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ZOOPLANKTON INTERACTIONS IN THE RIVER THAMES
Final Report

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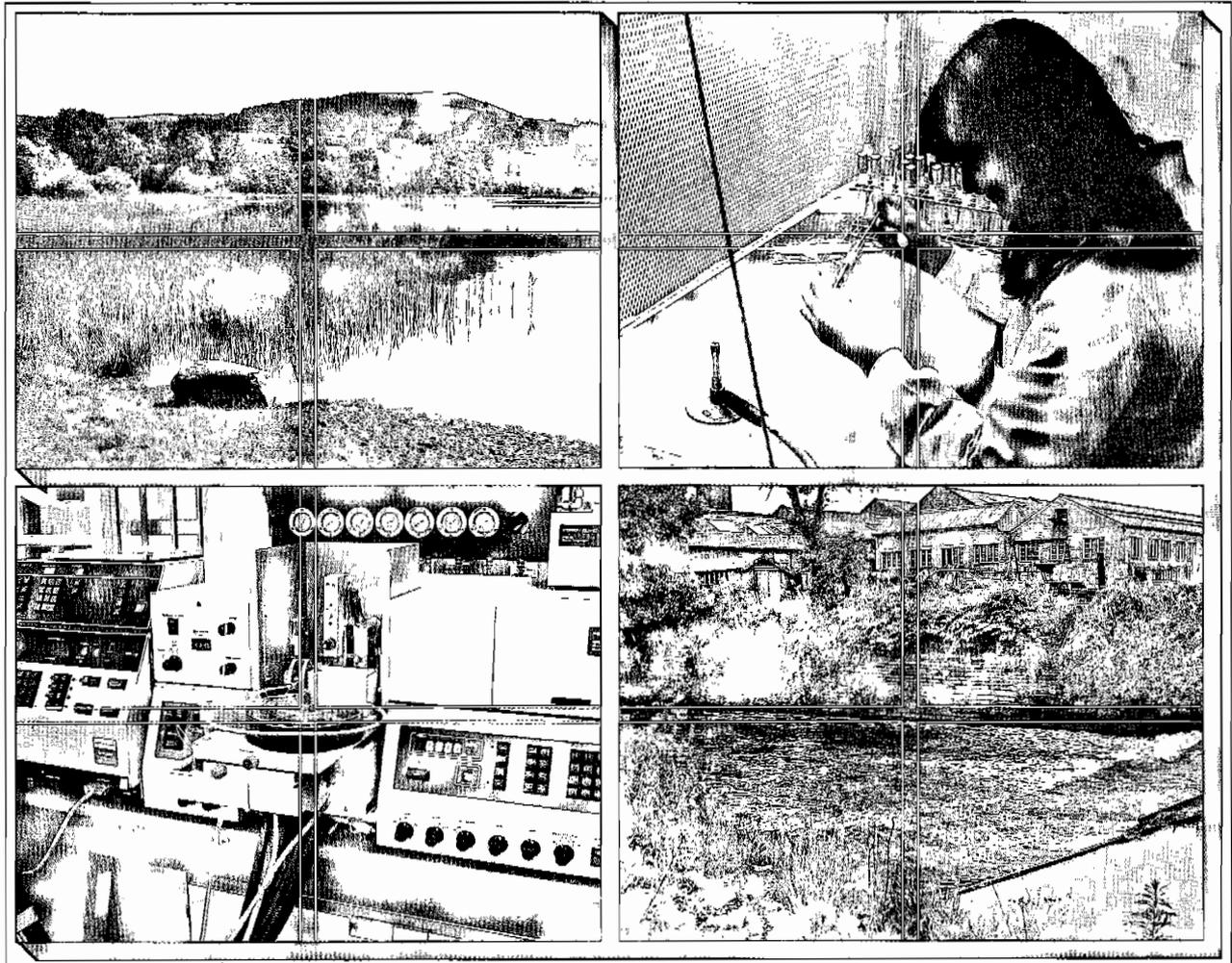
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ZOOPLANKTON INTERACTIONS IN THE RIVER THAMES

Final Report

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EXECUTIVE SUMMARY

This study addresses the role of zooplankton in large rivers, considering the trophic links with phytoplankton, other invertebrates and young fish. It also evaluates the potential role and importance of zooplankton in the middle reaches of the R.Thames.
A zooplankton sampling programme was presented in the Interim Report (Bass & May, 1996).

Main conclusions of the literature review -

Rotifera are often mentioned in studies on the zooplankton of running waters, however, in most cases, the sampling strategies used have been designed, primarily, for the study of the larger crustacean zooplankton. In all studies which have considered Rotifera, this group had the greatest potential for influencing the phytoplankton-zooplankton dynamics. However, there are few references which assess the role of rotifers in controlling phytoplankton abundance and species composition in large rivers.

Planktonic Copepoda, within riverine situations, are represented predominantly by the juvenile stages (copepodites and nauplii). With a few notable exceptions, planktonic Cladocera appear disfavoured by riverine conditions and frequently occur in comparatively very low population densities for much of the year.

Waterbodies connected to rivers, with similar water chemistry and nutrient status, frequently maintain higher phytoplankton and zooplankton populations through the summer, indicating the potential for greater plankton development in rivers should water retention time increase.

The overriding influence of discharge on plankton density is widely reported in the literature, with plankton development inhibitted or diluted as retention time decreases with increasing river flows. The role of "dead zones" or "storage zones", with respect to phytoplankton within river channels, contributing to the delay of downstream displacement, has been demonstrated in a range of rivers in Britain.

Recent studies on the habitat utilisation and gut contents of juvenile fish indicated that zooplankton contribute a sequence of prey increasing in size, as the fish grow, with Rotifera providing the main prey in the first few weeks after fish absorb their yolk sack.

Future river regulation:
implications for zooplankton trophic interactions in the R Thames -

Several scenarios were considered on the basis that river regulation and augmentation flows to the Thames may change in the future.

1) We conclude that river regulation or augmentation of river flows in autumn will have no appreciable impact on river zooplankton, as it is universally reported to occur at low population densities at this time.

2) During autumn and winter months with, typically, high river flows and low temperatures, augmentation flows containing a significant algal component are not considered likely to promote the development of river zooplankton.

3) Spring diatoms, released from a reservoir, would be readily utilised and transferred to other trophic levels including zooplankton in the Thames, however, releases of the larger algae, such as filamentous blue-greens in the summer may have consequences for other trophic levels, such as filter feeding macroinvertebrates, rather than the river zooplankton.

4) Reductions in summer discharge within the middle reaches of the Thames may result in an upstream extension of the plankton community characteristic of the lower reaches, where retention time is greatly increased. Based on studies in other rivers, changes to the zooplankton would include an increase in the crustacean component.

5) During spring and early summer the discharge of augmentation flows that substantially reduce retention time within the river will inhibit plankton development, whilst the discharge of intermittent augmentation flows may interupt the sequence of plankton development and act as "re-setting" events, where populations are diluted sufficiently to promote repeated cycles of phytoplankton development followed by zooplankton development.

In order to establish the current situation with regard to Thames zooplankton, the following sampling regime was proposed in the Interim Report (Bass & May, 1996) -

1) Relatively large sample volumes of river water should be collected from discreet depths with a small battery-powered submersible pump.

2) Monitor separately the abundance of small abundant taxa (eg Rotifera and Protozoa) and large comparatively infrequent taxa (eg Cladocera and copepodites).

3) Examine contemporary and seasonal differences in zooplankton at 5 river sites.

4) Examine spatial differences in zooplankton populations at 2 river sites, considered of relevance to grazing pressure on phytoplankton and food resource availability to other dependant fauna.

CONTENTS

1. Background

NRA Thames Region have commissioned a series of reviews and research studies focused on the middle reaches of the River Thames. From the outset, it has been the intention that these studies provide the basis for informed policy decisions relating to future river management, particularly with respect to modified flow regimes and their consequences for the ecology of the River Thames. This study addresses the role of zooplankton in large rivers, considering the trophic links with phytoplankton, other invertebrates and young fish. It is comprised of two parts: firstly, an Interim Report (Bass & May, 1996) scoping a zooplankton sampling programme secondly a literature review and evaluation of the potential role and importance of zooplankton in the middle reaches of the R.Thames (this report). The former exercise preceded the review and evaluation allowing time for the appropriate season-specific sampling to be planned.

2. Introduction

Changes in water quality and quantity in the middle reaches of the River Thames may result from proposed river management schemes, such as the construction of new reservoirs or the transfer of water from other catchments. Such schemes are likely to impact on the river zooplankton by changing their abundance and seasonal occurrence. These effects may have important implications for other trophic levels within the river community. For example, phytoplankton populations may be modified by altered grazing pressures, leading to an increase in troublesome algal blooms in some areas. The growth and survival of the juvenile fish, which feed on zooplankton, may also be changed, altering the balance of fish species within this popular coarse fishery. In addition, the macroinvertebrate community, which includes species used as water quality indicators, is likely to respond to the changed food supply.

Much of the early literature on zooplankton in running waters is reviewed by Hynes (1970). The author refers to many early records of rotifers collected from the main water channel of rivers and streams, including the Rhine (Lauterborn, 1893) and many other German rivers (Zacharias, 1898), and the Missouri (Berner, 1951). As early as 1898, Zacharias concluded

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that rivers, especially lowland rivers, could have a true plankton community ('potamoplankton'). However, for many years after that some authors were still stressing that planktonic organisms found in running water must have originated from still waters in the drainage basin (eg Brehm, 1911). Hynes (1970) concludes that plankton found in headwater streams probably originates from standing waters in the catchment while the sluggish waters further downstream probably support a truly planktonic zooplankton community. Berrie (1972) provided an overview of the aquatic communities in the R.Thames at Reading, highlighting the "Nuphar zone" as an area associated with the main production within the system contrasting this with the dominance of the biomass by fish and large bivalves. Later, Bottrell (1977) compared the Thames zooplankton with the microfauna in the Nuphar zone. The more recent literature on this subject is reviewed below.

In spite of their apparent importance as grazers of phytoplankton and food for fish within the river community, the zooplankton of the middle reaches of the River Thames has received little attention from biologists in the past, the study by Bottrell (1977) provided a notable exception. However, now that management changes to the river are planned, it is important to collect baseline data for the River Thames zooplankton community which can be used to predict the likely effects of a variety of proposed river management strategies and monitor the effects of the water management policies ultimately adopted. This report, together with the Interim Report (Bass & May, 1996), addresses the problem of designing a suitable zooplankton sampling strategy which will provide baseline zooplankton data for the River Thames and effectively detect and monitor changes resulting from the water management policies ultimately adopted.

3. Project Objectives

The aims of the present study are:

1. To review recent literature on the composition, density, temporal and spatial distribution, energy budgets of zooplankton in large rivers.

2. To review the recent literature on the importance of zooplankton in controlling the abundance and composition of phytoplankton (including pico-plankton) and fish in large rivers.

3. To review the factors controlling zooplankton density, distribution and succession in large rivers.

4. To evaluate the role and contribution of zooplankton to trophic interactions in the River Thames, with reference to the existing literature on the River Thames and the literature reviewed under objectives 1 - 3.

5. To review literature on the impact of river regulation on river zooplankton communities.

6. To evaluate the likely impacts of reservoir discharges, on the trophic interactions of zooplankton in the River Thames, with reference to the existing literature on the Thames, and the literature reviewed under objective 5.

7. To evaluate the likely impacts of altering the flow regimes of the River Thames on its zooplankton communities, with reference to existing literature on the River Thames and the literature reviewed under objective 5.

8. To recommend, if appropriate, a sampling programme to determine trophic relationships, of zooplankton in the River Thames, taking into account current NRA sampling procedures for phytoplankton and fish.

4. Literature Review

4.1 Introduction

Although rotifers and protozoans, together, are known to transfer bacterial production efficiently to higher levels in the riverine food chain (Dolan & Gallegos, 1991; Carlough & Meyer, 1991), there are very few studies of river zooplankton which include protozoa. One exception is the study by Admiraal *et al.* (1994) who looked at planktonic communities in the lower River Rhine. Unusually, these authors included counts of the larger protozoa (ie those retained by a 50 μm mesh net) yielding estimates of maximum biovolume around 80×10^6 μm^3 l^{-1} (based on those protozoa recorded during phytoplankton counts) as compared with contemporary rotifer biovolumes of around 500×10^6 μm^3 l^{-1}. However, most studies neglect the protozoa altogether and there is clearly a need for further work in this area.

In contrast to the situation with protozoa, rotifers are often mentioned in studies on the zooplankton of running waters. However, in most cases, the zooplankton sampling strategies used have been designed, primarily, for the study of the larger crustacean zooplankton using nets and sieves which have mesh sizes large enough to allow a significant proportion of rotifers to pass through. Bottrell *et al.* (1976) indicate that up to 80% of smaller rotifers may be lost through the use of nets and sieves with mesh sizes as small as 45 μm, 50% of these animals passing through the mesh and up to 30% adhering to it. Shiel *et al* (1982) also notes that the use of a 50 μm mesh net to sample rotifers has probably led to underestimates of population densities in the River Murray .

Table 1 summarises the mesh sizes used by some of the authors whose work is reviewed below. Most are well in excess of 45 μm which suggests that the rotifer densities recorded by these authors may have been underestimated by 80-90%, or more. The use of such inappropriate mesh sizes also biases samples towards the larger genera (such as *Keratella*, *Brachionus*, *Polyarthra* and *Asplanchna*) which are more likely to be retained by larger mesh

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sizes. In spite of these fundamental problems, it is still possible to make some general remarks on planktonic rotifers in rivers in relation to a variety of factors. These are detailed below.

Planktonic Copepoda, within riverine situations, are represented predominantly by the juvenile stages (copepodites and nauplii) of Cyclopoid species. Numerically, they are reported to be generally subordinate to the Rotifera (where the latter are sampled adequately). Comparatively large populations of Copepoda develop within tidal river reaches (eg Pace *et al.*, 1991; Tubbing *et al.*, 1994; Castel, 1993), impoundments (Martin *et al.*, 1981; Pillard & . 1993; Pinel-Alloul *et al.*, 1982), embayments (Saunders & Lewis, 1988; Storms *et al.*, 1981) and off-river connected waterbodies such as marinas and gravel pits (Neumann *et al.*, 1994; Van der Brink *et al.*, 1994). Localised high population densities are reported from within submerged marginal plant stands (Bottrell, 1977; Ejsmont-Kerabin *et al.*, 1993; Garner *et al.*, in press; Martin *et al.*, 1981) from where they may be flushed into the plankton during flood events.

With a few notable exceptions, planktonic Cladocera appear disfavoured by riverine conditions and frequently occur in very low population densities for much of the year. The influx of planktonic species below impoundments (eg, Sabri *et al.*, 1993; Sandlund, 1982) or their appearance following flushing of static areas of water connected to the main river channel (Sanders & Lewis, 1988 & 1989), is generally followed by rapid downstream declines. One species, *Bosmina longirostris*, has been widely reported to have the capability to increase in numbers in riverine conditions (eg Sabri, *et al.*, 1993). Benthic (Chydoridae, Macrothricidae), epiphytic (Chydoridae, Sididae) and littoral zone (Daphniidae, Polyphemidae) species of Cladocera occur in the plankton sporadically, generally in low numbers. Their impacts on open-water phytoplankton grazing and contributions to the riverine foodweb depend on the proportion of river channel providing their specialised microhabitat requirements and the exchange of water or migration of mobile taxa between these habitats and the open water of the main channel.

Table 1. Some examples of mesh sizes used by a range of investigators for collecting rotifer samples from rivers; values above 45 µm may correspond to underestimates of 80-90%, or more, in the numbers recorded.

Investigators	River	Mesh size (µm)
Admiraal et al. (1994)	Rhine, Netherlands	50
Blackwell et al. (1995)	Lower Trinity, Texas, USA	80
Bottrell (1977)	Thames, England	"70 meshes/cm"
Holland et al. (1983)	Atchafalaya, Louisiana, USA	79
Kowalczewski et al. (1985)	Vistula River, Poland	50
Neitzel et al. (1982):	Columbia, Washington, USA	150
de Ruyter van Steveninck et al. (1992)	Rhine & Moselle, Germany	50
Sabri et al. (1993)	River Tigris, Iraq	55
van Dijk & van Zanten (1995)	Lower Rhine, Netherlands	50
Ferrari et al. (1989)	Po, Italy	50
Harris et al. (1992)	La Trobe, Australia	200
Sandlund (1982)	Strandaelva, Norway	20
Saunders & Lewis (1988, 1989)	Orinoco & Apure, Venezuela	35
Shiel (1985)	Darling, Australia	35
Shiel et al. (1982)	Murray, Australia	53

Thorp et al. (1994)	Ohio, USA	63
Vranovský (1995)	Danube, Hungary	40

4.2 The composition, density, temporal and spatial distribution, and energy budgets of zooplankton in large rivers

4.2.1 Species composition and abundance

In spite of the fact that most studies have probably significantly underestimated rotifer abundance in rivers through the use of inappropriate mesh sizes to concentrate their samples (see above), rotifers still emerge as the dominant planktonic metazoan in most rivers (Sandlund, 1982; Kowalczewski et al., 1985; Shiel, 1985; Ferrari et al., 1989; Admiraal et al., 1994; Gosselain et al., 1994; Blackwell et al. (1995); van Dijk & van Zanten, 1995; Pillard & Anderson, 1993; Sabri et al., 1993). One notable exception to this is the study by Neitzel et al. (1982) who concluded that, in the Columbia River, Washington, crustacean zooplankton dominated most samples. Closer inspection of his sampling methods reveal that this result is probably an artefact of his sampling methodology which employed an unusually large, 150 μm mesh, net. It has been suggested that the apparent dominance of rotifers in rivers could be explained by their very brief generation times compared to larger zooplankton (van Dijk & van Zanten, 1995); on occasion, de Ruyter van Steveninck et al. (1992) found that rotifers were found to double at twice the rate (0.89 d^{-1}) of crustacea (0.45 d^{-1}) in the Rhine.

Many species lists are given in the studies considered here. In general, these indicate that, in most situations, the rotifer species present tend to reflect the species composition of the planktonic communities occurring in nearby lakes and ponds from which they probably originate (Reinhard, 1931; Cowell, 1970; Hynes 1970; Kallemeyn & Novotny, 1977; Sandlund, 1982; Harris et al., 1992). Most of these species are found in relatively low numbers, with their abundance decreasing with distance from these sources (Hynes, 1970; Sandlund, 1982). In contrast, some species are far more abundant and appear to be part of the

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true plankton of large, slow flowing rivers, especially those belonging to the genera *Brachionus*, *Keratella* and *Polyarthra* (Sandlund, 1982; Holland *et al.*, 1983; Shiel, 1985; Sabri *et al.*, 1993; Gosselain *et al.*, 1994; Thorp *et al*, 1994; Blackwell *et al.*, 1995; van Dijk & van Zanten, 1995). However, in drawing any conclusions from this, it should be noted that individuals from these genera tend to be larger than many other rotifer species, and bear pronounced spines and appendages. This may increase their chance of being caught by the wide meshed nets and sieves used in many of these studies, causing sampling bias.

Rotifer densities in eutrophic flowing waters tend to be much lower than those recorded in eutrophic lakes (van Dijk & van Zanten, 1995). For example, in the lower River Rhine, maximum rotifer densities of 1100 ind. l^{-1} (van Dijk & van Zanten, 1995) are 8 to 10 times lower than in the nearby Loosdrecht lakes (9000 ind. l^{-1} - Gulati, 1990). Although different mesh sizes were used in each of the studies [ie. 33 µm by Gulati (1990); 50 µm by van Dijk & van Zanten (1995)], this is unlikely to explain all of the discrepancy recorded and it seems likely that flowing waters do tend to have lower rotifer densities than standing waters of similar trophic status. In general, rotifer abundances tend to range from about 0.02 ind. l^{-1} in fast flowing and relatively unproductive streams such as the River Strandaelva, Norway (Sandlund, 1982) to about 7,000 ind. l^{-1} in large, slower, more nutrient rich rivers, such as the River Po, Italy (Ferrari *et al.*, 1989). Rotifer abundance in rivers is, however, affected by a variety of factors other than nutrient availability and rates of flow. These are discussed below.

Variability in species composition and density over a range of timescales is a feature also of Copepoda. Many studies compare contrasting river reaches or pre- and post-"development" changes to biota over a one or two year period, whilst overlooking both natural longer term variability (noted by Tubbing *et al*, 1994). and the day-to-day changes that can occur in some rivers (Rossaro, 1988). The latter author, studying the mid-Po River in Italy, concluded that a long time series of data is required to clarify the most important seasonal zooplankton trends, with all taxa capable of exhibiting highly variable and significant population changes over one week and changes between successive days for some taxa. In general, the copepoda are most abundant in downstream reaches of the larger rivers, where retention time increases under the influence of tidal movements (eg, R.Gironde, Castel, 1993; R.Rhine, Admiraal *et al*, 1994; Tubbing *et al*, 1994,). This situation is reversed below river impoundments, where

a downstream decline in Copepoda has been noted (R.Tigris, Sabri *et al*, 1993; Mississipi R., Pillard & Anderson, 1993; R.Strandaelva, Sandlund, 1982).

The Cladocera represented in river zooplankton studies are considerably less diverse than those recorded from lakes and are always less abundant than the Copepoda and Rotifera. *Bosmina* spp are the most widely and frequently recorded planktonic species of the open water habitat in rivers (eg, Bothar & Kiss, (1990); Neitzel *et al*, 1982; Sabri *et al.*, 1993; Saunders & Lewis, 1989), with Daphniidae providing a significant component to the zooplankton where impoundments or side channels increase water retention time (Martin *et al*, 1981; Sabri *et al.*, 1993). Other Cladocerans are largely confined to benthic and epiphytic habitats, entering the plankton during flood events.

4.2.2 *Temporal variation*

Interpretation of temporal variation in river plankton is confounded by the downstream movement of the population within a volume of water, ideally this same volume of water would be sampled at intervals (eg. Ruyter van Steveninck *et al.*, 1992). Most records of temporal variation tend to relate to repeated sampling of the river water passing a certain point, over time. For this reason, the data collected do not refer to the development or decline of a given population over time, as it does in a lake, but, instead, reflect changes which have occurred upstream of the sampling site over the sampling period.

Nevertheless, some authors have monitored temporal changes in zooplankton abundance in rivers (eg. Reinhard, 1931; Saunders & Lewis, 1988; Admiraal *et al.*, 1994; Tubbing *et al.*, 1994; van Zanten & van Dijk, 1994; van Dijk & van Zanten, 1995) and their results tend to suggest that there is an underlying tendency for a similar seasonal pattern of abundance to develop as is usually found in lakes, ie a spring/early summer peak following a spring phytoplankton bloom. The exception to this is Thorp *et al.* (1994) who recorded peak rotifer numbers in summer and autumn in the Ohio River. However, the spring/early summer peak in zooplankton may be modified to a greater or lesser extent by changes in other factors such as rates of flow, turbidity, levels of pollution, water temperature, food availability, predation levels, etc. most of which are discussed in the relevant sections, below. The general temporal

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pattern in most studies indicate peak seasonal abundance for Copepoda and Cladocera occurring shortly after the Rotifera (eg. R.Rhine, Admiraal *et al.*, 1994; Potomac R., Storms, 1981; Ohio R., Thorp *et al*, 1994).

Over much shorter timescales, diel variations in crustacean zooplankton have been described in estuaries (eg, Pagano, et al, 1993) lakes (Lampert & Taylor, 1985) and embayments dominated by submerged plants (Timms & Moss, 1984). However, the numerous studies on Rotifera, which are the dominant river zooplankton fauna, have not addressed diel variation. Unlike certain Copepoda and Cladocera, planktonic rotifers provide no indication of elevated numbers within submerged plants stands (eg, R.Great Ouse, IFE unpubl. data), therefore it is considered unlikely that movement of rotifers between open water feeding areas and such refugia will result in significant diel changes in population densities. There remains the possibility of movement by Copepoda and Cladocera from submerged plants, or from within the gravel interstices, into the open water at night. The diel vertical movements of zooplankton noted in lakes have seldom been recorded from rivers.

4.2.3 *Spatial distribution*

Most studies of the spatial distribution of zooplankton in rivers have looked at variations in species composition and abundance along the river at the reach scale, rather than with depth or across the river channel. Along river variation depends on many factors including the position of backwaters and pools (Blackwell et al., 1995); the influence of inflows and lake/reservoir outlets (Cowell, 1970; Kallemeyn & Novotny, 1977; de Ruyter van Steveninck *et al.*, 1992); the effect of pollutants which favour one zooplankton taxon over another (Guisande & Toja, 1988; Hanazato & Yasuno, 1990); changes in water temperature (Gosselain *et al.*, 1994) and water velocity.

Blackwell *et al.* (1995) showed that, in Lower Trinity River, Texas, rotifers tended to be most abundant in backwaters (mean 40 ind. l^{-1}) compared to mid-river stations (mean 19 ind. l^{-1}). It has also been shown that zooplankton communities downstream of lakes and reservoirs often originate in the upstream waterbody (Cowell, 1970; Kallemeyn and Novotny 1977) and

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that their density usually decreases rapidly with distance below this source (Hynes 1970; Sandlund, 1982; Sabri *et al.*, 1993). Conditions in rivers are often different from the reservoirs and may not be conducive to zooplankton survival. However, in some rivers, the abundance of plankton increases downstream. For example, Harris *et al.*, (1992) found that, in the La Trobe River, Australia, plankton density downstream of the outfall from a pulp and paper mill was 100 times higher than upstream. Such increases probably reflect the slower rate of flow which allows these stretches of water to support a true zooplankton community (Hynes 1970). Gosselain *et al.* (1994) suggest that the tendency for increased zooplankton abundance downstream in the River Meuse, Belgium, may be due to higher temperatures and longer travel times which allow further generations to appear. This is supported by Shiel *et al.* (1982) who estimate that the slow flow and relatively high water temperature of the River Darling, Australia, would allow rotifers to produce 18-20 generations during their passage from the headwaters. However, in some cases, such increases could be due to the influence of inflowing water from tributaries. De Ruyter van Steveninck (1992) showed that, in the River Rhine, rotifer densities increased after its confluence with the River Moselle, while Shiel *et al.* (1982) describe the composition of the rotifer plankton in the lower River Murray as determined, principally, by the flow contributions of the Rivers Murray and Darling, respectively, at their confluence.

At the site scale, many authors have combined stratified samples to provide an "averaged" within-channel zooplankton assessment, so avoiding the confounding influence of possible short timescale changes in zooplankton spatial distribution. Bottrell (1977) detected small spatial differences in Thames zooplankton concentration within the water column in winter when population densities were extremely low. However, this aspect was investigated on only four occasions during his 15 month study. He concluded flow conditions in the Thames at Reading in 1971 were sufficiently turbulent to maintain even mixing of the open water community. Small-scale spatial distribution of zooplankton formed the basis of some detailed studies (eg, Rossaro, 1988; Pace et al., 1991; Garner *et al.*, in press). The hypothesis that river zooplankton patchiness, at the site scale, would be more homogeneous than observed in lakes was tested by Pace *et al.* (1991). At an unstratified site on the Hudson River they detected increasing small-scale patchiness with rising zooplankton density and concluded populations were uniformly distributed at low densities (<1 l^{-1}), random at moderate densities

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(1-100 l^{-1}) and aggregated at high densities (>100 l^{-1}). Similar enhanced zooplankton patchiness, as population densities increased, were observed in the open water of the R.Great Ouse (Bass *et al.*, in press). On a larger scale, variations in zooplankton density may develop in asociation with "dead zones" or "storage zones", as described by Reynolds (1995), which influence river phytoplankton.

4.2.4 · *Energy budgets*

The energy budgets of rotifers in large rivers appear to have received little or no attention from the research community, as no references to this type of study were found in the literature. In a few studies (eg, Admiraal, *et al*, 1994; Bothar & Kiss, 1990;) components of the plankton biomass have been expressed in terms of carbon and attempts made to consider grazing impacts. The regeneration/cycling of phosphorus by river zooplankton has also been investigated (Ejsmont-Karabin *et al.*,1993), with respect to spatial variation.

4.3 The importance of zooplankton in controlling the abundance and composition of phytoplankton (including pico-plankton) and fish in large rivers

4.3.1 *Importance of zooplankton in controlling the abundance and composition of phytoplankton*

In all studies which have considered Rotifera, this group had the greatest potential for influencing the phytoplankton-zooplankton dynamics. However, there are few references to the role of rotifers in controlling phytoplankton abundance and species composition in large rivers. In a study of the Netherlands reach of the River Rhine, Admiraal *et al.* (1994) concluded that algal density is more likely to control grazer abundance, than the other way around. They estimated that, in terms of algal biomass, losses between two river reaches due to metazoan grazing during 1990 ranged from 28% in May to 2.3% in September. Similarly, de Ruyter van Steveninck (1992) estimated that, in the River Rhine, losses of phytoplankton due to grazing were about 25-30% in spring and 5-10% later in the year. Gosselain *et al.* (1994) attempted to estimate grazing losses due to rotifers in the River Meuse, Belgium. These authors calculated that 1000 ind. l^{-1} *Brachionus calyciflorus* feeding for 24 h at their

maximal ingestion rate of 18.5 ng C ind^{-1} l^{-1} at 20°C on the spring bloom of algae in 1992 would consume 445 µg algal C l^{-1} d^{-1} (equivalent to a grazing rate of 0.15 d^{-1}). This apparent lack of "top-down" control on phytoplankton does not explain the mid-summer decline widely recorded in rivers. We must conclude that other loss processes, in combination with zooplankton grazing pressure, lead to declines in algal biomass, despite the continuous input of nutrients to rivers.

4.3.2 *Importance as food for fish*

Developments in the aquaculture industry have highlighted the early feeding requirements of young fish and field studies have established that rotifers are the first food source for many fish species, following adsorption of the yolk sac. In rivers, the seasonal sequence: phytoplankton-Rotifers-Copepoda/Cladocera, provides a continuum of increasing prey size to match fish growth and prey capture capabilities. Fish/zooplankton studies have addressed seasonal and habitat aspects of this relationship. In backwaters of the Lower Trinity River, Texas, Blackwell *et al.* (1995) found zooplankton were significantly more abundant, with lower current velocities conducive to higher zooplankton densities (food for fish) and lower energy expense for fish in maintaining position. Harris *et al.* (1992) noted that the plankton density downstream from an extensively treated wastewater outfall was 100 times higher than upstream; with this increased food for zooplankton and fish derived from productive impoundments above the mill. Martin *et al.* (1981) described contrasting zooplankton availability and consequences for fish growth in the Missouri River system, comparing years with high and low water levels that influenced the types and quantity of zooplankton developing in the littoral zone. Similarly, two contrasting habitats provided by the main river and connected riverside gravel pits on the Rhine (Neumann *et al.*,1994) yielded 300 times higher zooplankton densities in the gravel pits, where juveniles of 12 riverine fish species utilised the areas for feeding and shelter from flood events. Habitats at the river margin include areas of increased retention-time and shelter for juvenile fish. Garner *et al.* (in press) described the rapid loss of planktonic Cladocera following weed-cutting and the resultant changes in prey ingested by young roach (*Rutilus rutilus*) along the margins of the R. Great Ouse. Mann *et al.* (1995) investigated the between-habitat, between-species and temporal changes in the diets of young fish in the R Thames at Abingdon. All species utilised

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components of the zooplankton for varying periods and a parallel study in a connected riverside marina indicated extended feeding on zooplankton where it persisted throughout the summer (Mann, *pers com.*). An experimental study on the influence of prey size on growth rate (Perrow & Irvine, 1992) indicated faster growth in under-yearling Roach supplied, *ad libitum*, with large *Daphnia hyalina* (>1.5mm), than with smaller *Daphnia* (<1.0mm).

4.4 The factors controlling zooplankton density, distribution and succession in large rivers

Zooplankton are often abundant in the main channels of large rivers, but the processes regulating their abundance may be difficult to discern due to advection (Saunders & Lewis, 1989). The growth and mortality processes that are primary regulators of zooplankton populations in lakes also affect zooplankton populations in rivers as they are transported downstream. However, superimposed on this are also advective processes that control the influx of zooplankton to rivers from source areas and the continual loss downstream (Rai, 1974; Hynes, 1970). Van Dijk & van Zanten (1995), working on the Lower Rhine, concluded that the dynamics of rotifers in this river were controlled, primarily, by water temperature, food availability and discharge, while other authors have suggested that mortality due to predation and mechanical damage is also important (Saunders & Lewis, 1989). These, and other factors thought to control the density, distribution and succession of zooplankton in large rivers are discussed below.

4.4.1 *Flow*

The plankton of large rivers 'potamoplankton' is partly allochthanous (derived from headwater lakes, backwaters and tributaries) and partly autochthonous (developed within the river) (Shiel *et al.*, 1982). The balance between the two types is determined, to a large extent, by the flow characteristics of the river and its tributaries. Rapidly flowing waters tend to increase the numbers of rotifers in the main channel of the river by washout from impoundments, lakes and ponds within the catchment, and quiet backwaters of the river itself. In general, the faster the current, the less able rotifers are to maintain their position and the more likely they are to be washed into the main channel of the river (Reinhard, 1931; Sandlund, 1982). This may

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affect the structure of the zooplankton community, as rotifers and cladocera are less able to maintain there position in flowing water than copepods and are, thus, more likely to be washed into the main channel than copepods (Richardson, 1992). It should also be noted, however, that, under spate conditions, increased flushing can rapidly deplete rotifer populations in the quiet backwaters and margins of rivers, leading to a sharp drop in zooplankton entering the main channel (Saunders & Lewis, 1988), unless the river inundates the floodplain and washes zooplankton from otherwise remote sources into the main river (Vranovský, 1985; Saunders & Lewis, 1988).

Once zooplankton have been washed into the main channel of the river, their fate is determined by the balance of growth and mortality factors which influence their reproduction and survival (Saunders & Lewis, 1988). Increasing current velocity has a strong negative influence on zooplankton reproductive rates (Rzoska, 1978). For example, rotifers in the Orinoco River were found to carry eggs only at current velocities of less than 1.5 m s^{-1} and egg ratios tended to increase with decreasing current velocity below 1.5 m s^{-1} (Saunders & Lewis, 1989). In addition, the dilution of algal food supplies by increased water supply may also reduce rotifer reproductive rates (Van Dijk & van Zanten, 1995).

Changes in water flow may also affect rotifer survival once they have entered the main channel of the river, primarily through mechanical damage (Saunders & Lewis, 1989). In addition, copepods and rotifers differ in their tolerance to flow (van Dijk & van Zanten, 1995) which may cause changes in zooplankton community structure. However, in most cases, these effects are likely to be masked by other influences on their survival, such as changes in environment, pollution incidents and increased selective predation pressure from other invertebrates and fish.

4.4.2 *Temperature*

Water temperature has a marked effect on the feeding, reproduction and growth rates of zooplankton in lakes, and probably in rivers. However, there is little mention of these effects in the literature, apart from the work of van Dijk & van Zanten (1995), working on the Lower Rhine, who attribute the spring peak in rotifer abundance to increases in water temperature

and chlorophyll$_a$ levels. Bottrell (1975a) investigated the influence of temperature on egg development in 8 species of cladocerans and a single copepod species from the R.Thames. He described a curvilinear relationship between time-to-hatching and temperature, with development times more than halved at 20°C when compared with 10°C. A similar growth response, following hatching was noted under laboratory conditions of unlimited food supply (Bottrell, 1975b). This topic clearly requires further investigation, as thermal pollution (eg from cooling water discharges, water transfer or pump storage systems) may have an important effect on zooplankton communities in rivers.

Water temperature may also affect species composition. Lair (1980) found that tropical rotifers were present in the River Loire, France, close to the sources of thermal effluent from nuclear power plants. In contrast, other rotifers, such as *Filinia terminalis*, seemed to be inhibited by the elevated temperatures downstream of these plants. In general, however, this thermal pollution had the effect of increasing total rotifer abundance downstream of the power stations.

4.4.3 *Food availability*

Studies on the Rhine have suggested that algal density controls grazer density in this river, rather than the reverse (Admiraal *et al.*, 1994). The authors estimated that, in May, July and September, 1990, metazoan grazing explained only 28%, 10% and 2.3%, respectively, of the algal biomass disappearing in the Netherlands reach of this river. Published studies imply that zooplankton populations are negligible in rivers without phytoplankton and in the absence of lake-sourced zooplankton inputs. That both phytoplankton and zooplankton in rivers are strongly influenced by discharge rates is widely reported. Bottrell (1977) concluded that Thames zooplankton did not become established whilst the mean velocity remained above 0.2m sec-1 and zooplankton development also required the presence of phytoplankton. With suitable conditions for growth and reproduction in spring the development of the larger and most conspicuous components within riverine zooplankton is inevitably slower than that achieved by relatively small, fast-growing phytoplankton, leading to a lag in grazing potential. There is, by contrast, less information on the population size and response rate of small zooplankters. Measurable grazing impacts of river zooplankton are reported to be generally

restricted to late spring and early summer (eg, Admiraal *et al*, 1994; Gosselain *et al*, 1994). Flood events, leading to reduced retention time in the river, impact both phytoplankton and zooplankton communities simultaneously. Whilst the concept of dead zones/storage zones (eg, Reynolds, 1995) leading to attenuation of downstream loss rates is considered likely to apply to both components. Waterbodies connected to the main river channel, with similar water chemistry and nutrient status frequently maintain higher phytoplankton and zooplankton populations through the summer (eg, R.Rhine, Neumann *et al.*,1994; R.Great Ouse, Marker & Collett, in press; Bass *et al.*, in press), indicating the potential for greater plankton development under conditions of extended retention. The physical constraints on plankton development in the main river are not fully explained by seasonally reduced downstream losses, as water movement is greatly restricted at times of low discharges which, typically, occur in summer. A long-term (10 year) study on the Gironde estuary (Castel, 1993) indicated that river discharge still provides the overriding control of crustacean zooplankton populations.

4.4.4 *Predation*

Zooplankton communities include predators within all the major groups (Protozoa, Rotifera, Copepoda & Cladocera). Within the Rotifera, *Asplanchna* spp are known to prey on other rotifers; loricate forms are often seen in the guts but they also take soft bodied rotifers (May, pers com). The less mobile small species are also preyed upon by passive benthic filter-feeders, such as sponges, bryozoans, bivalve molluscs filter-feeding and net-spinning insect larvae. Larger species are targeted by specialist predators that ambush or actively chase their prey. Within most rivers the ephemeral nature of river zooplankton as a resource may explain the rather few studies that address this topic. Below impoundments and reservoirs, greatly modified benthic invertebrate communities result from the discharge of plankton-rich water (eg. Armitage, 1978).

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Specialist zooplankton feeders, such as young fish which are highly mobile, may seek out optimal prey types and prey densities. Experimental studies (Panov et al., 1969 cited in Opuszynski, et al., 1985) established that newly hatched cyprinids require 1500 rotifers per litre for optimal growth, with the growth rate dropping to 43% at 300 and 20% at 100 per litre, respectively. Such optimal densities of Rotifera are rarely maintained, at least as mean densities, within rivers. Blackwell et al. (1995) considered that juvenile paddlefish utilised zooplankton which were significantly more abundant in backwaters of Lower Trinity River, Texas; the backwaters providing lower current velocities conducive to higher zooplankton densities (food for fish) and lower energy expense for fish in maintaining position. Garner et al. (in press) observed high predation rates on Cladocera adjacent to aquatic plants and greater gut-fullness in under-yearling Roach when the area of plant cover was reduced during weedcutting on the R.Great Ouse.

The habitat utilisation by juvenile fish and their gut contents were studied on the Thames at Abingdon in 1995 (Mann et al., 1995), this work indicated that, in the five fish species looked at in detail, broadly similar prey types were ingested with zooplankton contributing a sequence of prey increasing in size, as the fish grew. It is interesting to note that despite a staggered hatching period all fish species ingested planktonic rotifers initially (with the exception of perch, which by chance were not captured before they were capable of ingesting larger prey items). The switch to aufwuchs feeding by Roach, observed on the R.Great Ouse (Mann, in press), also occurred in the R.Thames from July onwards, but did not take place in the adjacent Abbingdon Marina, where zooplankton feeding continued throughout the study.

4.4.5 *Pollution*

The effects of pollution on downstream rotifer communities are complex and depend on the exact cause of the pollution problem. However, Hanazato & Yasuno (1990) have shown that rotifers are less sensitive to micropollutants than are crustacea. This suggests that contamination may favour the dominance of rotifers in river zooplankton communities, a hypotheses which is supported by observations in the river Guidalquivir (Guisande & Toja, 1988). In contrast, Kulshrestha et al. (1991) noted an absence of rotifers due to pollution

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from a synthetic fibre factory on the Chambal River. They noted that rotifer numbers recovered some 8km downstream, but failed to quote the retention time between monitoring sites.

4.5   The role and contribution of zooplankton to trophic interactions in the River Thames

The present role of Thames zooplankton, as it influences the phytoplankton and other trophic levels, is considered in the light of detailed relevant studies on similar rivers together with the work on the Thames by Bottrell in the 1970s (cited in sections 2, 4.1, 4.2.3, 4.4.2). The Rotifera clearly provide the universally dominant components of river zooplankton, where studies have sampled them adequately. There is also broad agreement between authors that, paradoxically, phytoplankton in rivers fails to exhibit significant grazing losses. Recent advances in understanding the development and maintenance of river phytoplankton (eg, Reynolds & Glaister, 1993; Reynolds, 1995), include establishing the importance of storage ("dead") zones within the river channel, where downstream washout processes are attenuated over a range of discharge conditions. Such enhanced retention produces higher phytoplankton population densities than could be accounted for with optimal growth rates in "plug-flow" conditions. It might be postulated that zooplankton should be equally favoured by enhanced retention time within the river, however, timescales may still be comparatively short, in terms of the zooplankton reproductive rates [see section 4.2.1., Ruyter van Steveninck et al (1992); section 4.4.2., Bottrell, 1975a & b].

The scope for the development of a diverse plankton community in rivers is limited by the erratic occurrence of flood events that "re-set" the system. Such flood events tending to favour small, short-lived taxa that opperate as as primary colonists. In parallel, the nature (or "quality") of the zooplankton food supply is constrained, possibly leading to dominance by a few "boom and bust" grazing taxa. As an example, occurrence of the rotifer, *Polyarthra vulgaris*, is strongly associated with phytoplankton dominated by cryptomonads, its main food source. It is widely reported from rivers, has frequently dominated populations on the R.Great Ouse (Bass, *et al.*, in press) and was prolific in the Thames at Abbingdon in 1995 (Mann, *et al.*, 1995), but was not recorded by Bottrell (1977). Interestingly, in terms of

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trophic interactions, *Polyarthra vulgaris* also presents a potential dead end for foraging juvenile fish as its erratic movements provide an effective escape mechanism from many predators. Another group of large predatory rotifers, *Asplanchna* spp., ingest *P.vulgaris* and in turn are preyed upon by juvenile fish, however the slower growth and reproduction rates of *Asplanchna* spp. result in few occurring in the main river channel, whilst large populations develop in riverside marinas (Mann, pers com; section 4.3.2).

A further route for zooplankton/phytoplankton interactions within a range of trophic levels is provided by the community associated with submerged plants. Certain planktonic (eg, *Ceriodaphnia* spp.), and epiphytic (eg, *Sida cristallina*) crustaceans live predominately within the shelter of these plants (Bottrell, 1977; Garner *et al.*, in press; Bass, *et al.*, in press), their seasonal abundance is controlled by the extent of suitable habitat, appropriate water flow, phytoplankton quantity and quality, also the predation pressure exerted by macroinvertebrates and fish.

Zooplankton and phytoplankton within the main river channel may be ingested by filter-feeding sponges, bryozoans and large bivalve molluscs. The latter group was reported to contribute a high proportion of the faunal biomass present in the Thames (Berrie, 1972), though the current status of the population of bivalves and their impacts on plankton dynamics is unknown.

4.6 The impact of river regulation on river zooplankton communities

River regulation, by implication, changes flow regimes. In this section we consider the impacts of reduced high flows and increased low flows as being most pertinent to the middle reaches of the R.Thames, in its role as an important conduit supplying the London area. At the same time, we acknowledge that in practice some rivers have regulation schemes that lead to a reduction in natural base flows. The latter situations are subject to local reviews and appraisals when abstraction consents are sought and renewed. River transfers, in the context of the Thames, have recently been the subject of a review for Thames NRA (Mann & Bass, 1995), therefore the potential changes associated with transfers are not repeated here. An

overview of the conditions pertaining in the UK (Petts, 1988) highlighted the fact that virtually all major rivers are regulated directly or indirectly.

The reduction of high river discharges, whether by interception into reservoirs sited at the top of the catchment or by direct river abstraction, result in fewer major "flushing flows". Though such river regulation implies increased scope for effective flood control measures, the compounding influences of extensively modified river channels within lowland Britain (Brookes, 1983) and improved land drainage, result in changes in river discharge occurring over comparatively short timescales. Augmented river discharge during low river flows, typically occurring in summer, has more potential to alter within-river conditions, simply by the greater proportional changes to baseflow and temperature driven physical (eg dissolved oxygen), chemical and biological processes.

The consequences of river regulation in the UK for the freshwater invertebrate fauna, as reviewed by Boon (1988), have focused almost exclusively on macroinvertebrates. North American (eg, Basu & Pick, 1995; Holland et al. 1983; Martin et al., 1981; Thorp, et al., 1994; Pillard, & Anderson, 1993) and European (eg, Gosselain et al., 1994; Lair, 1980; Neumann, et al.,1994; Pinel-Alloul et al., 1982; Sabri, et al., 1993) studies on zooplankton, which also consider the consequences of river regulation, stressed such potential impacts as altered dilution, washout rates, water levels, retention time, changes in water quality, transfer of species within the modified river system, or from elsewhere.

All of the North American studies cited above included extensive impoundments on rivers which resulted in highly modified plankton communities. These effects were noted in the similar European studies conducted by Pinel-Alloul et al. (1982) and Sabri, et al. (1993). By contrast, Neumann et al. (1994) compared phytoplankton and zooplankton in the highly regulated lower Rhine with much larger populations in connected gravel pit lakes, the latter providing valuable biotopes lost from the main river, where washout during flood events can be severe. Lair (1980) considered the influences of enhanced retention time within a small impoundment and elevated temperatures below a power station discharge on the R.Loire, in this situation river zooplankton populations increased and species composition was altered. Gosselain et al. (1994) described the phytoplankton community of the R Meuse, highlighting

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the management of the reservoir. Sandlund (1982) observed that maximum numbers of *Synchaeta* spp (Rotifera) in a lake outflow coincided with highest concentration in the upper waters of the lake, which is pertinent to the timing of augmentation flow release in relation to diurnal migration. The potential extension of river zooplankton presence throughout the summer months, under the influence of reservoir discharges, would increase the currently limited supply of planktonic organisms utilised by young fish at this time of year (Mann *et al*, 1995).

Food quality and quantity

The release of reservoir water with low plankton densities, or with taxa incapable of surviving riverine conditions, will result in a corresponding dilution of river zooplankton. The potential impact from such releases is anticipated to be greatest in early summer, when riverine zooplankton grazing impacts on phytoplankton has been reported (Admiraal et al, 1994; Gosselain et al, 1994) and at the time when young-of-the-year fish are feeding almost exclusively on zooplankton (Mann, et al. 1995). The dilution of Thames plankton by reservoir releases of clear water later in the summer may be anticipated to have less impact on Thames zooplankton population patterns [populations described as negligible after July, at Reading, in 1971 (Bottrell, 1977)], but the current situation (1990s) remains to be established. The seasonal changes in plankton composition within released reservoir water will have an impact on river zooplankton, especially on the Rotifera which tend to dominate river zooplankton communities (Section 4.2.1). The spring diatoms released from a reservoir would be readily utilised and transferred to other trophic levels, however, releases of the larger algae, such as filamentous blue-greens in the summer may have consequences for other trophic levels, such as filter feeding macroinvertebrates, rather than the river zooplankton. The discharge from reservoirs of crustacean zooplankton is considered likely, however downstream losses below such inputs are widely reported (Sections 4.1 & 4.2.1) for most taxa. In contrast, higher densities of *Bosmina longirostris* may result and littoral epiphytic Cladocerans may benefit from increased phytoplankton concentrations (Section 4.5). In addition to topics covered in *Seasonal Aspects*, the intermittentnature of inputs associated with reservoir discharges into rivers may inhibit the development of new stable foodwebs dependant on the reservoir

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resource. However, as rivers are subject to intermittent flood events superimposed on seasonal cycles the development and abundance of the aquatic fauna are a characteristically unstable feature.

4.8 The likely impacts of altering the flow regimes of the River Thames on its zooplankton communities

The following conclusions are based mainly on published studies conducted in other rivers and an investigation of the characteristics of the Thames zooplankton are the subject of proposed new studies (Bass & May, 1996; and section 4.9). Bottrell (1977) compared the zooplankton community of the Thames and Kennet at Reading in a single year, 1971. Though this study was particularly thorough, conditions within the Thames are likely to have altered in the interim period and the author did not investigate characteristics of the zooplankton at different points along the Thames.

The potential impacts of an altered Thames flow regime on zooplankton are considered within the following scenarios, with scenarios 3, 4 and 5 regarded to be particularly relavent to consequences of a Severn - Thames transfer :

1) *Reduced river discharge in spring (abstraction to storage)*

2) *Reduced river discharge in summer (abstraction to storage)*

3) *Increased river discharge in summer (augmentation of river flows)*

4) *Increased river discharge in autumn (augmentation of river flows)*

5) *Intermittent increases in river flow, associated with augmentation*

1) *Reduced river discharge in spring (abstraction to storage)*

The seasonal appearance of significant populations of rotifers, the major component of river zooplankton, is closely tied to spring phytoplankton development. A reduction in river discharge increases retention time, decreasing washout rate and leading to a more rapid development of plankton, within the constraints imposed by the prevailing water temperature and light climate. An exceptionally dry and warm spring in 1990 resulted in larger and

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unusually prolonged phytoplankton and zooplankton communities developing in the R.Great Ouse (Marker & Collett, in press; Bass *et al*, in press).

2) *Reduced river discharge in summer (abstraction to storage)*

Within the majority of published studies examined the normal seasonal pattern of declining baseflow in summer is accompanied by a temporary or longer term decline in river phytoplankton (measured as chlorophyll $_a$) and zooplankton. Though this trend is less marked in the lower reaches of rivers. The reasons for the decline in phytoplankton, in the apparent absence of nutrient limitation, are currently debatable. A change in dominance by diatoms to dominance by species of green algae is a common feature. Further reductions in summer discharge within the middle reaches of the Thames may result in an upstream extension of the plankton community characteristic of the lower reaches of rivers, where retention time is greatly increased (eg, R.Rhine, Admiraal, *et al.*, 1994). Changes to the zooplankton would include an increase in the crustacean component.

3) *Increased river discharge in summer (augmentation of river flows)*

The influx of additional water to the Thames in summer, whether by direct river transfer or via a reservoir, will give rise to a decrease in retention time within the river. An increased summer river discharge appears likely to accentuate or advance the natural seasonal decline in zooplankton reported from most other rivers, at this time. Environment Agency research underway on the relationship between Thames phytoplankton development and river discharge will provide the baseline from which some of the impacts of future discharge modifications can be predicted. Consideration of the influence of "dead zones/storage zones" within the river (Reynolds and Glaister, 1993; Reynolds, 1995) and the plankton composition of incoming water, will also require consideration.

4) *Increased river discharge in autumn (augmentation of river flows)*

Some rivers exhibit small increases in phytoplankton during autumn but, within the constraints imposed by declining ambient temperatures and increasing natural baseflow, corresponding

increases in zooplankton are not recorded in the literature. Therefore, we conclude that, generally, augmentation of river flows in autumn will have no appreciable impact on river zooplankton. However, in circumstances where additional water carried its own zooplankton, there may be some localised enhancement of Thames zooplankton populations.

5) *Intermittent increases in river flow, associated with augmentation*

As established in sections 4.2 & 4.4, natural flood events disrupt the development of river plankton. The extent and severity of such disruption will depend on the scale of change in discharge and, most crucially, the time of year. Contrasting discharge patterns and the presence/absence of flood events observed in different years on the R.Great Ouse (Marker & Collett, in press; Bass *et al.*, in press) indicated that such "re-setting" events (where populations are diluted temporarily followed by repeated cycles of phytoplankton and zooplankton development) may be critical in redefining the pattern of plankton development in a particular year. The consequences of augmentation flows carrying introduced plankton are considered in section 4.7.

4.9 Recommended sampling programme to determine trophic relationships of zooplankton in the River Thames, taking account of current NRA sampling procedures for phytoplankton and fish

The Interim Report (Bass & May, 1996) provided an outline sampling programme which proposed visits to five river locations at two week intervals between April and October. Sampling was to include the Rotifera, Copepoda and Cladocera. At two of the five river locations a series of separate samples across the river taken at two depths would yield information on spatial variation in population densities of the various taxa.

Three questions arose, following submission of the Interim Report:
(Reply to Carolyn Ingles - 13.2.96, further discussion invited on question 1)

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1-Choice of sampling sites.

The five sites proposed for zooplankton sampling were selected from twelve locations used for phytoplankton sampling by Thames NRA (August 1992-August 1994). However, from September 1994 the sites for phytoplankton sampling conducted by Thames NRA were reduced to four of these twelve sites. As it would be desirable to have coinciding sampling locations for phytoplankton and zooplankton it is now proposed that at least two sites are common to both studies. Selection of two zooplankton sampling sites at maximum distance from upstream lock/weir systems is considered desirable in order to investigate the seasonal development of zooplankton "patchiness", of potential significance to trophic interactions, such as the foraging success of juvenile fish.

2-Selected depth of stratified samples (2 sites)

It was proposed initially to take cross-channel samples from water depths of 0.3m and 1.0m. Sampling from the bottom of the water column (as suggested by Thames NRA) introduces the risk of sample contamination with benthic taxa. It is now proposed to sample at 0.3m fom the water surface and 0.3m from the river bed.

3-Consider the practical implications and additional costs incurred in sampling and monitoring planktonic protozoa

The additional sampling procedures and the types of examination appropriate for Protozoa were outlined, these were included within the detailed costings submitted in "Priority studies relating to the Severn-Thames Transfer" (8.3.96).

The Executive Summary from the Interim Report (Bass & May,1996) is reproduced below:

"River management schemes proposed for the River Thames, such as the construction of new reservoirs or the transfer of water from other catchments, are likely to result in changes in water quality and quantity downstream with potential impacts on the river zooplankton. This report aims to provide guidance to the NRA on sampling procedures suitable for monitoring

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zooplankton populations in the River Thames in order to establish current (baseline) conditions and detect and monitor future change.

Recommendations:

1) Relatively large sample volumes of river water should be collected from discreet depths with a small battery-powered submersible pump.

2) Monitor separately the abundance of small abundant taxa (eg rotifers) and large comparatively infrequent taxa (eg Cladocera and copepodites).

3) Examine contemporary and seasonal differences in zooplankton at 5 river sites.

4) Examine spatial differences in zooplankton populations at 2 river sites, of relevance to grazing pressure on phytoplankton and food resource availability to other dependant fauna."

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