.9754
70	12.0639	.766421	13.7715	10.3563

RESPONSE CURVE IS LINEAR

TABLE 10.1 i : NUMBERS OF TAXA IN RUN 1

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	6	250.572	41.762	11.9321
LINEAR EFF.	1	189	189	54.0006
QUAD EFF.	1	61.0159	61.0159	17.4333
CUBIC EFF.	1	.5	.5	.142859
RESIDUAL	3	5.59082E-02		
BLOCKS	2	2.57178	1.28589	.367401
ERROR	12	41.9995	3.49996	
TOTAL	20	292.571		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
7	6.18254	.942804	8.23691	4.12817
14	10.1429	.577347	11.4009	8.88482
21	13.119	.577347	14.3771	11.861
28	15.1111	.623606	16.4699	13.7523
35	16.119	.577347	17.3771	14.861
42	16.1429	.577347	17.4009	14.8848
49	15.1825	.942804	17.2369	13.1282

RESPONSE CURVE IS QUADRATIC

TABLE 10.1 ii : NUMBERS OF TAXA IN RUN 2

TABLES 10.1 i-iv : ANOVAR TABLES INCORPORATING BREAKDOWN OF TREATMENTS INTO POLYNOMIALS FOR TESTS ON THE EFFECT OF IMMERSION PERIOD ON THE TOTAL NUMBERS OF TAXA AND INDIVIDUALS COLLECTED ON S.AUF.U. AT SAXONS LODE (R. SEVERN). (POINTS OF BEST FIT ARE SHOWN WHERE ANOVAR GIVES A SIGNIFICANT VALUE).

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	5	4.75607E+06	951213.	54.3439
LINEAR EFF.	1	4.65974E+06	4.65974E+06	266.216
QUAD EFF.	1	1226.83	1226.83	7.00904E-02
CUBIC EFF.	1	43271.8	43271.8	2.47217
RESIDUAL	2	51826.		
BLOCKS	2	1952	976	.05576
ERROR	10	175036.	17503.6	
TOTAL	17	4.93110E+06		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
7	191.653	51.3569	306.076	77.2298
14	351.443	43.9774	449.429	253.457
28	671.023	33.2109	745.017	597.029
42	990.603	32.234	1062.42	918.785
56	1310.18	41.7417	1403.18	1217.18
70	1629.76	56.6832	1756.05	1503.47

RESPONSE CURVE IS LINEAR

TABLE 10.1iii : NUMBERS OF INDIVIDUALS IN RUN 1

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	6	2.14144E+06	356907.	14.9546
LINEAR EFF.	1	475053.	475053.	19.905
QUAD EFF.	1	1.39286E+06	1.39286E+06	58.3616
CUBIC EFF.	1	45702.7	45702.7	1.91497
RESIDUAL	3	227827.		
BLOCKS	2	11900	5950	.249309
ERROR	12	286392.	23866	
TOTAL	20	2.42783E+06		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
7	744.072	77.8538	913.715	574.428
14	447.548	47.6755	551.432	343.663
21	299.714	47.6755	403.599	195.829
28	300.571	51.4954	412.78	188.363
35	450.119	47.6755	554.004	346.234
42	748.357	47.6755	852.242	644.472
49	1195.29	77.8538	1364.93	1025.64

RESPONSE CURVE IS QUADRATIC

TABLE 10.1iv : NUMBERS OF INDIVIDUALS IN RUN 2

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	5	1.08998	.217995	3.23724
LINEAR EFF.	1	.612578	.612578	9.09681
QUAD EFF.	1	.2738	.2738	4.06594
CUBIC EFF.	1	3.88764E-03	3.88764E-03	5.77316E-02
RESIDUAL	2	.199711		
BLOCKS	2	.047143	2.35715E-02	.350038
ERROR	10	.673399	6.73399E-02	
TOTAL	17	1.76338		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
7	.742512	.100733	.966945	.518079
14	.684576	8.62624E-02	.876768	.492383
28	.568703	6.51409E-02	.713837	.42357
42	.452831	6.32245E-02	.593696	.311967
56	.336959	8.18733E-02	.519373	.154545
70	.221087	.11118	.468796	-2.66225E-02

RESPONSE CURVE IS LINEAR

TABLE 10.2 i : COLONISATION RATE (RUN 1)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	6	.7729	.128817	1.45721
LINEAR EFF.	1	.335668	.335668	3.79717
QUAD EFF.	1	6.06671E-02	6.06671E-02	.686282
CUBIC EFF.	1	2.80056E-02	2.80056E-02	.316807
RESIDUAL	3	.348559		
BLOCKS	2	.287327	.143663	1.62516
ERROR	12	1.06079	8.83996E-02	
TOTAL	20	1.83369		

TABLE 10.2 ii : COLONISATION RATE (RUN 2)

TABLES 10.2 i-iv : ANOVAR TABLES INCORPORATING BREAKDOWN OF THE TREATMENTS INTO POLYNOMIALS FOR TESTS ON THE EFFECT OF IMMERSION PERIOD ON COLONISATION AND EXTINCTION RATES OF TAXA AT SAXONS LODE (R. SEVERN). (POINTS OF BEST FIT ARE SHOWN WHERE ANOVAR GIVES A SIGNIFICANT VALUE).

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	5	.40505	.08101	2.09979
LINEAR EFF.	1	.16425	.16425	4.25739
QUAD EFF.	1	6.03471E-02	6.03471E-02	1.56421
CUBIC EFF.	1	8.24695E-02	8.24695E-02	2.13762
RESIDUAL	2	9.79837E-02		
BLOCKS	2	6.41333E-02	3.20666E-02	.831173
ERROR	10	.3858	.03858	
TOTAL	17	.79085		

TABLE 10.2 iii : EXTINCTION RATE (RUN 1)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	6	1.18966	.198276	4.31922
LINEAR EFF.	1	.556972	.556972	12.133
QUAD EFF.	1	.420992	.420992	9.17085
CUBIC EFF.	1	1.07556E-02	1.07556E-02	.234298
RESIDUAL	3	.200938		
BLOCKS	2	6.02946E-02	3.01473E-02	.656725
ERROR	12	.550866	4.59055E-02	
TOTAL	20	1.74052		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
7	-3.34128E-02	.107975	.201864	-.26869
14	.252381	6.61207E-02	.396458	.108304
21	.456429	6.61207E-02	.600506	.312352
28	.57873	7.14186E-02	.734351	.423109
35	.619286	6.61207E-02	.763363	.475209
42	.578095	6.61207E-02	.722172	.434018
49	.455159	.107975	.690436	.219882

RESPONSE CURVE IS QUADRATIC

TABLE 10.2 iv : EXTINCTION RATE (RUN 2)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	64.6665	21.5555	3.31623
LINEAR EFF.	1	46.6667	46.6667	7.17949
QUAD EFF.	1	15.2728	15.2728	2.34966
CUBIC EFF.	1	2.72717	2.72717	.417565
RESIDUAL	0	-9.15527E-05		
ERROR	8	52	6.5	
TOTAL	11	116.667		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
0	16	1.14018	18.6292	13.3708
1.5	14.6667	.825199	16.5696	12.7638
3	13.3333	.74642	15.0546	11.6121
6	10.6667	1.33986	13.7564	7.57694

RESPONSE CURVE IS LINEAR

TABLE 10.3 i : NUMBERS OF TAXA

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	957217.	319072.	6.27341
LINEAR EFF.	1	745086.	745086.	14.6494
QUAD EFF.	1	201647.	201647.	3.96466
CUBIC EFF.	1	10482.4	10482.4	.206099
RESIDUAL	0	1.625		
ERROR	8	406889.	50861.1	
TOTAL	11	1.36411E+06		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
0	12.9999	100.857	245.577	-219.577
1.5	181.476	72.9953	349.803	13.147
3	349.952	66.0267	502.21	197.695
6	686.905	118.521	960.215	413.594

RESPONSE CURVE IS LINEAR

TABLE 10.3 ii : NUMBER OF INDIVIDUALS

TABLES 10.3 i-xxiii : ANOVAR TABLES INCORPORATING BREAKDOWN OF THE TREATMENTS INTO POLYNOMIALS FOR TESTS ON THE EFFECT OF TRANSITION FROM RHITHRON TO POTAMON ZONE ON THE NUMBERS OF TAXA AND INDIVIDUALS OF DIFFERENT TAXA COLONISING S.AUF.U. (POINTS OF BEST FIT ARE SHOWN WHERE ANOVAR GIVES A SIGNIFICANT VALUE)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	1.11627E+06	372090.	9.21627
LINEAR EFF.	1	813233.	813233.	20.1333
QUAD EFF.	1	286155.	286155.	7.08777
CUBIC EFF.	1	14879.2	14879.2	.368542
RESIDUAL	0	2		
ERROR	8	322985.	40373.1	
TOTAL	11	1.43925E+06		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
0	91.1454	111.16	347.481	-165.191
1.5	-6.38776	75.0185	166.605	-179.38
3	70.2911	95.1492	289.705	-149.123
6	746.285	115.479	1012.58	479.99

RESPONSE CURVE IS QUADRATIC

TABLE 10.3 iii : Corophium curvispinum

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	10.8937	3.63123	2.81913
LINEAR EFF.	1	.768324	.768324	.596479
QUAD EFF.	1	3.18129	3.18129	2.46981
CUBIC EFF.	1	6.94402	6.94402	5.39104
RESIDUAL	0	5.72205E-05		
ERROR	8	10.3046	1.28807	
TOTAL	11	21.1982		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
0	2.52417	.655253	4.03518	1.01316
1.5	1.67021	.655254	3.18123	.159176
3	3.8619	.655252	5.37291	2.35089
6	1.42556	.655253	2.93658	-8.54487E-02

RESPONSE CURVE IS CUBIC

DERIVED VALUES

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
0	11.4805	.925629	55.553	1.75429
1.5	4.31028	.925632	23.0763	.172568
3	46.5555	.925627	214.488	9.49489
6	3.16018	.925629	17.8512	-.685389

TABLE 10.3 iv :
Gammarus pulex

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	.301736	.100579	.509849
LINEAR EFF.	1	.140811	.140811	.71377
QUAD EFF.	1	.12801	.12801	.648901
CUBIC EFF.	1	3.29173E-02	3.29173E-02	.166863
RESIDUAL	0	-1.72853E-06		
ERROR	8	1.57817	.197272	
TOTAL	11	1.87991		

TABLE 10.3 v :

Ephemoptera

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	2.06117	.687056	1.32075
LINEAR EFF.	1	1.39357	1.39357	2.6789
QUAD EFF.	1	.454391	.454391	.873489
CUBIC EFF.	1	.213208	.213208	.409856
RESIDUAL	0	-1.90735E-06		
ERROR	8	4.16162	.520203	
TOTAL	11	6.22279		

TABLE 10.3 vi :

Hydropsychidae

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	1.24504	.415015	.453117
LINEAR EFF.	1	.67879	.67879	.741109
QUAD EFF.	1	.558289	.558289	.609545
CUBIC EFF.	1	7.97153E-03	7.97153E-03	8.70340E-03
RESIDUAL	0	-5.48363E-06		
ERROR	8	7.32729	.915911	
TOTAL	11	8.57233		

TABLE 10.3 vii :

Cased Trichoptera.

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	1.33735	.445783	.830181
LINEAR EFF.	1	.940184	.940184	1.7509
QUAD EFF.	1	.315801	.315801	.588117
CUBIC EFF.	1	8.13597E-02	8.13597E-02	.151516
RESIDUAL	0	3.33786E-06		
ERROR	8	4.29576	.53697	
TOTAL	11	5.63311		

TABLE 10.3 viii :

Coleoptera

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	3.72179	1.2406	1.51076
LINEAR EFF.	1	1.83747	1.83747	2.23761
QUAD EFF.	1	1.84133	1.84133	2.24231
CUBIC EFF.	1	4.29838E-02	4.29838E-02	5.23443E-02
RESIDUAL	0	5.72205E-06		
ERROR	8	6.5694	.821175	
TOTAL	11	10.2912		

TABLE 10.3 ix :

Chironomid larvae

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	1.72005	.573349	1.17639
LINEAR EFF.	1	.043569	.043569	8.94093E-02
QUAD EFF.	1	1.67487	1.67487	3.43703
CUBIC EFF.	1	.001612	.001612	3.30803E-03
RESIDUAL	0	-2.38419E-07		
ERROR	8	3.89838	.487298	
TOTAL	11	5.61843		

TABLE 10.3 x :

Chironomini (L)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	1.33526	.445087	1.7863
LINEAR EFF.	1	.305734	.305734	1.22703
QUAD EFF.	1	.27794	.27794	1.11548
CUBIC EFF.	1	.75159	.75159	3.01642
RESIDUAL	0	-4.05312E-06		
ERROR	8	1.99333	.249166	
TOTAL	11	3.32859		

TABLE 10.3 xi :

Tanytarsini (L)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	3.52895	1.17632	1.3029
LINEAR EFF.	1	2.86147	2.86147	3.16939
QUAD EFF.	1	.645787	.645787	.715275
CUBIC EFF.	1	2.16933E-02	2.16933E-02	2.40277E-02
RESIDUAL	0	-5.72205E-06		
ERROR	8	7.22278	.902847	
TOTAL	11	10.7517		

TABLE 10.3 xii :

Orthocladiinae (L)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	10.25	3.41667	1.86364
LINEAR EFF.	1	6.6881	6.6881	3.64905
QUAD EFF.	1	.261906	.261906	.142858
CUBIC EFF.	1	3.30001	3.30001	1.80001
RESIDUAL	0	-1.33514E-05		
ERROR	8	14.6667	1.83333	
TOTAL	11	24.9167		

TABLE 10.3 xiii :

Tanypodinae (L)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	183.583	61.1945	.928362
LINEAR EFF.	1	27.2595	27.2595	.413545
QUAD EFF.	1	106.675	106.675	1.61834
CUBIC EFF.	1	49.6471	49.6471	.75318
RESIDUAL	0	1.58691E-03		
ERROR	8	527.333	65.9167	
TOTAL	11	710.917		

TABLE 10.3 xiv :

Gastropoda

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	9	3	.782609
LINEAR EFF.	1	8.57143E-02	8.57143E-02	2.23603E-02
QUAD EFF.	1	4.98701	4.98701	1.30096
CUBIC EFF.	1	3.92724	3.92724	1.0245
RESIDUAL	0	2.67029E-05		
ERROR	8	30.6667	3.83333	
TOTAL	11	39.6667		

TABLE 10.3 xv :

Lymnaea peregra

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	4.81992	1.60664	2.01064
LINEAR EFF.	1	2.08231	2.08231	2.60592
QUAD EFF.	1	.587971	.587971	.735819
CUBIC EFF.	1	2.14966	2.14966	2.6902
RESIDUAL	0	-2.38419E-05		
ERROR	8	6.39257	.799071	
TOTAL	11	11.2125		

TABLE 10.3 xvi :

Bithynia tentaculata

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	66.	22.	1.41176
LINEAR EFF.	1	2.4381	2.4381	.156455
QUAD EFF.	1	58.2164	58.2164	3.73581
CUBIC EFF.	1	5.3457	5.3457	.34304
RESIDUAL	0	-2.28882E-04		
ERROR	8	124.667	15.5833	
TOTAL	11	190.667		

TABLE 10.3 xvii :

Potamopyrgus jenkinsi

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	121.	40.3333	17.2857
LINEAR EFF.	1	93.3428	93.3428	40.0041
QUAD EFF.	1	26.1904	26.1904	11.2245
CUBIC EFF.	1	1.46651	1.46651	.628505
RESIDUAL	0	2.44141E-04		
ERROR	8	18.6666	2.33333	
TOTAL	11	139.667		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
0	.199999	.845069	2.14873	-1.74873
1.5	-.533332	.570309	.7818	-1.84846
3	.400002	.723348	2.06804	-1.26804
6	7.26666	.877899	9.2911	5.24223

RESPONSE CURVE IS QUADRATIC

TABLE 10.3 xviii :

Theodoxus fluviatilis

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	16.3333	5.44444	.933333
LINEAR EFF.	1	.466667	.466667	.08
QUAD EFF.	1	15.2727	15.2727	2.61818
CUBIC EFF.	1	.593981	.593981	.101825
RESIDUAL	0	-4.57764E-05		
ERROR	8	46.6667	5.83333	
TOTAL	11	63		

TABLE 10.3 xix :

Viviparus viviparus

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	2.0404	.680132	1.77257
LINEAR EFF.	1	.764878	.764878	1.99344
QUAD EFF.	1	1.04295	1.04295	2.71817
CUBIC EFF.	1	.232561	.232561	.606105
RESIDUAL	0	1.90735E-06		
ERROR	8	3.06958	.383697	
TOTAL	11	5.10997		

TABLE 10.3 xx :

Bivalvia

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	1.02402	.341341	.443026
LINEAR EFF.	1	.946289	.946289	1.22817
QUAD EFF.	1	1.78379E-02	1.78379E-02	2.31518E-02
CUBIC EFF.	1	5.98972E-02	5.98972E-02	7.77406E-02
RESIDUAL	0	-1.43051E-06		
ERROR	8	6.1638	.770475	
TOTAL	11	7.18783		

TABLE 10.3 xxi :

Hirudinea

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	4.22863	1.40954	1.24123
LINEAR EFF.	1	2.40269	2.40269	2.11579
QUAD EFF.	1	1.382	1.382	1.21698
CUBIC EFF.	1	.443942	.443942	.390931
RESIDUAL	0	-6.67572E-06		
ERROR	8	9.08481	1.1356	
TOTAL	11	13.3134		

TABLE 10.3 xxii :

Oligochaeta

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	2.86084	.953613	.68248
LINEAR EFF.	1	.14097	.14097	.100889
QUAD EFF.	1	1.51528	1.51528	1.08445
CUBIC EFF.	1	1.20459	1.20459	.8621
RESIDUAL	0	-4.76837E-07		
ERROR	8	11.1782	1.39728	
TOTAL	11	14.039		

TABLE 10.3 xxiii :

Tricladida

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	49.583	16.5277	1.92554
LINEAR EFF.	1	38.6674	38.6674	4.50492
QUAD EFF.	1	9.44392	9.44392	1.10026
CUBIC EFF.	1	1.47258	1.47258	.171562
RESIDUAL	0	-8.77380E-04		
ERROR	8	68.667	8.58337	
TOTAL	11	118.25		

TABLE 10.4 i : NUMBERS OF TAXA

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	2.07422E+06	691407.	4.16064
LINEAR EFF.	1	159455.	159455.	.959543
QUAD EFF.	1	559047.	559047.	3.36415
CUBIC EFF.	1	1.35574E+06	1.35574E+06	8.15836
RESIDUAL	0	-19		
ERROR	8	1.32942E+06	166178.	
TOTAL	11	3.40364E+06		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	505.331	235.356	1048.06	-37.4012
400	1576.67	235.356	2119.4	1033.94
800	974.666	235.356	1517.4	431.934
1600	628.004	235.356	1170.74	85.2726

RESPONSE CURVE IS CUBIC

TABLE 10.4 ii : NUMBERS OF INDIVIDUALS

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	.951046	.317015	.356798
LINEAR EFF.	1	.590198	.590198	.664262
QUAD EFF.	1	.358725	.358725	.403741
CUBIC EFF.	1	2.12178E-03	2.12178E-03	2.38804E-03
RESIDUAL	0	1.54972E-06		
ERROR	8	7.10801	.888501	
TOTAL	11	8.05906		

TABLE 10.4 iii : Asellus aquaticus

TABLES 10.4 i-xxxiv : ANOVAR TABLES INCORPORATING BREAKDOWN OF THE TREATMENTS INTO POLYNOMIALS FOR TESTS ON THE EFFECT OF DISTANCE DOWNSTREAM OF A RIFFLE ON THE NUMBERS OF TAXA AND INDIVIDUALS OF DIFFERENT TAXA COLONISING S.AUF.U. (POINTS OF BEST FIT ARE SHOWN WHERE ANOVAR GIVES A SIGNIFICANT VALUE)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	2.45152E+06	817172.	5.1395
LINEAR EFF.	1	172525.	172525.	1.08507
QUAD EFF.	1	590244.	590244.	3.71226
CUBIC EFF.	1	1.68876E+06	1.68876E+06	10.6213
RESIDUAL	0	-16.5		
ERROR	8	1.27199E+06	158998.	
TOTAL	11	3.72350E+06		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	238.665	230.216	769.544	-292.214
400	1413.34	230.216	1944.22	882.457
800	722.667	230.216	1253.55	191.788
1600	391.338	230.216	922.217	-139.541

RESPONSE CURVE IS CUBIC

TABLE 10.4 iv : Corophium curvispinum

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	10.35	3.44999	1.27647
LINEAR EFF.	1	3.91043	3.91043	1.44683
QUAD EFF.	1	6.02283	6.02283	2.2284
CUBIC EFF.	1	.416684	.416684	.15417
RESIDUAL	0	3.43323E-05		
ERROR	8	21.6221	2.70276	
TOTAL	11	31.972		

TABLE 10.4 v : Gammarus pulex

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	3.98516	1.32839	2.05371
LINEAR EFF.	1	3.75179	3.75179	5.80033
QUAD EFF.	1	7.58813E-03	7.58813E-03	1.17314E-02
CUBIC EFF.	1	.225758	.225758	.349025
RESIDUAL	0	2.28882E-05		
ERROR	8	5.17459	.646824	
TOTAL	11	9.15975		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	2.82251	.33259	3.58946	2.05555
400	2.61394	.277252	3.25329	1.9746
800	2.19681	.233175	2.73451	1.65911
1600	1.36256	.435155	2.36602	.359087

RESPONSE CURVE IS LINEAR

DERIVED VALUES

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	18.919	1.39458	36.2144	7.81112
400	13.5827	1.3195	25.8733	7.20373
800	8.28626	1.2626	15.4022	5.05453
1600	2.80818	1.5452	10.6549	1.42202

TABLE 10.4 vi : Ephemoptera

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	2.55041	.850136	.749023
LINEAR EFF.	1	1.98966	1.98966	1.75302
QUAD EFF.	1	.535365	.535365	.47169
CUBIC EFF.	1	2.53854E-02	2.53854E-02	2.23661E-02
RESIDUAL	0	-4.29153E-06		
ERROR	8	9.07994	1.13499	
TOTAL	11	11.6304		

TABLE 10.4 vii : Caenis moesta

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	7.30491	2.4283	3.88512
LINEAR EFF.	1	7.24122	7.24122	10.7039
QUAD EFF.	1	.122081	.122081	.180438
CUBIC EFF.	1	.521604	.521604	.771027
RESIDUAL	0	5.72205E-06		
ERROR	8	5.41204	.676505	
TOTAL	11	13.297		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	2.4375	.340135	3.27193	1.70324
400	2.19734	.283542	2.85169	1.544
800	1.61834	.238465	2.16824	1.06844
1600	.459333	.445027	1.48557	-.5669

RESPONSE CURVE IS LINEAR

DERIVED VALUES

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	12.0323	1.40514	26.3626	5.49171
400	9.00553	1.32782	17.317	4.68328
800	5.0447	1.2693	8.74287	2.91083
1600	1.58302	1.56053	4.41748	.567281

TABLE 10.4 viii : Ephemerella ignita

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	3.70060	1.23354	1.66580
LINEAR EFF	1	1.64772	1.64772	2.22514
QUAD EFF.	1	1.90241	1.90241	2.5691
CUBIC EFF.	1	.150307	.150307	.203051
RESIDUAL	0	-1.90739E-06		
ERROR	8	5.92288	.740488	
TOTAL	11	9.62461		

TABLE 10.4 ix : Hydropsychidae

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	31.3333	10.4444	1.24092
LINEAR EFF.	1	1.66957	1.66957	.198364
QUAD EFF.	1	29.625	29.625	3.51981
CUBIC EFF.	1	3.86916E-02	3.86916E-02	4.59702E-03
RESIDUAL	0	1.52588E-05		
ERROR	8	67.3333	8.41667	
TOTAL	11	98.6667		

TABLE 10.4 x :

Polycentropus flavomaculatus

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	8.91667	2.97222	1.98148
LINEAR EFF.	1	.60942	.60942	.40628
QUAD EFF.	1	6.8352	6.8352	4.5568
CUBIC EFF.	1	1.47201	1.47201	.98134
RESIDUAL	0	3.43323E-05		
ERROR	8	12	1.5	
TOTAL	11	20.9167		

TABLE 10.4 xi :

Cased Trichoptera

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	7.33333	2.44445	5.86667
LINEAR EFF.	1	3.75602	3.75602	9.01365
QUAD EFF.	1	1.76928	1.76928	4.24628
CUBIC EFF.	1	1.80753	1.80753	4.33801
RESIDUAL	0	-3.91370E-06		
ERROR	8	3.33333	.416667	
TOTAL	11	10.6667		

TREATMENT LEVEL	MEAN	S.E. OF MEAN	UPPER LIMIT	LOWER LIMIT
200	1.24056	.266708	1.83614	.622982
400	1.02183	.328982	1.78693	.577041
800	.614443	.187147	1.04603	.182849
1600	-.23035	.347007	.569079	-1.02649

RESPONSE CURVE IS LINEAR

TABLE 10.4 xii :

Coleoptera

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	3.78511	1.2617	3.44795
LINEAR EFF.	1	.159349	.159349	.435465
QUAD EFF.	1	3.28774E-02	3.28774E-02	8.98465E-02
CUBIC EFF.	1	3.59294	3.59294	9.81869
RESIDUAL	0	-5.24521E-05		
ERROR	8	2.92743	.365929	
TOTAL	11	6.71254		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	.366199	.349251	1.17157	-.439174
400	1.84315	.349251	2.64852	1.03778
800	.693146	.349251	1.49852	-.112226
1600	1.2459	.349251	2.05127	.440524

RESPONSE CURVE IS CUBIC

DERIVED VALUES

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	.442242	.418005	2.22705	-.355431
400	5.31639	.418005	13.1331	1.82294
800	.999997	.418005	3.47506	-.106157
1600	2.47606	.418005	6.77776	.553521

TABLE 10.4 xiii : Agrion splendens

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	8.72725	2.90908	6.86973
LINEAR EFF.	1	8.24443	8.24443	19.469
QUAD EFF.	1	.451784	.451784	1.06688
CUBIC EFF.	1	.031043	.031043	7.33074E-02
RESIDUAL	0	-5.72205E-06		
ERROR	8	3.38771	.423464	
TOTAL	11	12.115		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	3.22151	.269107	3.84207	2.60095
400	2.91233	.224332	3.42964	2.39503
800	2.29399	.188668	2.72906	1.85892
1600	1.0573	.352094	1.86923	.245369

RESPONSE CURVE IS LINEAR

DERIVED VALUES

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	35.0639	1.30879	46.6218	13.4765
400	18.3976	1.25149	30.8654	10.9605
800	9.91441	1.09764	15.3185	5.41379
1600	[illegible]	1.02204	6.48[illegible]	1.27909

TABLE 10.4 xiv : Chironomid larvae

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	5.240273	1.71791	5.78045
LINEAR EFF.	1	1.024756	1.024756	3.448921
QUAD EFF.	1	1.126461E-02	1.126461E-02	3.790675E-02
CUBIC EFF.	1	3.404857	3.404857	11.45441
RESIDUAL	0	-2.811708E-05		
ERROR	8	2.376266	.3970833	
TOTAL	11	8.193439		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	1.2904	.330753	2.09933	.481561
400	2.51724	.330753	3.32603	1.70844
800	.998577	.330753	1.80711	.189742
1600	.828309	.330753	1.63714	1.94729E-02

RESPONSE CURVE IS CUBIC

DERIVED VALUES

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	2.63424	.420136	7.15987	.618399
400	11.3943	.420136	26.829	4.52017
800	1.71442	.420136	5.09464	.208937
1600	1.28944	.420136	4.14044	.301519

TABLE 10.4 xv :

Chironomini (L)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	5.66973	1.88991	16.0691
LINEAR EFF.	1	.626237	.626237	5.32505
QUAD EFF.	1	.753149	.753149	6.40371
CUBIC EFF.	1	4.29026	4.29026	36.4702
RESIDUAL	0	4.005436E-05		
ERROR	8	.940891	.117611	
TOTAL	11	6.61062		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	2.12796	.178	2.53965	1.67237
400	.231053	.178	.68764	-.225534
800	1.15514	.177999	1.61183	.698455
1600	.923295	.178	1.33498	.511708

RESPONSE CURVE IS CUBIC

DERIVED VALUES

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	7.40611	.218962	12.2706	4.32477
400	.259926	.218962	.989015	-.20191
800	2.17478	.218961	4.01197	1.01105
1600	1.28941	.218962	2.61423	.450209

TABLE 10.4 xvi :

Tanytarsini (L)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	1.86297	.620990	1.77307
LINEAR EFF.	1	1.83207	1.83207	5.23106
QUAD EFF.	1	.030804	.030804	[illegible]
CUBIC EFF.	1	9.31312E-05	9.31312E-05	2.65914E-04
RESIDUAL	0	7.10256E-07		
ERROR	8	2.80184	.35023	
TOTAL	11	4.66481		

TABLE 10.4 xvii :

Orthocladiinae (L)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	735.	245.	21.6176
LINEAR EFF.	1	298.67	298.67	26.3501
QUAD EFF.	1	212.743	212.743	18.7714
CUBIC EFF.	1	223.587	223.587	19.7262
RESIDUAL	0	-7.32422E-04		
ERROR	8	90.667	11.3334	
TOTAL	11	825.667		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	20.3333	1.94366	24.8134	15.8513
400	2.33333	1.94365	6.8154	-2.14874
800	3.33332	1.94365	7.81537	-1.14875
1600	1.33328	1.94366	5.81535	-3.14879

RESPONSE CURVE IS CUBIC

TABLE 10.4 xviii :

Tanypodinae (L)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	3.79922	1.26641	2.42527
LINEAR EFF.	1	2.65448	2.65448	5.08354
QUAD EFF.	1	2.70291E-02	2.70291E-02	.051763
CUBIC EFF.	1	1.11756	1.11756	2.14022
RESIDUAL	0	1.56403E-04		
ERROR	8	4.17737	.522171	
TOTAL	11	7.97659		

TABLE 10.4 xix : Gastropoda

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	7.66076	2.55359	9.94512
LINEAR EFF.	1	6.56052	6.56052	25.1944
QUAD EFF.	1	.487356	.487356	1.87189
CUBIC EFF.	1	6.10303E-03	6.10303E-03	2.34375E-02
RESIDUAL	0	7.62939E-06		
ERROR	8	2.00441	.250551	
TOTAL	11	9.66839		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	.413774	.206997	.890109	-6.45614E-02
400	.622371	.172356	1.00849	.236637
800	1.24016	.143123	1.57482	.903511
1600	2.34035	.270851	2.96499	1.71572

RESPONSE CURVE IS LINEAR

DERIVED VALUES

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	.511003	.229979	1.43539	-.582614
400	.990868	.188338	1.96385	.337306
800	2.45616	.156182	3.82987	1.47319
1600	9.41605	.311053	18.4508	4.57794

TABLE 10.4 xx ;

Lymnaea peregra

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	6.76076	2.25359	1.55646
LINEAR EFF.	1	3.28527	3.28527	2.269
QUAD EFF.	1	.340748	.340748	.23534
CUBIC EFF.	1	3.13462	3.13462	2.16495
RESIDUAL	0	1.18256E-04		
ERROR	8	11.5832	1.4479	
TOTAL	11	18.3439		

TABLE 10.4 xxi :

Bithynia tentaculata

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	8.91667	2.97222	.849477
LINEAR EFF.	1	3.2539	3.2539	.930074
QUAD EFF.	1	2.32928	2.32928	.665794
CUBIC EFF.	1	3.13538	3.13538	.896067
RESIDUAL	0	1.02997E-04		
ERROR	8	69	3.5	
TOTAL	11	78.8167		

TABLE 10.4 xxii :

Potamopyrgus jenkinsi

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	13.6875	5.12343	21.0967
LINEAR EFF.	1	2.00198	2.00198	7.99674
QUAD EFF.	1	10.2688	10.2688	41.0725
CUBIC EFF.	1	2.42705	2.42705	11.1257
RESIDUAL	0	6.10352E-05		
ERROR	8	1.70317	.212902	
TOTAL	11	17.276		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	-4.23193E-06	.27296	.629442	-.629451
400	.331058	.27296	.860504	-.198388
800	2.88991	.27296	3.51935	2.26046
1600	.963453	.27296	1.5929	.334007

RESPONSE CURVE IS CUBIC

DERIVED VALUES

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	-1.04352E-02	.313847	.876563	-.467116
400	.259932	.313847	1.36435	-.328598
800	16.9917	.313847	32.7624	8.58748
1600	1.62073	.313847	3.91799	.396553

TABLE 10.4 xxiii :

Theodoxus fluviatilis

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	1.32182	.440608	.917965
LINEAR EFF.	1	.302687	.302687	.626212
QUAD EFF.	1	.316408	.316408	.67196
CUBIC EFF.	1	.472736	.472736	.983733
RESIDUAL	0	-8.98307E-06		
ERROR	8	4.00821	.480631	
TOTAL	11	8.12703		

TABLE 10.4 xxiv :

Viviparus viviparus

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	5.24533	1.74844	1.0962
LINEAR EFF.	1	3.55285	3.55285	2.22742
QUAD EFF.	1	1.61609	1.61609	1.01322
CUBIC EFF.	1	7.62805E-02	7.62805E-02	4.78874E-02
RESIDUAL	0	1.43061E-05		
ERROR	8	12.76	1.595	
TOTAL	11	18.0053		

TABLE 10.4 xxv :

Sphaeridae

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	45.5833	15.1944	3.14368
LINEAR EFF.	1	16.963	16.963	3.5096
QUAD EFF.	1	28.1461	28.1461	5.82333
CUBIC EFF.	1	.474213	.474213	9.81131E-02
RESIDUAL	0	-1.52588E-05		
ERROR	8	38.6667	4.83333	
TOTAL	11	84.25		

TREATMENT LEVEL	POINT	S.E. +/-	UPPER LIMIT	LOWER LIMIT
200	2.84731	1.13071	5.45472	.239906
400	4.35054	.769723	6.12552	2.57556
800	5.4914	1.16467	8.17712	2.80567
1600	.310753	1.26725	3.23302	-2.61152

RESPONSE CURVE IS QUADRATIC

TABLE 10.4 xxvi :

Hirudinea

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	8.33333	2.77778	1.96078
LINEAR EFF.	1	5.86936	5.86936	4.14322
QUAD EFF.	1	.286349	.286349	.202128
CUBIC EFF.	1	2.17742	2.17742	1.537
RESIDUAL	0	-1.90735E-06		
ERROR	9	11.8333	1.41667	
TOTAL	11	19.6667		

TABLE 10.4 xxvii :

Erpobdella octoculata

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	2.91667	.972222	2.33333
LINEAR EFF.	1	1.33929	1.33929	3.21565
QUAD EFF.	1	.833437	.833437	2.0012
CUBIC EFF.	1	.619351	.619351	1.48644
RESIDUAL	0	2.38419E-06		
ERROR	9	3.75	.416667	
TOTAL	11	6.25		

TABLE 10.4 xxviii :

Glossiphonia complanata

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	[illegible]	.024062	[illegible]
LINEAR EFF.	1	[illegible]	[illegible]	[illegible]
QUAD EFF.	1	[illegible]	[illegible]	[illegible]
CUBIC EFF.	1	[illegible]	[illegible]	[illegible]
RESIDUAL	0	[illegible]	[illegible]	[illegible]
ERROR	8	[illegible]	[illegible]	
TOTAL	11	[illegible]		

TABLE 10.4 xxix :

Helobdella stagnalis

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	6.11133	2.03000	1.03426
LINEAR EFF.	1	2.74616E-02	2.74616E-02	1.39818E-02
QUAD EFF.	1	5.40015	5.40015	2.73528
CUBIC EFF.	1	.656093	.656093	.333943
RESIDUAL	0	2.47955E-05		
ERROR	8	15.872	1.98399	
TOTAL	11	21.9862		

TABLE 10.4 xxx :

Oligochaeta

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	710.917	236.972	.888369
LINEAR EFF.	1	7.24638E-04	7.24638E-04	2.71654E-06
QUAD EFF.	1	181.019	181.019	.678611
CUBIC EFF.	1	529.886	529.886	1.98645
RESIDUAL	0	1.12305E-02		
ERROR	8	2134	266.75	
TOTAL	11	2844.92		

TABLE 10.4 xxxi :

Tricladida

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	138	46	.987478
LINEAR EFF.	1	4.18551	4.18551	8.98499E-02
QUAD EFF.	1	28.4715	28.4715	.611195
CUBIC EFF.	1	105.342	105.342	2.26136
RESIDUAL	0	1.31226E-03		
ERROR	8	372.667	46.5833	
TOTAL	11	510.667		

TABLE 10.4 xxxii :

Dendrocoelum lacteum

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	1.64085	.546951	.405109
LINEAR EFF.	1	.296604	.296604	.219685
QUAD EFF.	1	1.23744	1.23744	.916529
CUBIC EFF.	1	.106804	.106804	7.91065E-02
RESIDUAL	0	8.34465E-06		
ERROR	8	10.8011	1.35013	
TOTAL	11	12.4419		

TABLE 10.4 xxxiii :

Dugesia polychroa

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-RATIO
TREATMENT	3	76.0002	25.3334	.912917
LINEAR EFF.	1	1.4029	1.4029	.050555
QUAD EFF.	1	.786359	.786359	2.83373E-02
CUBIC EFF.	1	73.8087	73.8087	2.65978
RESIDUAL	0	2.28882E-03		
ERROR	8	222.	27.75	
TOTAL	11	298		

TABLE 10.4 xxxiv :

Polycelis tenuis

	CHANNEL	A		B		C	
		SS	MS	SS	MS	SS	MS
Lower Riffle	Deviations from linear	-	-	117.26		2.07	
	Deviations from quadratic	-	-	31.87	7.97	1.92	0.48
	Reduction in SS	-	-	85.39	85.39	0.15	0.15
Upper Pool	Deviations from linear	42.51		33.75		17.45	
	Deviations from quadratic	32.92	10.97	31.92	10.64	17.25	5.75
	Reduction in SS	9.59	9.59	1.83	1.83	0.20	0.20
B.Auf.U.	Deviations from linear	48.20		42.55		121.00	
	Deviations from quadratic	45.70	11.43	35.64	.91	117.82	29.46
	Reduction in SS	2.50	2.50	6.91	6.91	3.18	3.18

TABLE **10.5** : ANOVAR TABLE FOR TEST OF LINEARITY OF MEAN WEIGHT - TIME RELATIONSHIPS IN L. peregra

CHANNEL	REG. COEFF.	DEVIATIONS FROM REG			F
		df	SS	MS	
Upper Pool					
A	0.1146	4	42.75	10.69	
B	0.0663	4	33.09	8.27	
C	0.0870	4	100.51	25.13	
		12	176.35	14.70	
Pooled	0.0893	14	259.44	18.53	
Difference between slopes		2	83.09	41.55	2.83
S.Auf.U.					
A	0.0962	5	48.51	9.70	
B	0.1176	5	41.70	8.34	
C	0.0965	5	120.70	24.14	
		15	210.91	14.06	
Pooled	0.1034	17	223.91	13.17	
Difference between slopes		2	13.00	6.50	0.46

TABLE 10.6 : ANALYSIS OF COVARIANCE TABLE FOR A TEST TO DETECT SIGNIFICANT DIFFERENCES BETWEEN THE SLOPES OF THE MEAN INDIVIDUAL WEIGHT - TIME RELATIONSHIPS IN L. peregra IN THE CHECKLEY CHANNELS

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