Report for 2001GA4261B: Impacts of Flow Regime on Ecosystem Processes in the Apalachicola-Chattahoochee-Flint River Basin

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FINAL REPORT

Impacts of Flow Regime on Ecosystem Processes in the Apalachicola-Chattahoochee-Flint River Basin.

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Problem and Research Objectives

The quantity and timing of river flow is critical to the ecological integrity of river systems (Poff et al. 1997). Flow is strongly correlated with physical and chemical characteristics of the river such as channel shape, water temperature and velocity, and habitat type and complexity (Jowett and Duncan 1990, Poff et al. 1997). Five main components of the flow regime impact ecological processes: magnitude of discharge at critical time periods, frequency of the various discharge magnitudes, duration of time associated with a particular discharge, timing or predictability of discharge events of particular magnitudes, and the rate of change of hydrologic conditions (Richter et al. 1996, Poff et al. 1997). These five components of the flow regime influence the ecological dynamics of river systems directly and indirectly by affecting water quality, energy sources, physical habitat, and biotic interactions (Karr 1991, Poff et al. 1997).

Although there are many different types of hydrologic and channel alterations that result in changes to the flow regime, dams are one of the most conspicuous and prevalent forms of flow alteration on large and some smaller rivers and streams. In the contiguous United States, there are only 42 rivers with greater than 200 river kilometers unregulated by major dams (Benke 1990). Though there have been a number of studies of the impacts of dams on channel morphology (Ligon et al. 1995), fish (Moyle et al. 1998), habitat availability (Bogan 1993), and riparian species survival and recruitment (Rood et al. 1995), less is known about the impact of dams and flow regime on basic ecosystem processes such as nutrient uptake and metabolism, especially in larger rivers. In many cases, these ecosystem processes are directly linked to the ecosystem services (e.g. water supply, pollution control, and fisheries) expected from the river system.

We are studying the relationship between flow and nutrient uptake and metabolism on the Chattahoochee River below Atlanta. The fixation of energy through primary production and the subsequent release through respiration are primary ecosystem functions, and the addition or loss of energy to the system can influence energy flows in downstream systems. In order to determine net addition or loss of energy to the system, net daily metabolism can be calculated. Net daily metabolism is defined as the difference between gross primary productivity and total system respiration (Bott 1996). Metabolism has been shown to vary with high stream discharge as a result of shifts in primary production (Uehlinger and Naegeli 1998). However, relationships between net daily metabolism and low flow conditions are uncertain, particularly in large river systems.

The uptake and processing of nutrients by rivers is essential to maintaining downstream and instream water quality. In unregulated rivers, the downstream ecosystems that could be affected by high nutrient loadings are typically estuaries. However, in regulated rivers, there are typically a series of reservoirs that are connected by sections of flowing water. This is the situation on the Chattahoochee River. In addition, the flowing river section between Lake Lanier and West Point Lake receives approximately 220 million gallons a day of wastewater treatment plant effluent (Frick et al. 1996). The retention and transformation of the nutrients associated with these inputs is essential to maintaining water quality in this section of the river and in West Point Lake. Nutrient uptake length is the length of stream traveled by the average nutrient molecule in the water column before being taken up by biota (Stream Solute Workshop 1990). Nutrient uptake lengths in small streams is related to discharge (Stream Solute Workshop 1990). Uptake lengths in streams receiving wastewater treatment plant effluent are typically much longer than uptake lengths in streams with similar discharge but no wastewater inputs (Marti et al. In press). However, it is uncertain how nutrient uptake lengths vary with low flows in large rivers.

Our objectives were to determine how net ecosystem metabolism and nutrient uptake lengths vary with discharge under baseflow conditions in the Chattahoochee River below Atlanta. In addition, we wanted to determine the importance other factors that may influence metabolism and nutrient uptake such as temperature, total suspended solids, light, dissolved organic carbon, water column chlorophyll a concentrations, and nutrient concentrations. We hope that these analyses will help to give a better understanding of how flow regime influences ecosystem processes in a regulated river.

Methodology

We examined the relationship between flow and ecosystem function through measures of nutrient uptake length and net daily metabolism on the Chattahoochee River below Atlanta, Georgia. We used the USGS real time gauging station at Fairburn, GA (station # 02337170) and at State Road 280 near Atlanta (station # 02336490) to obtain discharge every 15 minutes. We sampled only during periods of stable flow. Because of hydropeaking during the week, sampling was conducted during weekend stable flows.

Nutrient uptake length was measured using the methods described by Webster and Ehrman (1996) and Stream Solute Workshop (1990). We used effluent of wastewater treatment plants as the source of the conservative tracer (chloride, Cl^-), soluble reactive phosphorus (SRP) and ammonium (NH_4^+) (Marti et al. in press). We sampled NH_4^+, SRP, and Cl^- concentration at one site above Atlanta, one site below the majority of the major municipal discharges from Atlanta, and thirteen sites below a small municipal wastewater treatment plant discharge (Camp Creek WWTP) on ten different days during summer 2001. The most upstream site was the Highway 166 crossing; Camp Creek WWTP is 3.68 km downstream, and the next thirteen sites were 0.66, 1.51, 3.01, 4.81, 5.78, 6.73, 9.93, 12.43, 14.51, 16.81, 18.47, and 20.67 km downstream respectively. The site above Atlanta was used to correct for background concentrations. All samples were taken during baseflow, filtered in the field with Gelman A/E glass fiber filters, and stored on ice for transport to the lab. Samples were then frozen until nutrient analysis could be performed. SRP concentration was determined using the colorimetric methods of Wetzel and Likens (1992). NH_4^+ concentration was determined using the fluorometric methods of Holmes et al. (1999). Chloride was determined with an ion chromatograph (UGA Soil Ecology Lab). Nutrient uptake length is the inverse of the slope of the regression line between distance (km) and ln (nutrient : chloride ratio) after correcting for background concentrations (Webster and Ehrman 1996). In cases where the SRP: chloride ratio increased downstream we assumed that there was no uptake, since this implies a net release of SRP from the sediments. We also assumed no uptake when the NH_4^+:chloride ratio increased downstream.

We determined net daily metabolism for a 650 m reach just below Highway 166 using the upstream-downstream diurnal dissolved oxygen change technique (Marzolf et al. 1994, Young and Huryn 1998). We determined travel time for a variety of discharges by floating oranges from the upstream to downstream station. Travel time was estimated from the median orange. We continuously measured dissolved oxygen and temperature using a YSI dissolved oxygen probe for a 40-hour period. Oxygen concentrations were corrected for diffusion using the energy dissipation model (APHA 1992). Channel slope for this model was determined by using 1:24,000 USGS topographic maps and determining the average slope for the river between Atlanta and West Point Lake.

Principal Findings and Significance

The Chattahoochee River at Highway 166 is a highly heterotrophic system. SRP uptake length for this 46 km reach of the river ranged from no uptake at all to 143 km, and no NH_4^+ uptake occurred (Table 1). Highly negative net ecosystem metabolism, low P/R ratios, and high rates of respiration demonstrate that this system is fueled by allochthonous carbon and that a large amount of organic matter processing is occurring. In contrast, long uptake lengths and evidence of a lack of uptake suggests that there is little assimilation of the nutrients from the wastewater treatment plants.

Nutrient Uptake

Uptake of ammonium was never observed, an uptake of soluble reactive phosphorus only occurred on one date in summer 2001 (Table 1). The other four dates had no measurable SRP uptake. The uptake length for the one date was 143 km. The distance between the Highway 166 crossing and Franklin, GA (the site of the river/reservoir transition) is 76 km. Therefore, the average phosphorus molecule will have not been assimilated prior to reaching West Point Lake. This means that much of the phosphorus and ammonium from Atlanta's municipal wastewater facilities is transported to West Point Lake. This high nutrient loading could lead to eutrophication of the reservoir and algal blooms. In addition, these long uptake lengths indicate that the river is no longer capable of providing the service of nutrient assimilation to downstream water users.

SRP uptake length (143 km) in this study was almost two orders of magnitude longer than those found in a Mediterranean river with similar discharge, but not receiving any waste water treatment plant effluent (1.5 km) (Butturini and Sabater 1998). Third order Mediterranean streams receiving wastewater treatment plant effluent also had much longer SRP uptake lengths than non-polluted streams with similar discharge (Marti et al.

in press). Similar to our study, phosphorus concentrations in the Mediterranean streams receiving effluent did not consistently decline downstream in 33% of the cases (Marti et al. in press). In our study, the instances of no measurable uptake were associated with an increase in phosphorus concentrations downstream with little change in chloride concentration. This increase in phosphorus concentrations could be caused by the flux of phosphorus out of the sediments (Reddy et al. 1996).

Net Ecosystem Metabolism

In contrast to nutrient uptake, organic matter processing rates seem fairly high. P/R ratios ranged from 0.01 to 0.7 indicating that this is a highly variable, but predominately heterotrophic system, which is dominated by allochthonous inputs. Gross primary production ranged from <0.1 to 3.3 g O_2 m^{-2} day^{-1}. GPP was lower than that of a similar sized river, River Thur, that also receives WWTP effluent in the pre-alpine region of Switzerland (Figure 1) (Uehlinger 2000). This difference in GPP may be partially attributable to the substrate composition of the 2 rivers. The study reach on the Chattahoochee was sandy bottomed and typically unstable, while the while the River Thur bed sediments are mainly gravel (Uehlinger 2000). Respiration was also variable and ranged from 3.04 to 12 g O_2 m^{-2} day^{-1}. These variations are similar to the variations seen in several streams and rivers throughout the U.S. and in Switzerland (Figure 2) (Meyer and Edwards 1990, Paul 1999, Uehlinger 2000, Mulholland et al. 2001). These P/R ratios are similar to P/R ratios (0.02 to 0.4) found in the Ogeechee River, which is dominated by allochthonous organic matter inputs from the floodplain (Meyer and Edwards 1990).

Neither GPP nor R were correlated with discharge in the Chattahoochee River. In two pre-alpine rivers in Switzerland, GPP dramatically declined following bed-moving spates and took several days to weeks to recover (Uehlinger 2000). Respiration was more resistant in these rivers, not declining as dramatically after bed-moving spates, but recovering more slowly (Uehlinger 2000). As a result of hydropeaking associated with power generation from upstream dams and the fine bed sediments, the Chattahoochee River below Atlanta has bed-moving spates almost daily during the week. Stable flows that are typically present on weekends, appear to not be long enough to allow a significant build-up of periphyton. Hence, GPP in the Chattahoochee River is al the lower end of the range observed in the Swiss rivers (Figure 1).

Multiple regression analysis indicated that 71% of the variation in GPP could be explained by a model that includes temperature, total solar radiation, and chlorphlyll *a* (Table 3). There was not a significant model for total ecosystem respiration or heterotrophic respiration. However, a model including total phosphorus, DOC, and total radiation explained 62% of the variation in NEP (Table 3).

Conclusions

Upstream dam operations exert a strong influence on ecosystem function in the Chattahoochee River below Atlanta. Daily discharge fluctuations appear to function as spates in unregulated systems, reducing GPP with inadequate time for system recovery between spates. Ecosystem respiration appears to be less affected by discharge fluctuations, and the ecosystem is consistently heterotrophic. There is little evidence for uptake of phosphorus or ammonium in the river. Hence these nutrients entering the river from wastewater treatment plants in Atlanta are being transported downstream to West Point Lake.

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Table 1: Soluble reactive phosphorus and ammonium uptake lengths on 5 dates in the Chattahoochee River, downstream of Atlanta, GA.

Date	Discharge ($m^3 s^{-1}$)	Initial SRP Conc (ug L^{-1})	SRP Uptake length (km)	Initial NH_4^+ Concentration (ug L^{-1})	NH_4^+ Uptake Length (km)
7/6/2001	28.9	71	No uptake	N/A	N/A
7/13/2001	34.0	40	No uptake	43	No uptake
7/20/2001	45.9	37	No uptake	149	No uptake
8/14/2001	73.2	31	143	606	No uptake
8/17/2001	54.8	52	No uptake	253	No uptake

Table 2: Gross primary production, respiration, and net ecosystem production for ten days for the Chattahoochee River below Atlanta, GA.

Date	Discharge ($m^3 s^{-1}$)	Gross Primary Production ($g O_2 m^{-2} day^{-1}$)	Respiration ($g O_2 m^{-2} day^{-1}$)	Net Ecosystem Production ($g O_2 m^{-2} day^{-1}$)
5/5/2001	27.6	1.03	6.64	-5.61
7/14/2001	34.0	0.86	2.87	-2.01
8/14/2001	73.2	1.2	4.55	-4.35
8/15/2001	54.8	0.1	4.53	-4.43
8/25/2001	39.9	0.1	8.41	-8.31
8/26/2001	38.1	0.1	9.74	-9.64
9/15/2001	32.2	0.55	5.79	-5.24
9/16/2001	32.4	0.99	5.97	-4.98
10/20/2001	31.9	3.29	4.26	-0.97
10/21/2001	32.8	3.13	5.29	-2.16

Table 3: Results of stepwise multiple regression analysis for rates of gross primary production (GPP), and net ecosystem production (NEP) (n=16 for GPP, n=14 for NEP).

Dependent Variable	Independent Variable	Parameter Estimate (SE)	r^2	Prob > F
GPP	Intercept	4.66 (1.43)		.007
	Temperature	-0.27 (.057)	.44	.0004
	Total Radiation	.0001 (.00003)	.18	.02
	Chlorophyll a	0.14 (.06)	.1	.03
	Full Model		.71	.002
NEP	Intercept	-32.6 (8.9)		.005
	DOC	10.72 (3.2)	.29	.008
	Total radiation	.0002	.19	.047
	Total phosphorus	-.042 (.021)	.14	.081
	Full Model		.62	.018

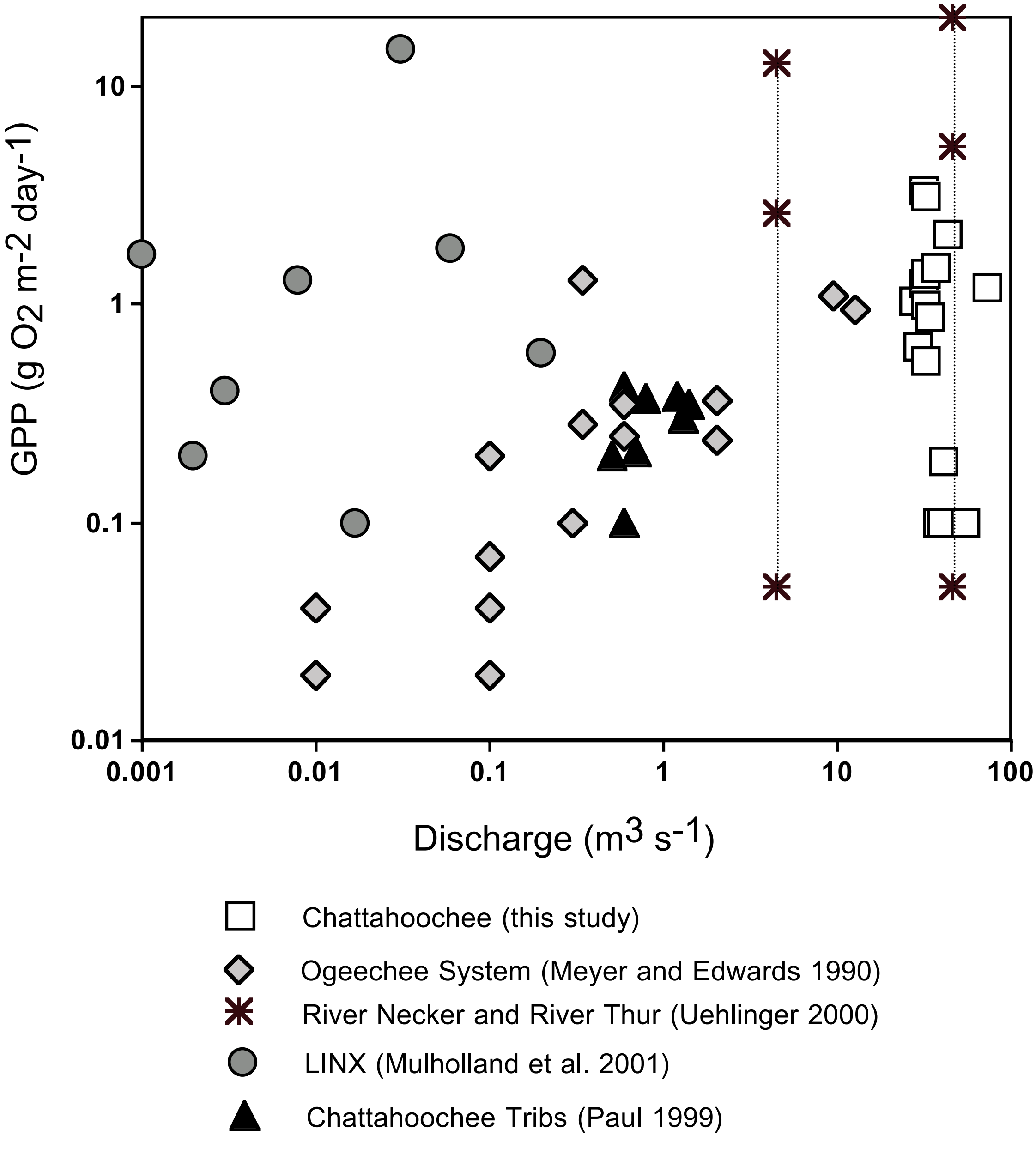

Figure 1: Comparison of gross primary production (GPP) rates in streams of a variety of different sizes. Rates for River Necker and River Thur are minimum, mean, and maximum of two years of continuous measurements. GPP rates from this study are below the mean GPP in a similar sized river in pre-alpine Switzerland (River Thur).

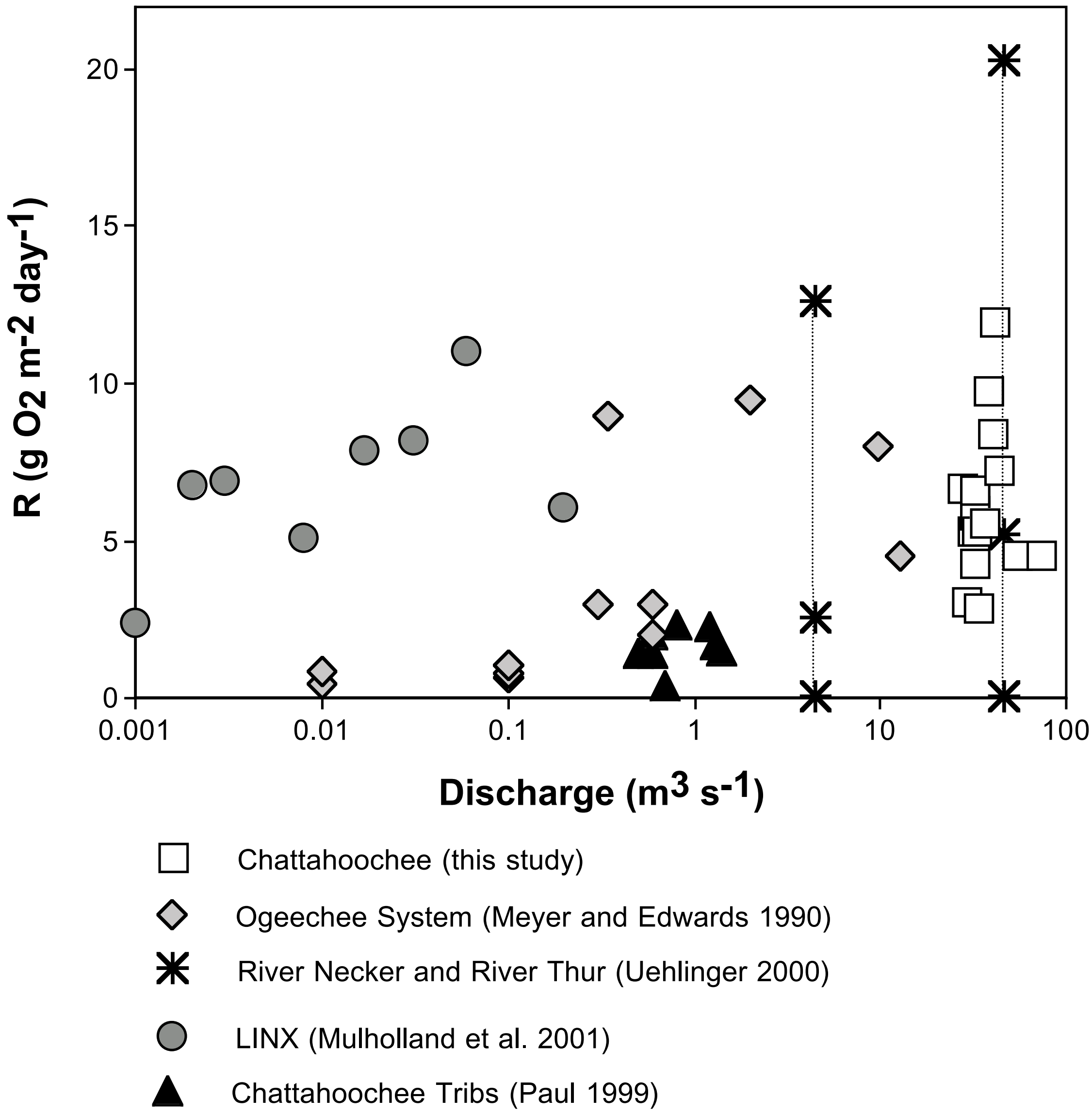

Figure 2: : Comparison of respiration (R) rates in streams of a variety of different sizes. Rates for River Necker and River Thur are minimum, mean, and maximum of two years of continuous measurements. R rates from this study are similar to those measured in a similar sized river in pre-alpine Switzerland (River Thur).