

Decline in the quality of suspended fine particulate matter as a food resource for chironomids downstream of an urban area

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SUMMARY

1. Urbanization and its associated contamination could degrade the quality of suspended fine particulate organic matter (SFPM) (20 μm to 1 mm) as a food resource for aquatic insects. SFPM was collected at four sites along the main stem of the Chattahoochee River, which drains metropolitan Atlanta at base and high flow during four seasons.
2. Composition of SFPM was estimated using measures conventionally associated with food quality: bacteria, N/C ratio, caloric content, % inorganic, and % lipids, and metal (Cd, Cu, Pb, and Zn) concentration. In SFPM collected during base flow, % inorganic matter, calories, Cu, Pb, and Zn concentrations increased with cumulative permitted wastewater treatment discharge (an indicator of extent of urbanization upstream). In SFPM samples collected during high flow, % diatoms, Cu, Pb and Zn concentrations increased with urbanization.
3. A growth assay was used as an integrated and direct measure of SFPM quality as a food resource. The instantaneous growth rate (IGR) of chironomids fed SFPM collected during base flow declined downstream of the city. IGRs of chironomids fed SFPM collected at all sites during high flow were as low as the lowest IGR measured during base flow.
4. Insects fed SFPM collected from the Chattahoochee River had IGRs only 20% of those of chironomids fed SFPM collected from the Little Tennessee River, a relatively undisturbed river in North Carolina. The mortality rate of chironomids fed SFPM was not different among sites or rivers. While the decline in SFPM quality in the Chattahoochee River is probably attributable to some aspect of urbanization, the decline was not related to conventional measures of food quality or metal contamination.

Keywords: contaminants, growth rates, seston, trace metals

Introduction

Suspended fine particulate matter (SFPM) (20 μm to 1 mm) is an important food resource in riverine food webs (Wallace *et al.*, 1987; Couch, Meyer & Hall, 1996; Benke & Wallace, 1997; Hall & Meyer, 1998; Rosi-Marshall & Wallace, 2002) and can be adversely affected by human activities, such as urbanization, in

the catchment. The quality of this food resource derives from that of the larger particles and dissolved organic matter (DOM) from which it is formed. Human activities in catchments affect the quality of the particles and DOM entering streams (Markosova, 1991; Servais & Garnier, 1993) and, hence, the quality of SFPM. In addition, contaminants entering streams, such as metals and pesticides, are incorporated into suspended particles in remarkably high concentrations (Rao, Dutka & Taylor, 1993 and references therein). The presence of toxic contaminants could decrease the quality of this food resource by

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making it less palatable and potentially toxic to its consumers.

Urbanization leads to a number of changes (Paul & Meyer, 2001), such as increased wastewater effluent discharge, increased impervious surface area and increased non-point source discharge. The loss of intact riparian zones could alter coarse particulate matter inputs, increase in-stream primary production and alter DOM inputs and processing. In addition, wastewater treatment facilities discharge particulate matter and nutrients. Increased impervious surface area in urban areas facilitates high rates of erosion and increased contaminant run-off (Rose *et al.*, 2001).

Many studies have demonstrated that the quality of food resources in aquatic ecosystems varies naturally (Fuller & Mackay, 1981; Pandian & Marian, 1986; Fuller, Fry & Roelofs, 1988, Rosillon, 1988, Fuller & Desmond, 1997; Meyer *et al.*, 2000; Rosi-Marshall, 2002); however, the decline of food quality as a consequence of urbanization has not been examined hitherto. Significant degradation of food quality could have consequences for the system as a whole (Wallace *et al.*, 1997).

Particles between 40–60 µm have the highest concentration of sorbed metals (Bremer & Geesey, 1993). I predicted that urbanization, with its associated point and non-point sources of pollution, could lead to metal-contaminated SFPM (Paul & Meyer, 2001), which may be of reduced food quality. Although metals represent only a fraction of the potential contaminants present in an urban river, they were examined for a number of reasons. Currently, the regulations for metals in surface waters of the United States are expressed as dissolved concentrations [US Federal Water Pollution Control Act §307 (US FWPCA §307), 1997], effectively ignoring metals associated with suspended particles (Science Advisory Board, 2000). Metals associated with particles are bioavailable to zebra mussels (*Dreissena polymorpha* Pallas) (Roditi & Fisher, 1999) amphipods (Schlekat, Decho & Chandler, 1999), clams and marine polychaetes (Wang & Fisher, 1999; Lee *et al.*, 2000). It has been established that metals sorbed to particles are bioavailable, although the effect of dietary metals on the growth rate of consumers has not been measured.

The first objective of this research was to measure the food quality of SFPM collected in an urban river, and two approaches were used. First, commonly adopted but indirect indicators of food quality, such

as N/C ratio, % diatoms, % inorganics, % lipids, caloric content and bacterial content, were measured to obtain the chemical composition of the SFPM. Then the SFPM was fed to an invertebrate consumer (chironomids) of this resource and their instantaneous growth rates (IGRs) were measured to estimate directly the food quality of the SFPM. This approach allowed me to estimate how well organisms in the river would grow on the SFPM present and also to address a second objective: to determine which of the usual indicators of SFPM quality (chemical composition) best reflect its quality as a food resource (as measured directly by growth rate) for aquatic insects. A third objective was to determine if contaminants (Cu, Cd, Pb and Zn) associated with SFPM degraded its quality as a food resource.

The three objectives lead to five hypotheses which structured the research: (i) SFPM collected from sites downstream of an urban area would be of lower quality, as measured by growth rates, than would SFPM collected upstream; (ii) SFPM samples with certain characteristics (high N/C ratio, % diatoms, % lipids, caloric content, bacterial content and low % inorganics) would result in a higher growth rate of insects fed the SFPM; (iii) SFPM collected from sites within an urban area would have higher concentrations of metals than SFPM collected upstream; (iv) SFPM samples with higher concentrations of metals would reduce the growth rate aquatic insects; (v) the concentration and deleterious effect of metals would be greater in samples collected during high flow than at base flow, because high flow samples would contain contaminants from non-point source run-off. An alternative to hypothesis five is that increased discharge would dilute the contaminants, leading to increased quality of SFPM collected during high flow.

Methods

Study sites

The upper Chattahoochee River flows through metropolitan Atlanta (Fig. 1). Point and non-point source pollution contributes to the problem of inorganic and organic pollution throughout the basin (Frick *et al.*, 1998). Trace metal concentrations in sediment and in tissues of the non-native clam *Corbicula* pose an ecological risk to native fauna (<http://www.ga.usgs>).

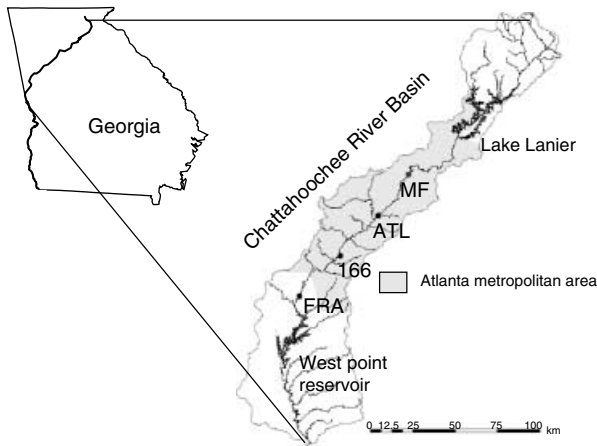


Fig. 1 Map of study sites [Morgan Falls (MF), Atlanta Road crossing (ATL), Route 166 crossing (166) and Franklin (FRA)] in the Chattahoochee River Basin, Georgia.

gov/nawqa, January 2002). I collected SFPM samples within and below the city of Atlanta on an unimpounded section of the river between two reservoirs (Table 1). The reservoirs upstream of the four sites have hypolimnetic releases, thereby creating a gradient of water temperature. The first site (MF) is in a northern section of the city of Atlanta, just downstream of the Morgan Falls impoundment, which is used for hydroelectric power generation. While this site is upstream of most of the city, it is downstream of suburban wastewater treatment plants and suburban runoff and, hence, is not an upstream reference site. The second site (ATL) is located at the Atlanta Road crossing of the Chattahoochee River. This site is just downstream of Peachtree Creek, the tributary that drains downtown Atlanta and is downstream of a major wastewater treatment facility. The third site

(166) is located at the Georgia Route 166 crossing of the Chattahoochee River. This site is downstream of most of the urban runoff, a number of tributaries draining industrialised areas, and a majority of the point sources in the major metropolitan area, including municipal and industrial facilities. The final site (FRA) is at the Georgia Route 27 crossing of the Chattahoochee River. This site is approximately 160 km downstream of Atlanta, in Franklin, GA, just upstream of West Point Reservoir. This site was chosen to determine the extent of contamination from upstream sources.

Collection and measurement of SFPM

I collected SFPM from the four sites in autumn 1998 and in winter, spring and summer 1999. In each season, particles were collected once during base flow and once following a storm sufficient to cause an increase in the hydrograph (Whitesburg gauge, HUC 03130002, <http://waterdata.usgs.gov/ga/nwis/> [accessed on 31 January 2002]). The high flow samples were collected while discharge was high although, because of the distance between the sites, I was not able to sample the rising limb at all sites (Table 2).

A non-metal 20 µm mesh net was used to collect SFPM and any large particles were removed. The net was placed in the flow of the channel for 10–20 min to collect a large integrated sample of SFPM; therefore replicates were not collected. The samples were placed on ice and taken to the laboratory for analysis. Subsamples of SFPM were preserved in the field in 2% formalin for later analysis of bacteria. Subsamples of the SFPM were placed in acid-washed high density

Table 1 Characteristics of the four study sites along the Chattahoochee River. Morgan Falls (MF), Atlanta Road crossing (ATL), Route 166 crossing (166) and Franklin, GA (FRA)

Variable	MF	ATL	166	FRA
Drainage area (km ²)*	4110	4121	5325	6941
Mean annual flow (m ³ s ⁻¹)*	71.47	72.04	100.9	115.6
Runoff (cm year ⁻¹)*	60.7	48.78	59.72	57.99
Temperature (°C) [†]				
2 October 1998	17.3	19.6	22.2	23.4
22 January 1999	11.2	12.9	15.9	14.9
4 May 1999	16.9	18.1	21.6	23.0
17 August 1999	20.8	24.4	29.6	32.7
Mean suspended organic matter concentration >0.45 µm (g AFDM L ⁻¹) [‡]	0.002	0.004	0.010	0.003
Permitted wastewater discharge (PWD) (10 ² L s ⁻¹)*	7.58	38.76	72.05	91.9

*From Frick *et al.*, 1996.

[†]Measured by Neumann, K. pers. comm.

[‡]Water samples were collected during baseflow and after highflow.

Table 2 Discharge during sampling dates at USGS station, Whitesburg, GA. Whitesburg is downstream of site 166 on the mainstem of the Chattahoochee, with a drainage area of 6061 km² (<http://waterdata.usgs.gov/ga/nwis/>). Conditions are base flow (BF) and high flow (HF)

Season	Condition	Date	Mean daily discharge (m ³ s ⁻¹)
Autumn	BF	2 October 1998	74.47
	HF	11 November 1998	91.75
Winter	BF	22 January 1999	54.09
	HF	24 January 1999	235.9
Spring	BF	4 May 1999	45.31
	HF	8 May 1999	122.9
Summer	BF	17 August 1999	33.7
	HF	25 August 1999	110.7

polyethylene (HDPE) containers in the field and frozen for metals analysis and for later use in the growth experiment. I measured the chemical composition of the frozen SFPM: % lipids, N/C ratios, % inorganic, total calories and bacteria. In addition, I measured the proportion of leaf material, diatoms and amorphous detritus.

Lipid content was measured using an ether extraction technique (APHA, 1985) and is expressed as % lipids [100 (mg lipids/mgDM)]. Nitrogen/carbon (by mass) was measured using a Carlo Erba NA1500 CHN Combustion Analyser (Carlo Erba Instrumentazione, Milan, Italy). Per cent inorganic material was measured by filtering SFPM onto tared and ashed glass fibre filters, drying at 60 °C for 2 days, weighing, ashing at 500 °C for 24 h and then reweighing to obtain ash free dry mass (AFDM) and % inorganic [100 (mg ash mass/mgDM)]. Samples for bacteria were sonicated for one minute to remove bacteria cells from the particles. Bacteria were stained with Acridine Orange and counted using a fluorescence microscope (Hobbie, Daley & Jasper (1977)). A subsample of the solution was dried to measure mg mL⁻¹, and bacteria density per g dry mass (gDM) of SFPM was then calculated. The proportion of leaves, diatoms and algae were measured using microscopy (Benke & Wallace, 1997). SFPM was filtered onto 0.45 µm filters (Gelman Corporation, Ann Arbor, MI, U.S.A.); filters were cleared with immersion oil; the areal proportion of leaves, diatoms and amorphous detritus was measured using imaging software (ImagePro[®] Plus 3.0.1, Media Cybernetics, Silver Spring, MD, U.S.A.) connected to a microscope (100×). Animal material was detected infrequently and was excluded from analysis.

Metal analysis was conducted at the University of Georgia Chemical Analysis Laboratory. Frozen samples of SFPM were freeze-dried and digested with nitric acid to obtain the total recoverable metals associated with the particles. Metals (Cu, Cd, Pb and Zn) were analysed using Thermo Jarrell-Ash 965 Inductively Coupled Argon Plasma (ICP).

Growth experiment

As an integrated and direct measure of SFPM quality, I measured the growth rate of chironomids fed frozen subsamples of SFPM collected seasonally (see above) from the Chattahoochee River. Other studies have used chironomid growth as an indicator of food quality, because of their short lifespan and rapid growth (Gresens, 1997; Meyer *et al.*, 2000; Vos *et al.*, 2000). Chironomids were collected from Little Tennessee River, in April 2000, at a relatively uncontaminated site in Macon Co. North Carolina (seventh order). This site was selected to insure that the organisms had not developed a tolerance for heavy metals (Clements, 1999). I removed the chironomids from the rocks and haphazardly collected individuals for the experimental treatments. Numerous chironomid taxa were present, although only non-Tanypodinae (non-predatory) taxa were used (Merritt & Cummins, 1996).

Individuals were measured using an ocular micrometer (total length), and a single chironomid was placed in a sterile Petri dish which contained 3–5 mg thawed SFPM collected seasonally from the Chattahoochee River and 10 mL dechlorinated tap water. Tests were performed with chironomids prior to the experiment to insure that the amount of SFPM provided an adequate food supply and that guts were full, indicating that they consumed SFPM provided. Thirty-two treatments (four sites × four seasons × two flows) were run concurrently using chironomids collected from a single pool of individuals. Twenty replicates (individuals) were used per treatment (resulting in 640 individuals total). Individuals of different sizes were distributed evenly across treatments to insure that potential effects of size on growth rate would not affect the results. High replication allowed for adequate replicates given potentially high % mortality from collection and handling. The experiment was housed in an incubator at 16 °C in a 12/12 h light/dark regime. After 5 days, the length of all the surviving individuals was measured again.

Mortality and emergence were also recorded. Lengths were converted to biomass using regressions from Benke *et al.* (1999). IGR of the individuals was calculated as follows (Waldbauer, 1968):

$$\text{IGR (day}^{-1}\text{)} = \frac{\ln \text{ final mass} - \ln \text{ initial mass}}{\text{days in interval}}$$

Relationship of urbanization to SFPM quality

At the four sites sampled along the Chattahoochee River, the cumulative amount of permitted wastewater discharge (PWD) steadily increases downstream (Table 1). PWD is the total amount of municipal waste permitted upstream of each site and represents the maximum possible municipal wastewater discharged into the river from numerous point sources. I used PWD as an indicator of the extent of urbanization upstream (Frick, Buell & Hopkins, 1996). To determine if variables measured were related to increased urbanization, the relationship between PWD and each variable (N/C ratio, % lipids, calories, etc) was explored using regression analysis. A high correlation (r^2) of a significant regression indicates a relationship, either positive or negative, with the indicator of urbanization upstream. Attributes of SFPM from base flow and high flow samples were regressed separately.

To determine if IGR was related to urbanization upstream, IGR was regressed against PWD for SFPM collected during base flow and high flow. Regression analysis was also used to determine whether growth rates were related to the chemical composition of the SFPM. Principal Components Analysis (PCA) can be used to combine a number of variables into a small set of linear combinations of the variables. I used PCA (on correlations) to reduce the chemical composition and metals (Cu, Cd, Pb and Zn) down to a few principal components that encompassed the variability in the measurements. Then I determined if the combinations of these variables were related to IGR. Statistical analysis was conducted using JMP[®] software (SAS Institute, Cary, NC, U.S.A.).

Results

The chemical composition of SFPM varied spatially and temporally in the Chattahoochee River (Table 3). Chlorophyll *a* concentration and diatoms were significantly higher in high flow samples than base flow

($P = 0.004$ and 0.06 respectively, Paired *t*-test). Flow conditions did not influence the other variables measured. No aspect of chemical composition was significantly related to urbanization (PWD) (Table 4). The concentrations of metals associated with SFPM varied along the Chattahoochee River (Table 3). In SFPM samples collected during base flow and high flow, Cu, Pb and Zn concentrations increased with increased urbanization (Table 4).

Chironomid growth rates as a measure of quality

Percent mortality in the growth experiments was transformed ($\arcsin X^{1/2}$) to achieve a normal distribution. The percent mortality was not different among sites for either base flow (ANOVA, mean = 55%; $P = 0.81$) or high flow (ANOVA, mean = 55%; $P = 0.72$). Only living individuals were used for growth measurements. The high initial replication allowed for sufficient numbers of surviving individuals for statistical analysis. The average annual IGRs of chironomids fed particles collected during base flow declined steadily with increased urbanization ($r^2 = 0.37$; $P = 0.02$) (Fig. 2). IGRs of chironomids fed particles collected during high flow were not related to increased urbanization ($r^2 = 0.14$; $P = 0.15$) (Fig. 2); however, the growth rates of chironomids fed SFPM from high flow samples were all as low as growth rates of chironomids fed SFPM collected from the most downstream site during baseflow.

Relationships of IGR to chemical composition and metals

Instantaneous growth rates were positively related to % diatoms ($r^2 = 0.13$; $P = 0.05$) and negatively related to bacterial density ($r^2 = 0.14$; $P = 0.04$), but were not significantly related to any other individual measure of food quality. PCA was effective at reducing the five conventional variables (N/C, % diatoms, % inorganics, % lipids and bacteria) to three variables that, in combination, explained 86% of the variability in the data set (Table 5). The first principal component was most weighted by % diatoms (positively), % inorganic (positively) and N/C (negatively). The second principal component was most weighted by N/C (negatively), % diatoms (negatively), bacteria (positively) and % lipids (positively). IGRs were negatively related

Table 3 Conventional parameters and total recoverable concentrations of metals ($\mu\text{g g}^{-1}$) associated with the SFPM. Samples were collected during base flow and following a high precipitation event at four sites in the Chattahoochee River, Atlanta, GA

Variable	MF	ATL	166	FRA
Base flow				
% Diatoms	0–0.33	0–0.15	0.02–0.1	0–0.34
% Inorganic	0.46–0.86	0.78–0.89	0.77–0.84	0.81–0.90
N/C (mass)	0.08–0.09	0.05–0.08	0.07–0.11	0.06–0.08
% Lipids	0.14–1.44	0.35–2.13	0.51–2.61	0.37–1.12
Calories (cal gDM ⁻¹)	250–323	359–368	353–569	230–586
Bacteria (cells gDM ⁻¹)	1.55×10^6 – 2.46×10^9	2.23×10^6 – 1.43×10^9	1.24×10^9 – 2.97×10^9	1.47×10^6 – 4.64×10^9
Cu	26.8–32.5	24–34.8	61.3–76.1	16.2–99.8
Cd	1.2–8.6	0.7–2.2	0–2.3	0.9–2.5
Pb	52–86	68–101	78–138	35–157
Zn	87–103	95–131	182–260	49–220
High flow				
% Diatoms	0.06–0.12	0.04–0.38	0–0.3	0–0.62
% Inorganic	0.88–0.9	0.78–0.91	0.79–0.86	0.83–0.9
N/C (mass)	0.002–0.08	0.06–0.07	0.06–0.07	0.06–0.07
% Lipids	0.03–0.99	0.38–0.64	0.52–1.99	0.42–1.27
Calories (cal gDM ⁻¹)	150–456	224–229	507–1437	211–717
Bacteria (cells gDM ⁻¹)	1.47×10^6 – 1.53×10^9	1.47×10^6 – 1.28×10^9	1.76×10^6 – 2.53×10^9	1.28×10^6 – 1.28×10^9
Cu	26.0–27.8	1.6–2.9	55.5–88.3	51.7–82.3
Cd	1.9–2.3	36.4–40.7	1.7–2.2	1.7–3.2
Pb	22–76	89–125	97–122	86–168
Zn	58–96	164–180	208–306	115–226

Table 4 Relationships of conventional measures of SFPM quality and permitted wastewater discharge (PWD) (L s^{-1}) along the Chattahoochee River, within and below Atlanta. Only relationships with $P < 0.20$ are shown. Slope is given when slope is significantly different from zero ($\alpha = 0.05$). Samples were collected during base flow and during high flow in October 1998, and in January, May and August 1999

PWD \times SFPM measure	r^2	P	Slope
During base flow			
Calories	0.24	0.15	NS
% Inorganic	0.17	0.12	NS
Cu	0.50	0.001	+
Pb	0.29	0.002	+
Zn	0.34	0.001	+
During high flow			
% Diatoms	0.13	0.08	NS
Cu	0.49	<0.0001	+
Pb	0.29	0.0008	+
Zn	0.34	0.0003	+

+ Indicates a positive slope.

to the second principal component ($r^2 = 0.28$; $P = 0.04$), but not with the first principal component. These results indicate that, in combination, N/C, % diatoms, bacteria and % lipids were related to IGR.

No single metal had a significant relationship with IGR. PCA was effective at reducing metals down to

two variables accounting for 93% of the variability in the data set (Table 6). The first principal component was weighted by Cd, Pb and Zn and the second principal component was weighted by Cu. IGR was not significantly related to either of the principal components. These results suggest that metals, either individually or in combination, are not related to IGR as measured in this experiment.

Discussion

Suspended fine particulate matter quality in the Chattahoochee River, as measured by the growth rate of chironomids fed this resource, was related to permitted wastewater discharge, a correlate of increased urbanization upstream. As urbanization upstream increased, IGRs of chironomids fed SFPM collected during base flow from the Chattahoochee River declined. This supports the initial hypothesis that the quality of SFPM would decline downstream of urbanization.

I predicted that conventional but indirect measures of food quality (chemical composition) would be related to growth as measured by chironomids fed SFPM. There were no significant relationships between these conventional measures of food quality and PWD, although the % inorganic matter and

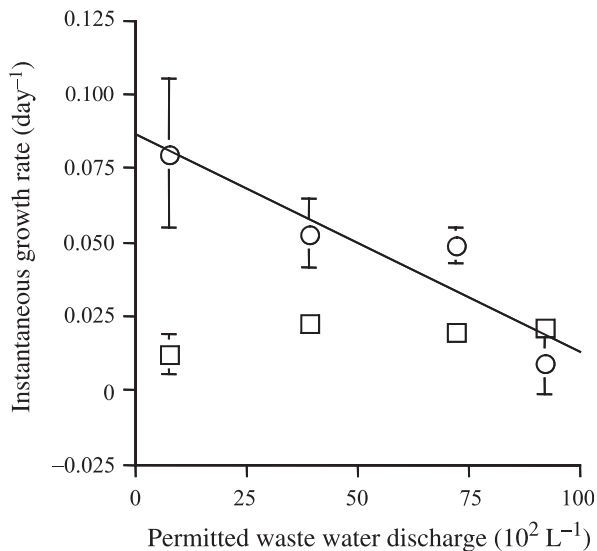


Fig. 2 The average annual instantaneous growth rates of chironomids fed suspended particles collected during high flow (□) ($r^2 = 0.14$, $P = 0.15$) and during base flow (○) ($y = -0.001x + 0.081$, $r^2 = 0.37$, $P = 0.02$) as a function of PWD. Error bars represent the standard error of the mean.

Table 5 Results of principal components analysis of conventional measures of food quality of SFPM collected at four sites along the Chattahoochee River, within and below Atlanta. The samples were collected during base and high flow in October 1998, and in January, May and August 1999

	Principal component 1	Principal component 2
Percent variance explained	40.4	31.1
Eigenvectors		
N/C	-0.45	-0.26
% Diatoms	0.53	-0.42
% Inorganic	0.61	0.19
% Lipids	0.29	0.53
Bacteria	-0.24	0.66

Table 6 Results of principal components analysis of Cu, Cd, Pb and Zn concentrations in SFPM collected at four sites along the Chattahoochee River, within and below Atlanta. The samples were collected during base and high flow in October 1998, and in January, May and August 1999

	Principal component 1	Principal component 2
Percent variance explained	68.5	24.3
Eigenvectors		
Cu	0.13	0.98
Cd	0.58	-0.04
Pb	0.56	-0.11
Zn	0.58	-0.09

calories in the SFPM increased with upstream urbanization during base flow and the % diatoms in the SFPM increased during high flow. Some of the factors may enhance quality (e.g. calories and % diatoms), while others may decrease quality (e.g. % inorganics). However, none of the conventional variables measured were significantly related, singly or in combination, to the growth rate of chironomids fed SFPM. This finding does not support the second hypothesis, that conventional measures will be related to growth. This result suggests that a surrogate measure of quality cannot be used to predict quality as measured directly by the IGR of insects.

Metal contamination was also not a factor leading to the decline of SFPM quality in the Chattahoochee River. The Cu, Pb and Zn concentrations increased with urbanization upstream during base flow and high flow; however, metal concentrations, individually or in combination, were not related to IGR. While metals are present in the SFPM in the Chattahoochee River, increase downstream, and are bioavailable (Rosi-Marshall, 2002), there is no evidence in this experiment to suggest that metal concentrations decrease the quality of SFPM as a food resource for chironomids in the Chattahoochee River.

The concentration of contaminants associated with SFPM may be highest as the river rises during or following a storm, and hence I hypothesised that samples collected during high flow would show a stronger trend with urbanization. However, the growth of chironomids fed SFPM collected during high flow was not correlated with increased urbanization upstream. Although the hypothesised trend was not observed, the mean IGRs for SFPM collected during high flow at all sites were as low as IGRs for SFPM collected during base flow at the most downstream site. During high flow conditions, the quality of SFPM from all sites measured was consistently low, suggesting a decline in the quality of this resource at all sites during high flow. This may be because of the widespread input of contaminants from temporary, non-point sources during high flow (i.e. which are not sources during base flow). Although increased discharge may lead to an increased dilution of contaminants, the data do not suggest this is occurring during high flow in the Chattahoochee River.

Concentrations of As and Hg or organic contaminants were not measured in these experiments,

Table 7 Comparison of measures of SFPM quality for samples collected during base flow in the Little Tennessee River and during base flow in the Chattahoochee River. Annual means from all sites are provided. The variables were all compared with Students *t*-tests. For statistical analysis, non-normally distributed data, % mortality, % diatoms, % lipids, and % inorganics, were transformed using the formula $(\arcsin X^{1/2})$

Variable measured	Little Tennessee		Chattahoochee		P
	Mean	SE	Mean	SE	
Instantaneous growth rate (day^{-1})	0.086	0.007	0.018	0.003	0.0001
Mortality (%)	53	2	52	4	0.10
N/C (mass)	0.059	0.005	0.077	0.005	0.02
Calories (cal gDM^{-1})	460	101	392	37	0.33
Lipid content (% DM)	0.56	0.11	0.98	0.17	0.06
% Inorganic	63.5	5	83	3	0.001
% Diatoms	2.8	0.6	13	4	0.001

although elevated concentrations of As and Hg have been observed in macroinvertebrates and fishes in this river (Rosi-Marshall, 2002). Detectable concentrations of polycyclic aromatic hydrocarbons (PAHs), phenol, phthalates, chlordane, dichlorodiphenyltrichloroethane (DDT), other pesticides and pharmaceutical products were found in urban tributaries and the Chattahoochee River mainstem (Frick *et al.*, 1998; Frick *et al.*, 2001). The presence of these contaminants may contribute to the low SFPM quality in the Chattahoochee River.

To examine further the effect of urbanization on the quality of SFPM, I compared the IGR of chironomids fed SFPM collected at base flow from the Chattahoochee River with those of chironomids fed SFPM collected at base flow from four sites along the Little Tennessee River, which drains an area of low population density in western North Carolina (Rosi-Marshall, 2002). Both experiments were run in the same fashion at the same temperature to ensure comparability. Similar conventional parameters were used to measure the chemical composition of SFPM in both rivers (Table 7). The N/C, % diatoms, % lipids, and % inorganics were significantly higher in Chattahoochee River SFPM samples than in Little Tennessee River SFPM samples. These conventional measures suggest that SFPM quality is higher in the Chattahoochee River, with the exception of % inorganics which should lower SFPM quality. The IGR of chironomids fed SFPM collected from the Chattahoochee River was only 20% of that measured on samples collected from the Little Tennessee River (Table 7). In the Little Tennessee River, IGR increased as % diatoms in SFPM increased (Rosi-Marshall, 2002), and this rela-

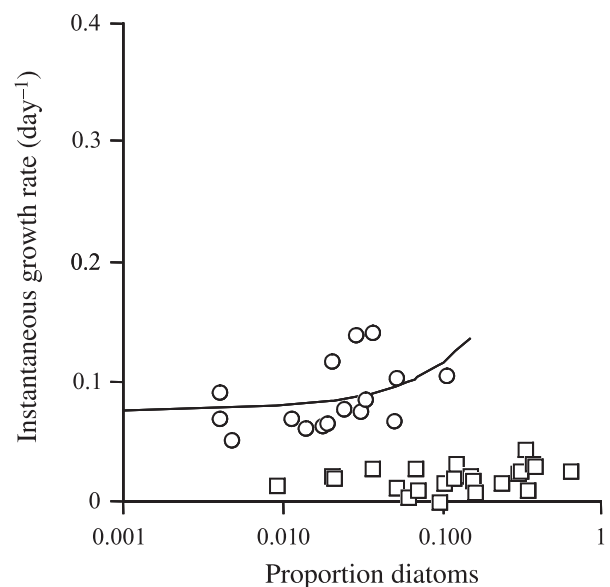


Fig. 3 The relationship of % diatoms in the SFPM and instantaneous growth rates of chironomids fed SFPM collected from the Little Tennessee (\circ) and the Chattahoochee River (\square). The relationship of % diatoms and IGR in the Little Tennessee River is given ($\text{IGR} = 0.406\% \text{ diatoms} + 0.075$).

tionship can be used to predict IGRs for chironomids fed SFPM collected from the Chattahoochee River (Fig. 3). IGRs are much lower than those predicted from SFPM diatom content in the Chattahoochee River. The presence of contaminants may mask the contribution of other attributes important to quality (Breitburg *et al.*, 1999). These differences emphasise the utility of IGR as an integrated measure of quality and provide further evidence of the effect of urban contaminants.

Mortality

An important result from the growth experiment is that mortality of chironomids is a poor indicator of differences in the quality of SFPM. The percentage mortality was not significantly different in experiments conducted with SFPM collected from the Little Tennessee than the Chattahoochee River (Table 7) despite striking differences in IGR (Fig. 3). Mortality and LC50s are typically used as indicators of toxicity; however, the findings of this study suggest that mortality, while a useful endpoint in some cases, is not an adequate measure of the quality of this particular food resource. Growth rates provide a sensitive indicator and provide information of the implications of changing food quality on the food web as a whole.

The quality of SFPM collected during base flow from the Chattahoochee River, as measured by chironomid growth rate, steadily declined downstream of Atlanta and was lower than observed in the Little Tennessee River (Rosi-Marshall, 2002). The quality of SFPM collected during high flow was low at all sites. Many components of SFPM (e.g. calories and % diatoms) increased with urbanization, although the food quality of SFPM declined with increased urbanization. This suggests that SFPM food quality may be low because of other factors associated with urbanization. The decline cannot be attributed to metal contamination. Other contaminants, such as PAHs, phenols, and phthalates, chlordane, DDT, other pesticides and pharmaceutical products, have been detected in the Chattahoochee River (Frick *et al.*, 1998; Frick *et al.*, 2001), however, and may be the cause of the decline in SFPM quality.

Decreases in the quality of riverine basal food resources that may accompany urbanization can have serious repercussions for organisms other than its primary consumers. System secondary productivity is an important ecosystem function that is tightly linked with the quality of basal food resources (Polis & Hurd, 1995). The secondary production of SFPM consumers could decline if the SFPM food quality decreases; leading to a reduced food supply to higher trophic levels (Rosi-Marshall & Wallace, 2002), including economically important fisheries in south-eastern rivers.

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