2004 MERRIMACK AND FRENCH & QUINEBAUG PERIPHYTON STUDY

Stream Velocity and Canopy Cover Considerations

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Introduction

In 2004, biological sampling, including macroinvertebrate, periphyton and habitat assessment, was conducted by MassDEP at primarily first-and second-order (i.e., "headwater") streams in the Merrimack River and French and Quinebaug watersheds. The periphyton data were collected to 1) learn more about the effects of stream velocity and canopy cover on periphyton community structure and function as they pertain to nutrient criteria development and 2) aid in the evaluation of whether or not the designated uses for the waterbody (e.g. aquatic life and aesthetics) were being met as outlined in the Massachusetts Water Quality Standards (MassDEP 2007). Most of MassDEP's biological sampling is conducted in higher order streams or rivers that function differently from these headwater streams.

Headwater streams have newly established stream channels and drain small basin areas (Janish 2006). They also often have wooded riparian zones resulting in shaded reaches that are characterized by waters low in nutrients and dissolved ions (Janish 2006). These shaded areas are highly suitable for heterotrophic organisms that are prevalent in headwater streams as dissolved organic matter from leaves is often readily available. The high gradient and often-closed-canopy affects the biota that can be established.

The determination of what controls the growth of the periphyton is complex. While phytoplankton in lakes are primarily controlled by light and nutrient levels, benthic algal communities respond to several different in-stream variables, including velocity, substrata type, light and nutrient levels. The periphyton were typically sampled in the riffle on cobble substrata, light levels were not measured directly, but the percent canopy cover was estimated. Velocity measurements were also included in the sampling at the stream surface and directly above the surfaces covered with periphyton referred to as the "substrate velocity" (Welch et. al. 1988) to evaluate, experimentally, the usefulness and the difficulties, if any, in obtaining these data.

The periphyton sampling included visual determination of the percent cover within the riffle and reach. Scrapes were made of the substrata to obtain samples for identification. When time allowed, different parts of the same reach were sampled to include both open and closed canopies.

Materials and Methods

Periphyton Identifications and Relative Abundance

The methods for gathering periphyton samples are described in Barbour et al. (1999). Sampling was done by the macroinvertebrate sampling crew and consisted of randomly scraping rocks and cobble substrates, typically within the riffle area, but other habitats were occasionally sampled. Material was removed with a knife or by hand from rock substrata and then added to labeled glass vials containing sample water. Table 1 contains descriptions of the station locations where periphyton was collected in the Merrimack River Basin and Table 2 presents station locations in the French and Quinebaug River basins. The samples were transported to the lab at MassDEP-Worcester in one-liter plastic jars containing stream water to keep them cool. At the lab, they were refrigerated until identifications were completed. Samples held longer than a week were preserved using a Lugol's solution-M^3 with a dose rate of 2 ml of preservative per 100 ml of sample (Reinke 1984).

Large clumps of filamentous algae were removed first from the vials. The vials were then shaken to homogenize the samples before subsampling. The filamentous algae were identified separately and then the remainder of the sample was examined. An Olympus BH2 compound microscope with Nomarski optics was used for the identifications (Appendix A contains the references used for taxonomic identifications). Slides were typically examined under 200 power. A modified method for periphyton analysis initially developed by Bahls (1993) was used. The scheme for describing the relative abundance of the algae in a sample is as follows:

R (rare)	fewer than one cell per field of view at 200x, on the average;
C (common)	at least one, but fewer than five cells per field of view;
VC (very common)	between 5 and 25 cells per field;
A (abundant)	more than 25 cells per field, but countable;
VA (very abundant)	number of cells per field too numerous to count.

In 2004, the percent macroalgal cover and the percent microalgae cover were determined by making a visual estimate of the coverage within the riffle. The microalgae (also described as periphyton) typically appear as a thin film, often green or blue-green, or as a brown floc (loose material without any structure that would break up when touched or when removed from the waterbody). The macroalgae, visible filamentous forms of green algae, are the "nuisance" type algae. Aesthetics, recreational use of the waterbody and aquatic life may be compromised if more than 40% of the substrata in the riffle/run are covered by macroalgal filaments (Barbour et al. 1999).

Table 1. List of benthic biomonitoring stations sampled during the 2004 **Merrimack River** watershed survey, including station identification number, upstream drainage area, station description, sampling date and whether algae or velocity were measured. (adapted from Mitchell, 2007)

Station ID	Upstream Drainage Area (Km^2)	Merrimack Watershed Station Description	Sampling Date	Algal cover (%), Algal ID (A), Velocity (V)
SO01	22.35	South Branch Souhegan River, downstream from Jones Hill Road, 275 m downstream from unnamed tributary, Ashby, MA	27 July 2004	%, A, V
RBR01	10.88	Richardson Brook, 200 m upstream from Methuen Street, Dracut, MA	30 July 2004	%, A, V
TB02	11.29	Trull Brook, 100 m downstream from River Road, Tewksbury, MA	30 July 2004	%, A, V
MRB01	5.15	Martins Pond Brook, 25 m upstream from footpath extending from Loomis Lane, Groton, MA	29 July 2004	%, V-partial
PO01	130.0	Powwow River, 125 m downstream from Rt. 150 (Main Street), off Mill Street, Amesbury, MA	23 August 2004	%, A (but sample disposed of during waste clean-up)
FI09	15.77	Fish Brook, ~300 m upstream from the dam at mouth of stream, south of Brundrett Ave., Andover, MA	2 August 2004	%, V
CR01	14.40	Creek Brook, 25 m upstream from West Lowell Ave., Haverhill, MA	2 August 2004	%, V
BA01	17.43	Bartlett Brook, 5 m upstream from Rt. 113 (North Lowell Street), Methuen, MA	2 August 2004	%, V
PE01	4.48	Peppermint Brook, ~100 m downstream from Lakeview Ave., Dracut, MA	30 July 2004	%, V
BR01	8.29	Bridge Meadow Brook, 80m downstream from road to Tyngsborough Elementary School (205 Westford Road), Tyngsborough, MA	29 July 2004	%, A, V partial
TA01	4.66	Tadmuck Brook, ~200 m upstream from Lowell Road, Westford, MA	29 July 2004	%, A, V partial
BE01	8.52	Bennets Brook, ~100 m downstream from Willow Road, Ayer, MA	27 July 2004	%, A, V partial

Table 2. List of biomonitoring stations sampled during the 2004 **French & Quinebaug River** watershed survey, including station identification number, upstream drainage, station description, and sampling date. Stations are listed hydrologically (from upstream-most drainage in the watershed to downstream-most). (adapted from Fiorentino, 2007)

Station ID	Upstream Drainage Area (mi^2)	French & Quinebaug River Watershed Station Description	Sampling Date	Algal cover (%), Algal ID (A), Velocity (V)
MO01	1.35	Mountain Brook, 100 m downstream from Rt. 20, Brimfield	25 Aug 2004	%
WS01	1.34	West Brook, 140 m upstream from confluence with Mill Brook, Brimfield	25 Aug 2004	%
W1183	5.92	Unnamed tributary to Mill Brook (locally known as “East Brook”), 5 m upstream from Rt. 20, Brimfield	25 Aug 2004	%, A
BR01	5.52	Browns Brook, 230 m upstream from May Brook Road, Holland	24 Aug 2004	%, V
ST01	4.32	Stevens Brook, 200 m upstream from Mashapaug Road, Holland	24 Aug 2004	%, A, V
LE01	2.47	Leadmine Brook, 600 m upstream from Rt. 84, near vacant Rt. 15 rest area, Sturbridge	24 Aug 2004	%, A
HA01	2.54	Hamant Brook, 100 m downstream from sandpit access road off Shattuck Road, Sturbridge	24 Aug 2004	%, A
HC01	3.58	Hatchet Brook, 100 m upstream from South Street, Southbridge	25 Aug 2004	%
MK01	8.11	McKinstry Brook, 140 m upstream from Pleasant Street, Southbridge	25 Aug 2004	%, A
CO01	4.09	Cohasse Brook, 175 m upstream from Cisco Street, Southbridge	26 Aug 2004	%
LB01	9.73	Lebanon Brook, 550 m upstream from Ashland Avenue, Southbridge	26 Aug 2004	%
W1186	8.07	Unnamed tributary to Quinebaug River (locally known as “Keenan Brook”), 550 m upstream from confluence with Quinebaug River, Southbridge	26 Aug 2004	%
TU01	2.40	Tufts Branch, 30 m upstream from Rt. 197, Dudley	26 Aug 2004	%, A
RB01	4.58	Rocky Brook, 100 m downstream from Midstate Trail footpath, off High Street, Douglas	27 Aug 2004	%
BU01	3.82	Burncoat Brook, 350 m upstream from confluence with Town Meadow Brook, Leicester	3 Sept 2004	%, A
GR01	2.82	Grindstone Brook, 170 m downstream from Rt. 56, Leicester	27 Aug 2004	%
FR04-1	15.67	French River, 300 m downstream from Clara Barton Road, Oxford	30 Aug 2004	%, A-but sample disposed of as hazardous waste
LR01	10.43	Little River, 20 m upstream from Turner Road, Charlton	30 Aug 2004	%, A-but sample disposed of as hazardous waste
W1197	13.89	Unnamed tributary to South Fork (locally known as “Potters Brook”), 150 m downstream from Potter Village Road, Charlton	26 Aug 2004	%, A
SU01	2.46	Sucker Brook, 100 m downstream from Kingsbury Road, Webster	27 Aug 2004	%, A
MI01	1.03	Mine Brook, 140 m downstream from Mine Brook Road, Webster	27 Aug 2004	%, A
MI01A	--	Mine Brook, upstream from Mine Brook Road, Webster	27 Aug 2004	%, A
BW01	1.20	Browns Brook, 130 m upstream from Gore Road, Webster	29 Aug 2004	%, A

Percent Canopy Cover

The percent canopy cover was obtained by standing midstream within the previously established reach and by making a visual estimation of the percent of the open sky that is not blocked by the overhead canopy (Table 3).

Table 3 Descriptions of canopy cover used to determine habitat characteristics described as % open to the sky

Percentage sky not blocked by canopy cover	**Canopy cover**
76-100	Open
51-75	Partially open
26-50	Partially closed
0-25	Closed

Velocity Measurements

A Sontek flow tracker (MassDEP, 1995) was used to determine stream velocity. Typically, three readings were taken within the riffle and averaged (Table 4). The readings for velocity were taken below the surface for the stream value and just above the surface of a rock containing algae for the "substrate velocity". Care was taken that no obstruction, such as another rock surface or aquatic weeds, created turbulent flow instead of laminar flow over the rock.

Results and Discussion

Velocity Considerations

Stream velocity and canopy cover are two important factors in the development of the algal population. In a few locations both open and closed canopies were sampled in the same stream These results are shown in Tables 4, 5 and 6. Since the organisms had the same exposure to nutrients the results help to distinguish the important factors affecting the growth and composition of the algal community.

Velocity can contribute to both the reduction of the algal population by scouring, as well as to growth by increasing the algae's exposure to nutrients. Horner et. al. 1990, examined the response of the periphyton to stream velocities between 0-50 cm/s and found that larger biomass accumulation was found in natural streams at higher velocities than at lower velocities. Above 50 cm/sec, however, scouring of the substrata and a reduction of the biomass often occurs if the benthic material has a lot of sand present (Horner et. al. 1990).

Stream velocity can also affect the constituents of the algal community. For example, McIntire (1966) found in streams with current velocities of approximately 38 cm/s the diatoms were more abundant while at 9 cm/s filamentous green macroalgae dominated. Horner et. al. 1990 also found that diatoms were more likely to dominate at high velocities and low phosphorus. If phosphorus was elevated the cyanobacteria *Phormidium* sp. was likely to dominate while in lower velocities *Mougeotia* sp. (green filamentous alga) predominated. Although we had limited data we wanted to examine if any trends similar to those cited were found, particularly at locations with high or low velocities recorded.

Table 4. Merrimack and French & Quinebaug Rivers - Canopy cover, average velocity and percent micro and macro algae in the riffle, as measured in 2004.

Date	Station	Stream (Watershed)	Canopy Cover (% Open)	Riffle Surface Average Velocity (cm/sec)	Riffle Above algae Average velocity (cm/sec)	% micro algal cover in riffle	% macro algal cover in riffle
Low velocity (0-20 cm/sec)							
27-Jul-04	SO01	South Branch Souhegan River (Merrimack)	20	nd*	17.7	<10	0
30-Jul-04	RBR01	Richardson Brook (Merrimack)	0	20.6	16.6	20	0
3-Aug-04	PO01	Powwow River (Merrimack)	100	nd	7.7	0	10
2-Aug-04	FI01	Fish Brook (Merrimack)	0	15.7	16.8	90	0
2-Aug-04	BA01	Bartlett Brook (Merrimack)	closed - % NR**	17.2	7.3	10	0
Medium velocity (21-50 cm/sec)							
30-Jul-04	RBR01	Richardson Brook (Merrimack)	70	nd	34.1	30	10
30-Jul-04	PE01	Peppermint Brook (Merrimack)	Closed % NR	nd	23.8	80	0
30-Jul-04	TB02	Trull Brook (Merrimack)	35	nd	32.3	80	0
24-Aug-04	ST01	Steven's Brook (French and Quinebaug)	10	nd	30.0	10	0
24-Aug-04	BR01	Browns Brook (French and Quinebaug)	60	nd	45.0	5	0
High velocity (>51 cm/sec)							
3-Aug-04	PO01	Powwow River (Merrimack)	100	66.3	69.3	0	100
27-Jul-04	BE01	Bennetts Brook (Merrimack)	30	nd	53.5	30	0

*nd=not done

**NR=not recorded

Table 5. Merrimack Watershed - Canopy cover and micro and macro algal cover at individual sampling locations and in the reach (July 27-30, 2004)

Station	Waterbody	Habitat	Canopy Cover (% Open)	Sampling location		Sampling Reach	
				% Microalgal cover	% Macroalgal cover	% Microalgal cover	% Macroalgal cover
SO01	S. Branch Souhegan River	Cobble, riffle	20	60	<10	0	<5
RBR01	Richardson Brook	Cobble, riffle	70	30	10	10	<2
RBR01	Richardson Brook	Cobble, riffle	0	20	0	<5	0
TB02	Trull Brook	Cobble, riffle	35	80	0	0	0
MRB01	Martin's Pond Brook	Cobble, riffle	5	10	0	<5	0
PO01	Powwow River	Cobble, riffle	100	0	100	0	80
PO01	Powwow River	Cobble, run	100	0	0	10	0
FI01	Fish Brook	Pool	0	90	0	~10	0
CR01	Creek Brook	Cobble, riffle	0	25	0	75	0
BA01	Bartlett Brook	Cobble, riffle	0	~10	0	<1	0
PE01	Peppermint Brook	Cobble, riffle	0	80	0	40	0
BR01	Bridge Meadow Brook	Cobble, riffle	10	0	0	10	0
BR01	Bridge Meadow Brook	Mat pool	25	0	0	2	0
TA01	Tadmuck Brook	Cobble, riffle	20	60	0	0	0
TA01	Tadmuck Brook	Mat	100	75	<10	25	<5
BE01	Bennetts Brook	Riffle	30	30	0	15	0

Table 6. French and Quinebaug Watersheds - Canopy cover and micro and macro algal cover at individual sampling locations and in the reach (Aug. 24-27, 30, Sept. 3, 2004)

				Station location		**Sampling Reach**	
Station	**Waterbody**	**Habitat**	**Canopy Cover (% Open)**	**% Microalgal cover**	**% Macroalgal cover**	**% Microalgal cover**	**% Macroalgal cover**
MO01	Mountain Brook	Riffle	5	0	0	0	0
WS01	West Brook	Riffle	30	0	0	0	0
W1183	Unnamed tributary to Mill Brook (“East Brook”)	Riffle	100	10	2	0	0
W1183	Unnamed tributary to Mill Brook (“East Brook”)	Run	100	0	0	10	2
BR01	Browns Brook	Riffle	10	0	0	0	0
ST01	Stevens Brook	Run	10	10	2	0	0
LE01	Leadmine Brook	Riffle	0	10	5	0	0
HA01	Hamant Brook	Riffle	5	100	0	95	5
HC01	Hatchet Brook	Riffle	10	0	0	0	0
MK01	McKinstry Brook	Riffle	100	100	0	70	0
CO01	Cohasse Brook	Riffle	35	0	0	0	0
LB01	Lebanon Brook	Riffle	15	0	0	0	0
W1186	Unnamed tributary to Quinebaug River (“Keenan Brook”)	Riffle	5	0	0	0	0
TU01	Tufts Branch	Riffle	30	nd*	nd	0	<5
RB01	Rocky Brook	Riffle	5	0	0	0	0
BU01	Burncoat Brook	Riffle	50	nd	nd	<5	0
GR01	Grindstone Brook	Riffle	10	0	0	0	0
FR04-1	French River – no samples	Riffle	5	0	0	0	0
LR01	Little River – no samples	Riffle	0	0	0	0	0
W1197	Unnamed tributary to South Fork (“Potters Brook”)	Riffle	15	nd	nd	20	0
SU01	Sucker Brook	Mat	25	nd	nd	0	10
MI01A	Mine Brook	Riffle	40	nd	nd	60	0
MI01	Mine Brook	Riffle	0	nd	nd	70	0
BW01	Browns Brook	Pool	60	5	<1	0	0

*nd=not done

Neither scour nor accrual were examined experimentally in this study, but when storms occurred with 1 inch or greater of rain the possible effects were noted (Appendix B). Long periods between storms allowed algal accrual to occur. However, if a storm occurred within the five-day antecedent period from the sampling date it was expected that some loss through scouring of algal biomass might have occurred or particular species might have been affected. During the summer of 2004, there were only two rain events that could have negatively affected algae and the invertebrates that graze on them. The two storm dates were July 24 (1.11 inches) and Aug. 21 (2.31 inches) (Appendix B). Because the precipitation data was not collected from a location within or near the basin (Lawrence) in the case of the French and Quinebaug Rivers, Appendix E contains graphs of flow data from both the Merrimack and Quinebaug Rivers to confirm that the storms on the dates described above were not just local events, but resulted in increased flows in these basins

Between July 24 and Aug 21 there were four weeks for algae to accumulate. Stations were not sampled over time so any algal accumulation or scouring can only be conjectured. Stations with measured velocities greater than 30 cm/sec were considered as possible scour candidates since this velocity is sufficient to move sand (Eisma, 1993**).**

Locations from the Merrimack and French and Quinebaug watersheds were grouped by low, medium and high velocity characteristics (Table 4). It was thought that low velocity coupled with open-canopy cover might contribute to a site having the most macroalgae and, correspondingly, microalgae would be elevated where velocity was high and the canopy was closed.

Low Velocity

The Powwow River site (PO01) had both low-and high-velocity areas represented. The low velocity site within the run was open to the sun. Unfortunately, we do not have the samples from this site, but field notes indicated that "green" filamentous algae, gelatinous to the touch, covered approximately 10% of the run sampled. The high-velocity, open-canopy site had 100% algal cover within the riffle. The algae were described as "green" filamentous, but no mention was made of gelatinous texture.

At Richardson Brook (RB01) the low-velocity site was shaded (Table 4) and had very little microalgal biomass on the cobble. The constituents were primarily diatoms and cyanobacteria (i.e. *Plectonema* sp. and *Lyngbya* sp.) surrounded by fungal hyphae (Appendix C).

The percent microalgal growth in the riffle of the low-velocity group peaked (i.e. 90%) at the Fish Brook station, a location with a closed in canopy. Diatoms were rare, but fungal hyphae were abundant. At other stations within the low-velocity group microalgae percent cover never was greater than 30%.

Where velocity was low and the canopy closed (e.g., Souhegan River (SO01) and Bartlett Brook (BA01), the few algal cells present were mainly diatoms although at SO01 filamentous cyanobacteria were also present.

Medium velocity

The medium-velocity site at Richardson Brook had an open-canopy. An algal scrape collected in the riffle was found to be dominated by the green macroalgae *Ulothrix* sp. while another green macroalga *Microspora* sp. was also common. The diatoms *Melosira varians* and *Synedra* sp. were also abundant. The change in environmental conditions at Richardson Brook from the closed to open-canopy and low-to medium-velocity sites had some influence on algal cover. The sunny, higher-velocity site, exhibited higher macroalgal cover (10 % vs. 0%) and microalgal cover (30 % vs. 20%) in the riffle than the low-velocity, closed-canopy site.

The two sites from the French and Quinebaug rivers included in the velocity measurements were in the medium-velocity grouping. At Browns Brook (BR01) the canopy cover was greater than 50% open and supported a mat composed primarily of the cyanobacteria *Lyngbya* Taylorii. Stevens Brook, with only a 10% open-canopy, exhibited little microalgal cover in the riffle. The sample from this shaded location contained few algal cells, but was dominated by the heterotrophic organisms included in “sewage fungus” i.e. filamentous bacteria, fungi, and protozoa.

From Appendix B it can be seen that 2.3 inches of rain fell at the Lawrence Airport three days prior to our sampling. This could have resulted in scouring of the substrata with no time allowed for recovery of the algal community. Most of the French and Quinebaug River stations were sampled within a week of this precipitation event.

Two tributaries in the Merrimack basin (i.e Peppermint and Trull Brooks) had good microalgal growth in the riffle zone-up to 80%-while the two from the French and Quinebaug-sampled after the 2.3 inches of rain-had no more than 10 % microalgal growth. The increased flow in August may have impacted the substrata.

At medium velocities with open canopies only Richardson Brook (RBR01) had any macroalgal growth present. Brown’s Brook (BR01) had a partially open-canopy, but no macroalgae present.

At partially open (35%) Trull Brook and closed (% not recorded) Peppermint Brook diatoms were abundant. Trull Brook also exhibited sewage fungus and the cyanobacteria *Lyngbya* sp.

High velocity

One Powwow River site was a high-velocity, open-canopy station (Table 4). This reach of the river receives nonpoint sources of contamination from a watershed containing areas of dense residential, commercial and historic industrial landuse. Nutrients from these sources along with sunlight may have contributed to the 100% macroalgal cover (Mitchell 2007). The highest percentage of macroalgae through the riffle zone was found at this site. It far exceeds the 40 % coverage which is indicative of algal biomass at nuisance levels (Barbour 1999).

At Bennetts Brook, also in the Merrimack River basin, the lack of irradiance resulting from the only partially open-canopy (30% open) may have reduced macro and microalgal percent cover at this high-velocity station. Macroalgae were not recovered while microalgae covered ~ 30% of the riffle. The microalgae were represented by diatoms and the cyanobacteria *Lyngbya* sp. (Appendix C). Landuse within this watershed is divided between forest and residential uses with a golf course also located upstream (Mitchell 2007).

Canopy and Percent Algal Cover Considerations

The percentages presented in table 3 to describe open and closed habitats are arbitrary, but the sites with their percentage closest to either open or closed-canopy cover are likely to have an algal population and biomass that is altered by light levels available. Lowe et al. (1986) found that chlorophyll a can be 4 to 5 times higher at open-canopy sites compared to sites described as closed. The algal community is also affected by differing amounts of light availability. Some groups like the Chlorophyta (green algae) generally are more prevalent at high light intensity than the Chrysophyta (diatoms) and some Cyanophyta (cyanobacteria). The light intensities are somewhat described by the open and closed-canopy sites. Steinman et al. (1989) found the same type of assemblage differentiation in a laboratory streams with diatoms dominating at < 50 µmole m^{-2} s^{-1}, diatoms and some cyanobacteria genera would be present at 50-100 µmole m^{-2} s^{-1} and the green algae would dominate at the highest light levels (irradiances) > 100 µmole m^{-2} s^{-1}.

Closed-Canopy Sites

Merrimack River Watershed

South Branch Souhegan River (SO01) was a closed-canopy site (Table 4) (Appendix C) with an extensive portion of the riffle area covered by microalgae. Sewage fungus was present in this sample, as well as a minimal amount of algal cells.

Bennetts Brook (BE01) had few phototrophic organisms recovered from the cobble substrata, but mats found on adjacent sand substrata had very abundant amounts of diatoms and the cyanophyceae *Lyngbya*. Other shaded locations, including Tadmuck Brook (TA01), Richardson Brook (RBR01), Trull Brook (TB02) and Bridge Meadow Brook (BR01) also had heterotrophic organisms present, typically fungal hyphae or “sewage fungus”. Pennate diatoms were often present at these sites, but in very low numbers.

At Martin’s Pond Brook (MRB01) and Creek Brook (CR01) between 0 and 5 % open-canopy was present and both had a small amount of algal material within a biofilm (algae, bacteria, fungi and polysaccharide material) primarily of fungal hyphae. Even at 10 % open-canopy the same trend continued at BR01 Bridge Meadow Brook where the sparse algal material was entangled with fungal hyphae. Macroalgae were not present in either the riffle or the reach.

At Tadmuck Brook (TA01), both an open and a closed location were sampled. But, at the shaded location with 20% open-canopy algal production again appeared limited while fungal hyphae were abundant. By contrast the open-canopy site at Tadmuck Brook (100% open) had algal mats composed of the cyanobacteria *Phormidium* sp. and *Anabaena* sp. as well as the diatom *Cymbella* sp. (Appendix C) These adjacent sites were exposed to the same nutrient inputs.

French and Quinebaug Watersheds

At the shaded Stevens Brook site the heterotrophic organisms (i.e. sewage fungus) were once again dominant in the periphyton. No “active” nonpoint sources of pollution were found at this location (Fiorentino 2007) or point sources, although sewage fungus is often an indicator of organic enrichment.

Hamant Brook, which had only 5% open-canopy, also supported a periphyton assemblage dominated by sewage fungus. At this location, as observed in Fiorentino 2007, additional influences may have factored into the growth of the periphyton. Instream turbidity, perhaps contributed by the local sand and gravel operations, may have led to reduced periphyton growth by limiting sunlight to the benthos, and possibly scouring since this location was sampled after heavy rains.

Leadmine Brook, a shaded stream site, had a few pennate diatoms, but also fungal hyphae and lots of amorphous matter, again indicating organic enrichment. Fiorentino (2007) describes the stream as flowing past wetlands in its upper areas before it passes under Route 84. The riffle was estimated as having 10% microalgae covering the bottom surfaces.

Although the canopy was only partially open at “Potters Brook” (15%) this stream exhibited abundant amounts of filamentous cyanophyceae *Chamaesiphon* sp.

Abundant amounts of cyanobacteria were found at Sucker Brook (SU01). A cyanobacterial mat composed primarily of O*scillatoria* sp.(Appendix D) was present at Sucker Brook. A small residential development was present along part of the reach. Fiorentino (2007) documented lawn clippings in the riparian zone.

Mine Brook is situated within an undeveloped watershed. Two sites were sampled here, upstream and downstream of Mine Brook Rd. Downstream had a completely closed-canopy and abundant cyanobacteria present *Scytonema* sp. and *Plectonema rupicola*, fungal hyphae were also recovered. At the upstream site algal mats were recovered from rocks and although it was 40 % open the mats were composed of cyanobacteria (Appendix D). The percent microalgal cover was estimated at 60% (Table 6).

Open-Canopy Sites

Merrimack River Watershed

At the Merrimack River Watershed the Powwow River had a 100% open-canopy. Although we do know that the algal coverage was elevated at this location (100%) further information on the algal assemblage is not available. Green macroalgae are believed to be dominant based upon field notes.

One location on Tadmuck Brook (TA01) also was 100% open-canopy. Mats of blue-green algae (cyanophyceae) were recovered in riffles in the open-canopy location. At the closed-canopy site at this location the Cyanophyceae were rare, but fungal hyphae and diatoms were present.

Richardson Brook at RBR01 also had open and closed sites at this location. At the open-canopy site green filamentous algae were identified (*Ulothix* sp., *Microspora* sp.). The centric diatom *Melosira varians,* often found in areas with organic enrichment, was found in abundance. The closed-canopy location was represented by small amounts of algal cells, although fungal hyphae were commonly observed in the sample.

French and Quinebaug Watersheds

McKinstry Brook (MK01) is a second-order stream that had 100% open-canopy over the riffle area. At the time of the 2004 sampling, the substrata were covered by a brown-colored algal film according to Fiorentino (2007). The diatom *Cymbella* was an important contributor to this biofilm along with several unidentified pennate diatoms (Appendix D). The microalgae covered 100% of the substrates in the riffle and 70% in the reach. Landuse in this watershed differed from many that were evaluated during the 2004 survey. It was highly developed with landuse including a golf course, residential, industrial and commercial use as well (Fiorentino 2007). Sources of nutrients to this part of the stream were identified to include Southbridge Municipal Airport and downtown Southbridge.

The lower part of the “East Brook” Brimfield watershed has numerous nonpoint sources of pollution present including several farms and several homes with lawns abutting the stream. As noted by Fiorentino (2007) from Sherman Pond to Mill Brook “East Brook “ is technically an intermittent stream. The stress created by the lack of flow may help to reduce the algal population at this open-canopy site and also restrict the macroalgae from becoming established. An indication of the impact of the nutrients contributed by the nonpoint sources include the presence of mats of the filamentous cyanobacteria *Oscillatoria* sp., as well as green “globs” of the filamentous green *Chaetophora* sp.

The green filamentous alga *Spirogyra* sp. was dominant at the Burncoat Brook (BU01) site with 50% open-canopy. Although dominant in the sample, the alga was present at <5 % in the riffle.

BR01, located in Browns Brook was used for all sites as the reference station for the macroinvertebrate bioassessments. BR01 was situated upstream from all known point sources of water pollution, and was presumed to be minimally impacted by nonpoint sources. Browns Brook (BR01), has a partially open-canopy (60%), had a mat of the cyanobacteria *Lyngbya* sp. and some diatoms, particularly *Synedra* sp. (Appendix D).

Algal Percent Cover

The percent cover of the benthic algae in a waterbody is a way of evaluating if excessive amounts of algal growth have occurred resulting in nuisance conditions and loss of aesthetic appeal (Barbour et al. 1999; Biggs 1996). In Massachusetts, the USEPA criteria (Barbour et al 1999) are used to determine if nuisance algal conditions exist (i.e. green macroalgae cover > 40 % of the benthos in the riffle/run zone) compromising aesthetics. At this amount of biomass, nutrient enrichment may also be indicated (Biggs 1996).

Results from the visual estimation of percent cover (Tables 5 and 6) and identification of dominant algal types (Appendix C and D) indicate that at the Merrimack River watershed macroalgal cover exceeded 40 % at the Powwow River site PO01 with 100% in the riffle area and 80% in the reach.

In the French and Quinebaug River system no station was identified as having macroalgae present in nuisance amounts.

Other Observations

Biggs et al. (1998) found that locations in headwater sites were dominated by filamentous cyanobacteria and diatoms. This observation was also made by Rounick and Winterbourn (1983) who studied two experimental channels located in a forested area, with one exposed to light and the other kept in the dark. An organic layer consisting of slime, fine particles, bacteria and fungi developed in the forested canopy stream, but when exposed to natural light intensities growth of diatoms and filamentous algae was evident that was not found in the darkened channel. The open-canopy headwater stations followed this pattern in this study while closed-canopy sites were more likely to be dominated by heterotrophic organisms.

It is easy to see how lack of light could influence the algal assemblage. Hill (1996) found that in small streams, leaf canopies can intercept 95% or more of incident radiation, reducing maximum photon flux densities to less than 40 umol m^2 s^{-1}. Photosaturation for most benthic algae ranges from 100-400 umol m^2 s^{-1}.

Several stations in the French and Quinebaug subwatersheds lacked algae in the riffle zone. Instead, moss covered large areas of the bottom, another common occurrence in headwater streams. Stations with moss as the dominant aquatic vegetation include: Browns Brook (BW01), Hacket Brook (HC01), Cohasse Brook (CO01), Lebanon Brook (LB01), Keenan Brook (W1186), Rocky Brook (RB01), and Grindstone Brook (GR01).

Use of the Sontek, or other similar instruments, provides a quick means of determining velocity values to which the algae are exposed and may help to determine if comparable habitats exist from one station to another. However, examination of stations where two or more velocity measurements were made reveals that a lot of variability exists in-stream caused by physical barriers, differences in slope and possibly rainfall. An example might be the Powwow River. For this 130 sq. mile watershed average velocity above the algae was 7.7 cm/s yet at another location, in the same reach, the average velocity above the algae was 69.3 cm/sec. In the slower flowing areas one type of algal vegetation appeared to be present while in the faster riffle the physical appearance indicated dominance by a different alga.

Stephenson (1996) discussed the complex relationship between current (velocity) and benthic biomass. He noted that current velocity up to a certain break point stimulates algal metabolism and phosphorus uptake while very high velocities create a drag on the algae and decrease "immigration rates" or recruitment. Biggs and Gerbeaux (1993) found peak benthic algal biomass on natural substrata is usually highest in velocities ranging from 10-20 cm/s, our low-velocity grouping, but this peak biomass development may be more likely in higher-order streams where other forms and quantities of nutrients are present.

The predicted impact of the velocity on the algal assemblage is not evident in these samples. It is not known if this is because they were primarily first-to third-order streams with potentially different nutrient regimes than higher-order streams or if other factors such as, the lack of re-establishment of the algal community following heavy rains was significant. Perhaps velocity data are not as pertinent to our evaluations as other data. For our purposes, the best use of the velocity data is probably for examining station comparability which is a requirement for all biomonitoring parameters.

The local changes in velocities-either substrate or surface- within a reach makes it a less useful parameter for describing wider impacts on communities than are created by differences in more widely applied parameters like light or nutrient regimes. In these headwater streams closed-canopy sites often were dominated by heterotrophic organisms and at open-canopy sites green (Chlorophyceae) or blue-green (Cyanophyceae) species often dominated.

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Appendix A

Taxonomic References for the Identification of Algae

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Appendix B: 2004 Precipitation data recorded at Lawrence Municipal Airport, Lawrence, MA

	Date	Precipitation (inches)
Sample Date	July 27	Trace
1 day prior	July 26	0.00
2 days prior	July 25	0.00
3 days prior	July 24	1.11
4 days prior	July 23	0.00
5 days prior	July 22	0.00
Sample Date	July 29	0.00
1 day prior	July 28	0.46
2 days prior	July 27	Trace
3 days prior	July 26	0.00
4 days prior	July 25	0.00
5 days prior	July 24	1.11
Sample Date	July 30	0.00
1 day prior	July 29	0.00
2 days prior	July 28	0.46
3 days prior	July 27	Trace
4 days prior	July 26	0.00
5 days prior	July 25	0.00
Sample date	Aug 2	0.00
1 day prior	Aug 1	Trace
2 days prior	July 31	0.00
3 days prior	July 30	0.00
4 days prior	July 29	0.00
5 days prior	July 28	0.46
Sample date	Aug 3	0.29
1 day prior	Aug 2	0.00
2 days prior	Aug 1	Trace
3 days prior	July 31	0.00
4 days prior	July 30	0.00
5 days prior	July 29	0.00
Sample date	Aug 24	0.00
1 day prior	Aug 23	0.01
2 days prior	Aug 22	0.01
3 days prior	Aug 21	2.31
4 days prior	Aug 20	0.08
5 days prior	Aug 19	0.09
Sample date	Aug 25	0.00
1 day prior	Aug 24	0.00
2 days prior	Aug 23	0.01
3 days prior	Aug 22	0.01
4 days prior	Aug 21	2.31
5 days prior	Aug 20	0.08
Sample date	Aug 30	0.09
5 days prior	Aug 29	0.00
4 days prior	Aug 28	0.19
3 days prior	Aug 27	0.00
2 days prior	Aug 26	0.01
1 day prior	Aug 29	0.00

Taken from http://cdo.ncdc.noaa.gov/ulcd/ULCD (NOAA National Climatic Data Center)

Appendix C Merrimack River Periphyton 2004

				Algae-Phototrophic Organisms			Heterotrophic Organisms	
Station #	Date	Water body	Location	Class	Genus	Abundance	Other organisms	Abundance
SO01	27-Jul	South Branch Souhegan River	South Branch Souhegan River, downstream from Jones Hill Road, 275 m downstream from unnamed tributary, Ashby, MA-riffle, cobble-partially open- canopy	Bacillariophyceae	*Surirella* sp.	R	sewage fungus	C
				Bacillariophyceae	pennate diatoms	R		
				Chlorophyceae	*Coleochaete*	R		
				Cyanophyceae	*Lyngbya*	R		
				Cyanophyceae	*Plectonema*	R		
RBR01	30-Jul	Richardson Brook	Upstream from Methuen St., Dracut, MA-riffle, cobble, open-canopy	Bacillariophyceae	*Cymbella*	R	fungal hyphae	R
				Bacillariophyceae	*Melosira varians*	A		
				Bacillariophyceae	*Synedra*	A		
				Chlorophyceae	*Microspora*	VC		
				Chlorophyceae	*Rhizoclonium*	C		
				Chlorophyceae	*Stigeoclonium*	R		
				Chlorophyceae	*Ulothrix*	VA		
RBR01	30-Jul	Richardson Brook	Upstream from Methuen St., Dracut, MA-riffle, cobble, closed-canopy	Bacillariophyceae	*Cymbella*	R	fungal hyphae	C
				Bacillariophyceae	*Surirella*	R		
				Bacillariophyceae	centric diatoms	R		
				Bacillariophyceae	pennate diatoms	R		
				Chlorophyceae	*Coleochaete*	R		
				Cyanophyceae	*Dictyopshaerium*	R		
TB02	30-Jul	Trull Brook	Downstream from River Rd.above golf course Tewksbury, MA-riffle, cobble-partially open	Bacillariophyceae	diatoms	A	sewage fungus	C
				Cyanophyceae	*Lyngbya*	C	filamentous bacteria	C
				Chlorophyceae	*Coleochaete*	R		
TB02	30-Jul	Trull Brook	Downstream from River Rd.above golf course Tewksbury-riffle, mat, closed-canopy				fungal hyphae	R
							ciliates	

				Algae-Phototrophic Organisms			Heterotrophic Organisms	
Station #	Date	Water body	Location	Class	Genus	Abundance	Other organisms	Abundance
							filamentous bacteria	R
MRB01	29-Jul	Martin's Pond Brook	25 m upstream of footpath extending from Loomis Lane, Groton, MA, riffle, closed-canopy	Bacillariophyceae	*ui pennate diatoms*	R	fungal hyphae	C
				Chlorophyceae	*Closterium*	R		
				Cyanophyceae	*ui filament*	C		
FI01	2-Aug	Fish Brook	Downstream from River Rd., Andover, pool, closed-canopy	Bacillariophyceae	*Fragilaria*	R	fungal hyphae	
				Bacillariophyceae	*Melosira*	R	bacterial filaments	
				Bacillariophyceae	*Synedra*	R		
				Bacillariophyceae	*ui spiralled diatom*	R		
				Bacillariophyceae	*ui pennate diatoms*	R		
CR01	2-Aug	Creek Brook	25 m upstream of West Lowell Ave., Haverhill, riffle, closed-canopy	Bacillariophyceae	*Cocconeis*	R	fungal hyphae	R
				Bacillariophyceae	*Cymbella*	R		
				Bacillariophyceae	*Fragilaria*	R		
BA01	2-Aug	Bartlett Brook	Upstream from Rte. 113 Methuen, MA riffle, closed- canopy	Bacillariophyceae	*Cocconeis*	R		
				Bacillariophyceae	*Fragilaria*	R		
				Bacillariophyceae	*Navicula*	R		
				Bacillariophyceae	*ui pennate*	R		
PE01	30-Jul	Peppermint Brook	100 m downstream of Lakeview Ave., Dracut, riffle, closed-canopy	Bacillariophyceae	*Surirella*	R		
				Bacillariophyceae	*Navicula*	C		
				Bacillariophyceae	*Euontia*	R		
				Bacillariophyceae	*ui pennate*	VA		
BR01	29-Jul	Bridge Meadow Brook	Bridge Meadow Brook, 80m downstream from road to Tyngsborough Elementary School (205 Westford Road), Tyngsborough, MA-riffle, cobble, closed- canopy	Bacillariophyceae	*Gyrosigma*	R	fungal hyphae	C
				Bacillariophyceae	pennate diatoms	R		
BR01	29-Jul	Bridge Meadow Brook	Bridge Meadow Brook, 80m downstream from road to	Chlorophyceae	*Closterium*	R	filamentous bacteria	C

				Algae-Phototrophic Organisms			Heterotrophic Organisms	
Station #	Date	Water body	Location	Class	Genus	Abundance	Other organisms	Abundance
			Tyngsborough Elementary School (205 Westford Road), Tyngsborough, MA-pool, mat, partially closed-canopy					
				Cyanophyceae	*Lyngbya*	R		
				Cyanophyceae	*Plectonema*	R		
				Cyanophyceae	*Spirulina*	R		
				Cyanophyceae	filamentous b-g	C		
TA01	29-Jul	Tadmuck Brook	Upstream from Lowell Rd., Westford, MA-riffle, mat, open-canopy	Bacillariophyceae	*Cymbella*	A	fungal hyphae	A
				Bacillariophyceae	*Gyrosigma*	R		
				Bacillariophyceae	*Navicula*	R		
				Bacillariophyceae	*Surirella*	R		
				Bacillariophyceae	ui pennate diatoms	A		
				Cyanophyceae	*Anabaena*	VC		
				Cyanophyceae	*Phormidium*	VA		
TA01	29-Jul	Tadmuck Brook	Upstream from Lowell Rd., Westford, MA -riffle, cobble-, partially closed-canopy	Bacillariophyceae	*Cymbella*	R	fungal hyphae	A
				Bacillariophyceae	*Fragilaria*	R		
				Bacillariophyceae	*Synedra*	R		
				Bacillariophyceae	ui pennate diatoms	C		
				Cyanophyceae	*Gomphonema*	R		
				Cyanophyceae	*Phormidium*	R		
BE01	27-Jul	Bennetts Brook	Downstream from Willow Road, Ayer, MA-riffle, cobble, partially closed-canopy	Bacillariophyceae	diatoms	R	sewage fungus	
				Chlorophyceae	*Coleochaete*	R	organic floc	
							sheathed bacteria	R
							iron floc	
BE01	27-Jul	Bennetts Brook	Dnst. From Willow Road, Ayer, MA-riffle, mat, partially-open	Bacillariophyceae	Diatoms	VA	bacterial filaments	C
				Bacillariophyceae	*Gyrosigma*	R		

				Algae-Phototrophic Organisms			Heterotrophic Organisms	
Station #	Date	Water body	Location	Class	Genus	Abundance	Other organisms	Abundance
				Bacillariophyceae	*Fragilaria*	R		
				Bacillariophyceae	*Synedra*	R		
				Bacillariophyceae	*Navicula*	R		
				Cyanophyceae	*Lyngbya*	VA		

Appendix D: French and Quinebaug Rivers Periphyton 2004

Quinebaug River Subwatershed

				Algae-Phototrophic Organisms			Heterotrophic Organisms	
Station #	Date	Water body	Location	Class	Genus	Abundance	Organism	Abundance
W1183	25-Aug	Unnamed tributary (East Brook)	Upstream of Route 20, Brimfield, MA-riffle, open-canopy	Bacillariophyceae	*Gyrosigma*	R		
				Bacillariophyceae	*Navicula*	C		
				Bacillariophyceae	*Tabellaria*	R		
				Cyanophyceae	*Anabaena*	R		
				Cyanophyceae	*Oscillatoria*	A		
				Cyanophyceae	*Oscillatoria splendida*	A		
W1183	25-Aug	Unnamed tributary (East Brook)	Upstream of Route 20, Brimfield-2 of 3-riffle, open-canopy	Chlorophyceae	*Chaetophora pisiformis*	A		
W1183	25-Aug	Unnamed tributary (East Brook)	Upstream of Route 20, Brimfield-3 of 3-riffle, open-canopy	Bacillariophyceae	*Cymbella*	R	fungal hyphae	C
				Bacillariophyceae	*Fragilaria*	R		
				Bacillariophyceae	*Navicula*	C		
				Bacillariophyceae	*Nitzchia*	R		
				Bacillariophyceae	*Synedra*	R		
				Chlorophyceae	*Closterium*	R		
				Chlorophyceae	*ui green filament*	R		
				Cyanophyceae	*Lyngbya*	C		
				Cyanophyceae	*Oscillatoria*	C		
BR01	24-Aug	Browns Brook	230 m upstream from May Brook Road, Holland, MA, riffle, partially-closed	Bacillariophyceae	*Eunotia*	R		
				Bacillariophyceae	*Gomphonema*	R		
				Bacillariophyceae	*Synedra*	C		
				Cyanophyceae	*Lyngbya Taylorii*	VA		
ST01	24-Aug	Steven's Brook	upstream of Brimfield Rd., Brimfield, riffle, partially-closed	Bacillariophyceae	ui pennate diatoms	R	sewage fungus	C
				Chlorophyceae	*Cladophora*	R		
				Cyanophyceae	ui b-g filaments	R		

LE01	24-Aug	Leadmine Brook	600 m upstream from Rte. 84, near vacant Rte 15 rest area, Sturbridge, MA	Bacillariophyceae	ui pennate diatoms	R	fungal hyphae	R
HA01	24-Aug	Hamant Brook	100 m downstream from sandpit access road off Shattuck RD, Sturbridge, MA	Bacillariophyceae	*Cymbella*	R	sewage fungus	R
				Bacillariophyceae	*Fragilaria*	R		
				Bacillariophyceae	ui pennate diatoms	R		
				Chlorophyceae	*Cladophora*	R		
HA01	24-Aug	Hamant Brook	100 m downstream from sandpit access road off Shattuck RD, Sturbridge, MA	Chlorophyceae	ui green filaments	VA		
MK01	25-Aug	McKinstry Brook	~140 m upstream from Pleasant St., Southbridge-riffle	Bacillariophyceae	*Cymbella*	C	sewage fungus	C
				Bacillariophyceae	*Melosira*	R		
				Bacillariophyceae	*Synedra*	R		
				Bacillariophyceae	*Surirella*	C		
				Bacillariophyceae	ui pennate	C		
				Chlorophyceae	*Scenedesmus*	C		
TU01	26-Aug	Tufts Branch	~30 m upstream from Rte 197, Dudley-riffle	Cyanophyceae	*Phormidium*	C	fungal hyphae	R

French River Subwatershed

				Algae-Phototrophic Organisms			Heterotrophic Organisms	
Station #	Date	Water body	Location	Class	Genus	Abundance	Organism	Abundance
BU01	3-Sep	Burncoat Brook	350 m upstream from confluence with Town Meadow Brook, Leicester	Chlorophyceae	*Spirogyra*	A		
W1197	26-Aug	Potters Brook	Unknown tributary to South Fork (locally known as "Potters Brook") 150 m downstream from Potter Village Rd., Charlton-1 of 2-riffle	Cyanophyceae	*Chamaesiphon confervioda*	A	fungal hyphae	R
W1197	26-Aug	Potters Brook	Unknown tributary to South Fork (locally known as "Potters Brook") 150 m downstream from Potter Village Rd., Charlton-1 of 2-riffle	Bacillariophyceae	*Cymbella*	R		

				Bacillariophyceae	*Melosira*	R		
				Bacillariophyceae	*ui pennate diatoms*	R		
SU01	27-Aug	Sucker Brook	downstream Kingsbury Rd., Webster-riffle	Bacillariophyceae	*Surirella*	R		
				Cyanophyceae	*Lyngbya*	C		
				Cyanophyceae	*Oscillatoria*	A		
				Cyanophyceae	*Oscillatoria amphibia*	VA		
MI01a	27-Aug	Mine Brook	upstream from Mine Brook Rd., Webster riffle, on rocks-algal mat	Cyanophyceae	*Lyngbya versicolor*	VA		
				Cyanophyceae	*Plectonema nostocarum*	VA		
MI01	27-Aug	Mine Brook	downstream from Mine Brook Rd., Webster-riffle	Cyanophyceae	*Scytonema*	VA	fungal hyphae	C
				Cyanophyceae	*Lyngbya*	C		
				Cyanophyceae	*Plectonema rupicola*	VA		

Appendix E: USGS flow data recorded at Merrimack River in Lowell and at the Quinebaug River in Southbridge-2004 (www.waterdata.usgs.gov)