

ABSTRACT

Title of dissertation: STUDIES OF PERIPHYTIC ALGAE ON ALGAL TURF SCRUBBERS™ ALONG THE CHESAPEAKE BAY: COMMUNITY STRUCTURE, SYSTEMATICS, AND INFLUENCING FACTORS

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This is an ecological and systematic study of periphytic algae growing in an ecologically-engineered system used for water quality improvement: the Algal Turf Scrubber or ATS™. This technology consists of an attached algal community growing on screens in a shallow flowway through which water is pumped. The study was conducted on small-scale, experimental flowways at three sites within the Chesapeake Bay watershed: on the Susquehanna River in southeastern Pennsylvania (freshwater) and on the Great Wicomico and York Rivers in Virginia (brackish water).

A total of 330 taxa were identified at the sites from 2008-2011. The majority of taxa at all three sites belonged to the phylum Bacillariophyta, but a large number of taxa from Chlorophyta and, to a lesser degree, Cyanobacteria were also found at the freshwater site. Algae found in the ATS™ exhibited a diversity of life forms and modes of attachment within the community. Although these system appear to be dominated by a “canopy” of attached, filamentous species, more than half of the total abundance (cell

density) were solitary, unattached taxa that grow as an “understory” within the three dimensional structure of the community.

Longitudinal patterns were examined on the longest flowways (90 m long) at the freshwater site. The community nutrient uptake rate (mass of nitrogen or phosphorus m^{-2} day^{-1}) for the harvested algal biomass was found to decline from the top to the bottom of the flowway for a system constructed at 2% slope but no distinct pattern was found for a system constructed at 1% slope. The majority of algal taxa were evenly distributed along the flowway from top to the bottom, in terms of frequency of occurrence, suggesting a general lack of longitudinal specialization within the community.

A detailed review of the systematics of the Order Oscillatoriales (Cyanobacteria) found on the ATSTM was undertaken since this group has not been studied much in the Chesapeake Bay watershed. Twenty-four taxa were examined, described morphologically and their nomenclature reviewed. Comparing 16s rRNA gene analyses of planktonic and periphytic *Pseudanabaena*, it was suggested that periphytic *Pseudanabaena* be revised and elevated to a new genus, *Ilyonema*

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SYSTEMATICS, AND INFLUENCING FACTORS

by

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To my life partner, Richard, for his understanding
and support during this process.

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Chapter 1. Introduction

General introduction

In recent decades, humanity has been faced with a series of global problems – environmental, financial, economical, and social. In this context, concerns about the environment, in general, and with water, in particular, are of special importance, since demands are becoming greater due to populational growth and greater water use. However, the quality of water on Earth is being degraded at an alarming rate, which directly affects aquatic communities and subsequently, humanity.

The quality of aquatic resources can vary greatly due to natural and human actions. The concept of sustainable development, widely discussed since the end of the last century, has modified the relationships between man and nature. The availability and commitment to the quality of (fresh) waters is today one of the principal problems relating to sustainable development, and one of the large challenges for mankind to face during this century.

Various human activities in watersheds result in large discharges of polluted water, with high concentrations of inorganic and organic material, which degrade and elevate the nutrient concentrations, provoking imbalances in natural biogeochemical cycles and a series of undesirable collateral effects. This consequence has been well-documented, reflecting anthropogenic action on aquatic ecosystems and is called eutrophication. This is a multifaceted term, which is generally associated with increased productivity, structural simplification of the biotic components, and a change in the metabolic ability of the organisms to adapt to changes caused by the environment

(Wetzel, 1983). In eutrophic environments, there are changes in the trophic state of the systems that promote alterations at the biological level: in primary production and the specific composition of the biological community, food webs, and energy flows (Harper, 1992). High population concentration and its rapid expansion have caused watersheds, which include large urban centers, to suffer increasing environmental impacts, principally due to agricultural, domestic, and industrial residues. Finding economical and natural technologies for (bio) remediating these degraded waters to their 'natural' state (an idea shared within the discipline of ecological engineering – Kangas, 2004) is required. This dissertation deals with one of these technologies, the 'Algal Turf Scrubber – ATSTM', which uses periphytic algae to remediate the aquatic environment.

The algal turf scrubber (ATSTM) system

The algal turf scrubber system (ATSTM) is an ecologically engineered system designed by Dr. W.H. Adey, with his observations of coral reef algal turfs in tropical coral reefs throughout the Caribbean Sea (Adey & Loveland, 2007). This observation stemmed from previous studies by Odum & Odum (1955), which stated that tropical coral reefs had high productivity. Adey and his collaborators carried out years of research on the algae of tropical reefs and found these ecosystems to be 5-10 times more productive than any terrestrial forest, limited by light (Adey & Steneck, 1985). This high productivity was due mainly to the thick, dense algal turf found covering carbonate substrates in reef environments. To test this productivity Adey and his team set out a series of plastic screens, at various depths, to verify if the productivity could be reproduced artificially. They discovered that the algal turf would grow on screens,

limited by the natural energy from the waves and sunlight, at the same rates as on the coral reefs. With this, Adey and his team were able to then grow artificial algal turfs on screens.

At that time, Dr. Adey was head of the Marine Systems Laboratory of the Smithsonian Institution, and much research was focused on microcosms, mesocosms, and aquaria. With the knowledge they had acquired in the field, they were able to build shallow troughs (a.k.a. raceways) lined with screens where algae could grow, and water passed through, at a pulsating motion due to a dump-bucket (artificial wave motion). These systems had artificial lighting and they found that the algae grew very quickly on these screens. When the algae grew, they also removed the nutrients from the water of the aquaria/mesocosm through uptake, and by removing the algae through harvesting the screens periodically, the nutrients could be permanently removed from the system, leading to water quality improvement (Adey & Loveland, 2007). These ATSTM systems were used to: (1) simulate export (to balance import – in the case of coral reef systems, export to lagoon to balance plankton input); (2) maintain O₂ at that of levels normal to wild systems; (3) especially in coral reefs to maintain high pH to support calcification; and (4) to maintain low N & P (especially reef systems) (Small & Adey, 2001).

During the 1980's and 1990's, researchers expanded the application of ATSTM to large-scale mesocosms and applying ATSTM for tertiary treatment, removal of nutrients from rivers and dairy manure effluents, transforming the idea of ATSTM to on-land systems (Adey et al., 1996; Craggs et al, 1996; Mulbry, 2008; Adey et al., 2011). The on-land ATSTM was designed to (bio)mimic the natural systems of which it was originally found. Thus shallow troughs with a plastic mesh screen lined inside were

placed at a slope where polluted water entered at the top in a pulsated manner through a dump-bucket or surge beams (to mimic waves, receiving energy flow) and exited through the bottom, as cleaned water. On the screens periphytic algae were seeded (or self-seeded from the incoming water) and allowed to self-organize into a ‘natural’ community and harvested at weekly intervals (dependent on season) to maximize production and prevent grazers from overtaking the systems. The algal production thus ‘scrubs’ the water, removing nitrogen, phosphorus, heavy metals, etc. (Adey et al., 1993; Adey & Loveland, 2007), as a result cleaning the water.

The pressures (harvesting and screens) on this ecologically designed system act as filters for a select periphytic community to grow (Figure 1.1). Algae have been around for millions (and the cyanobacteria for billions) of years; however, synthetic materials have only been around for a little over one hundred years. Thus, the capability for certain algae to grow and or settle on a screen of an ATSTM is an interesting concept, since they have not evolved with this substrate (filter), during their evolutionary history. However, in the evolution of the species colonizers of artificial substrates, they have developed a mechanism in their native ecosystem, which in turn, helps them to colonize these artificial substrates. This community is composed of bacteria, algae, occasionally invertebrates, and detritus, though the bulk of the scrubbing (cleaning) activity, and the focus of this dissertation, is carried out by the algae. Furthermore, with novel ‘green’ technologies entering the market with algal by-products, the algal community receives the most attention.

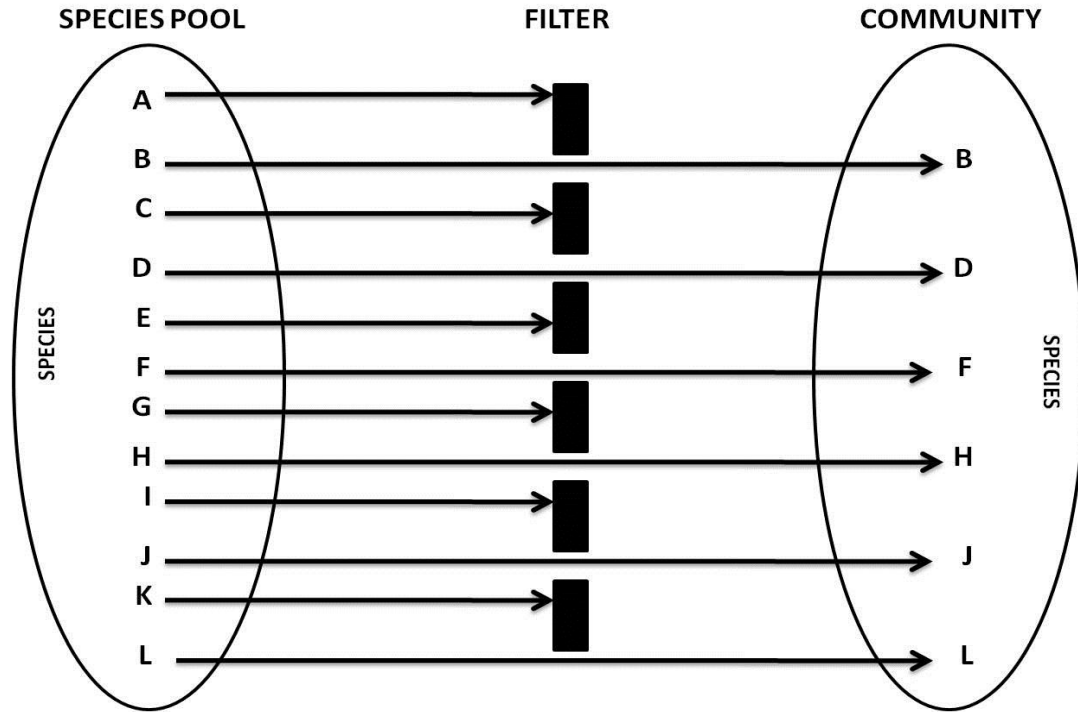


Figure 1.1. Self-organization of a community from a species pool. Not all species are able to pass through the filter and become part of the ATSTM community.

Interestingly, due to harvesting, this community never reaches ‘full maturity’ (Biggs, 1996), since this would lead to slower growth rate, sloughing, and loss of biomass, thus reducing the nutrient uptake and overall biomass, which is important to retain due to the applied aspect of the ATSTM (Figure 1.2).

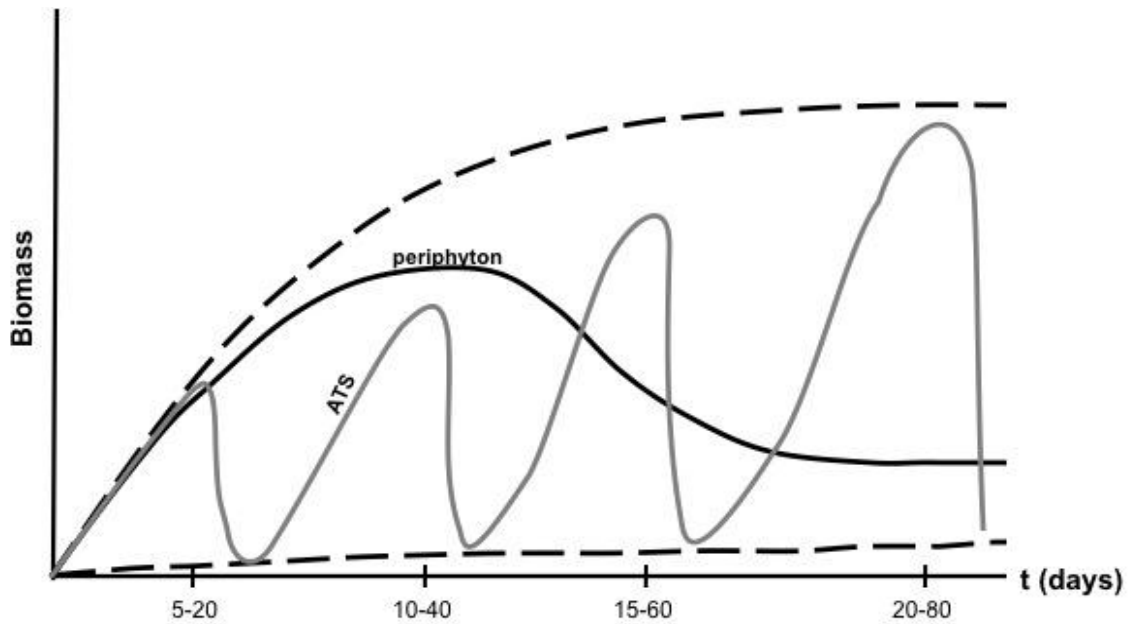


Figure 1.2. An idealized growth curve for ‘wild’ periphyton (black line, adapted after Biggs, 1996), found in streams, compared to the growth curve for ATSTM periphyton (grey line), due to harvest. Dotted lines indicate the maximum and minimum of the growth curves.

Harvest on an ATSTM is carried out according to the size of the system. In the pilot, small-scale systems, the input water is turned off so that the algal turf is allowed to dry for 1 to 1.5 hours. Using a wet/dry vacuum, and starting at the top of the system, the system is essentially vacuumed of its biomass, until reaching the bottom. In this manner the biomass is capable of being harvested, and the nutrients within the biomass can be removed from the environment.

Up to 2008, the periphytic algal community on ATSTM systems had been largely taxonomically neglected, with the focus on biomass production and identification of the ‘key-species’. Thus, with this dissertation, our understanding of the diversity and dynamics of this community has been enhanced.

Periphyton

Periphytic algae are among the principal primary producers in aquatic environments, contributing with up to 85% of total primary production in lotic environments (Wetzel, 1983). The rate of primary production of periphytic algae depends on the area available for colonization, of the physicochemical conditions of the water, of the morphometry of the aquatic system, and of the type and quality of the substrate.

The study of periphyton can be traced for a little over 100 years, but concepts have changed over time. One of the first terms used to designate the community that lives fixed to the substrate was sessile. In 1905, the German term *aufwuchs* was initially used, referring to organisms attached, though not penetrating the substrate. In 1920, this same term was limited to organisms attached on live substrates and the term *bewuchs* was utilized for organisms collected on glass plates in channels around Hamburg (Cooke, 1956).

Behning, in 1924, used the term periphyton (Cooke, 1956) to describe organisms that grow on artificial substrates in the water. Subsequently, it was extended to all aquatic plants attached to submerged surfaces. According to Sládecková (1962), there are two types of organisms that compose the periphytic community: those that live fixed, immobile, adapted to the sessile life via rhizoids, gelatinous stalks, etc., consisting of the euperiphyton (true *aufwuchs*) and those mobile organisms, that live aggregated without

fixing themselves to the substrates, thus composing the pseudoperiphyton (false *aufwuchs*).

In 1983, Wetzel defined the term metaphyton, defining the algae that live within the submerged aquatic macrophytes (SAVs). Schwarzbald (1992) stated that frequently free-floating organisms from the pelagic zone are found in the periphyton, and participate in the metabolic processes, thus considered in the study of this community. Moreover, according to the same author, in heterogeneous environments (especially littoral), several microhabitats are created, making a representative sample difficult, because it is practically impossible to separate the euperiphyton and pseudoperiphyton from the metaphyton when trying to evaluate composition, biomass, or functional processes.

Nowadays, the term used by the scientific community is the definition by Wetzel (1983), who unified the concept of periphyton into a 'complex community of microbiota composed of bacteria, fungi, algae, animals, and inorganic/organic detritus that live attached to live or dead submerged substrates'. By the type of habitat, their development is favored in shallow environments, due to light availability and the presence of various types of substrates, such as SAV, rocks, and sediments.

With the recognition that the many lotic/lacustral ecosystems in the world are shallow, with a predominance of areas of land-water interface (Wetzel, 1996), studies on periphytic communities become essential for a better ecological understanding of freshwater and brackish ecosystems. This community plays an important role in the energetic cycles, consisting of the principal or dominant source in the synthesis of organic material in littoral regions or in shallow ecosystems, being responsible for carbon fixation and sequestering essential nutrients, such as phosphorus and nitrogen, making

them available to consumers (Wetzel, 1996; Dodds, 2003). Thus, periphytic algae are key components in aquatic environments for both nutrient cycling and for the food chain (Lowe & Pan, 1996; Wetzel, 2001; Vadeboncoeur & Steinman, 2002). It is notable, though, the significant biodiversity of the community even in relation to the phytoplankton (Ferragut et al., 2005), which results in part from the heterogeneity in habitats, combined with the different strategies for colonizing substrates (Goldsborough & Robinson, 1996; Stevenson, 1996), as well as the interaction and exchange of species with the phytoplanktonic community (Margalef, 1998; Taniguchi et al., 2005).

Besides the ubiquity of periphyton and its relevance in the functioning of shallow environments, several features contribute to its use in studies of water quality. Among the highlights is the attached habit, short life cycles, which provide rapid responses to environmental changes, and it is species-rich compared to other aquatic groups, providing an informative system (Lowe & Pan 1996; Stevenson, 1996; McCormick & Stevenson, 1998).

Much emphasis has been given to the algal group, since it composes the bulk of the periphytic biomass (Pômpeo & Moschini-Carlos, 2003). According to Hill & Webster (1982), periphytic algae are the dominant producers in lotic ecosystems of low order. Periphyton is also the major regulator of the flow of energy and nutrients in aquatic ecosystems, especially in benthic environments (Lock et al., 1984; Wetzel, 1990). Lowe & Pan (1996) emphasize the key role that periphytic algae have on aquatic food chains, thus linking the biotic and physicochemical components, where alterations in the composition, structure or biomass will lead to changes in the dynamics of the food webs in these ecosystems.

Artificial substrates can be used properly to research the environmental impact and interactions within the periphytic community (Watanabe, 1990). In the study of phycoperiphyton (periphytic algae), artificial substrates provide a substantial amount of attached periphytic material, easy definition of area and volume, and allow an efficient removal of the attached organisms (Pômpeo & Moschini-Carlos, 2003). The periphytic colonization on glass substrates occurs by, first, the formation of an organic layer followed by the attachment of bacteria, opportunistic diatoms (with simple morphological structures), diatoms morphologically rosette-formed and with long stalks, and finally, filamentous green algae (Hoagland et. al, 1982; Biggs, 1996). The choice of the artificial substrate in this thesis was due to the use of the ATSTM for bioremediation and biomass production.

During the growth of periphytic algae, there is a simultaneous increase in the number of species because immigration, and decrease due to processes such as mortality, emigration, and grazing, so Ács & Kiss (1993) state that measuring the actual growth rate of the periphytic community is not an easy task. Now, Roos (1983), studying the dynamics of the periphytic community affirms that growth occurs until a climax situation, like in higher plants.

While studying algal turfs, Adey & Steneck (1985) observed seasonal shifts in both biomass and abundance within this community. According to Adey & Hackney (1988) this community consists of unicells, uniseriate filaments, simple branching filaments, and weakly corticated filaments that vary from a couple millimeters to several centimeters thick. These authors state that herbivory is what controls the thickness and height of these algae. During initial stages of turf development, diatoms (centric and

pennate; unicellular and filamentous), cyanobacteria (cocci and filamentous), and benthic dinoflagellates attach to an organic layer, which is found among the basal holdfasts of the larger algae. This organic layer also contains bacteria and protozoans. These species generally persist throughout the latter stages of development. In latter development, smaller sizes of macroalgae develop.

For Odum (1986), ecological succession in the ecosystems involves changes in community structure and community processes over time. The author proposed the studies of ecological succession of periphyton on artificial substrates in a short time (few weeks), in order to observe the establishment of this community, from the initial stage to the climax.

The distribution, abundance, and succession of many organisms depend on the use of different types of habitats in space and time (Fisher, 1993). Roos (1983) considers that the environmental conditions, seasons and characteristics of the species colonized influence directly on species richness. The main problem in studying the structure and dynamics of periphytic algal communities is the difficulty in discriminating among the influence of each abiotic and biotic variable. For Moschini-Carlos et al. (2000) colonization of the substrate is the result of the combination of abiotic variables and this process can be easily affected by changes in water quality and hydrodynamics of the ecosystem.

Site Descriptions

All sites studied are located on tributaries of the Chesapeake Bay. Six ATSTM systems were installed in four locations along Chesapeake Bay tributaries, on the Susquehanna River, Great Wicomico River, and the York River (Figure 1.3). Two ATSTM systems were installed at Muddy Run Reservoir on the Susquehanna River, one at the Peach Bottom Atomic Power Plant on the Susquehanna River, two at the Great Wicomico River, and one at the Virginia Institute of Marine Science (VIMS) on the Boat Basin at York River. These are all tributaries to the Chesapeake Bay.

The Chesapeake Bay (Figure 1.3) is the largest estuary in the United States, located on the Atlantic Coast, sharing borders with the states of Virginia and Maryland, with a surface area of $6.5 \times 10^3 \text{ km}^2$, mean depth of 8.42m, and expanding 320 km in length (Pritchard & Schubel, 2001). The climate of the region is of temperate geographic zone, marked by seasonal changes in temperature (Lippson & Lippson, 1984). The Bay ecology is influenced greatly by its salinity, which varies from the tidal freshwaters of the north, through the more brackish middle zones (salinity of 1 to 18) to the more saline mouth of the Bay and open ocean (salinity of 18 to 30). These values change dependent on depth and time of year, where the denser, salty water travels from the sea, at the bottom of the bay, towards the head of the bay, and the fresh water travels on the top, towards the mouth. This is generally a stable pycnocline, oscillating seasonally, but recurring annually. More rain, storm events or snowmelt, may cause an increase in fresh water into the Chesapeake Bay, and a drought can cause the contrary, thus changing the position of the pycnocline.

The Susquehanna River is the longest river on the eastern US coast, draining into the Atlantic Ocean, and the largest tributary of the Chesapeake Bay. It is also one of the most ancient rivers in the world (Thomas-Blate et al., 2011). It is responsible for almost half (49.3%) of the total freshwater input into the Bay (Pritchard & Schubel, 2001). This river passes through fertile agricultural and farmlands in New York and Pennsylvania, and as a result it is also responsible for 44% of nitrogen and 21% of phosphorus which enters the bay, according to Blankenship (2005).

In southeastern Pennsylvania, near Lancaster, on the banks of the Susquehanna River, two ATSTM flowways were installed at the Muddy Run Pumped Storage Facility (N39°48'36" and W76°17'14"). Incoming water for these systems came from the bottom of the Muddy Run Reservoir, which is filled from and drains back into the Susquehanna River daily during the operation of Exelon's pumped-storage hydroelectric facility. Thus the water input into the ATSTM is modified from ambient river conditions by a retention time in this reservoir. This is a freshwater system.

Located slightly south of this location is the Peach Bottom Atomic Power station (N39°45'8" and W76°15'36"), in which another ATSTM flowway was located. The input water for this system was pumped from the hot water discharge canal used for cooling the high-temperature reactors. This location is also a completely freshwater locality.

The Great Wicomico River is a small tributary to the Chesapeake Bay on its northwestern shore in the central Chesapeake Bay. Although it is called a river, it has no significant fresh water input, thus, it is actually most like a bay. It is mesohaline in character with salinities varying from 11 to 18. The ATSTM flowways were installed on a 70m long dock located on a 1 km wide embayment, about 6km from the open

Chesapeake Bay in Burgess, VA (N37°45'17" and W76°19'48"). Thus water from the pelagic zone was pumped from below the dock into these systems.

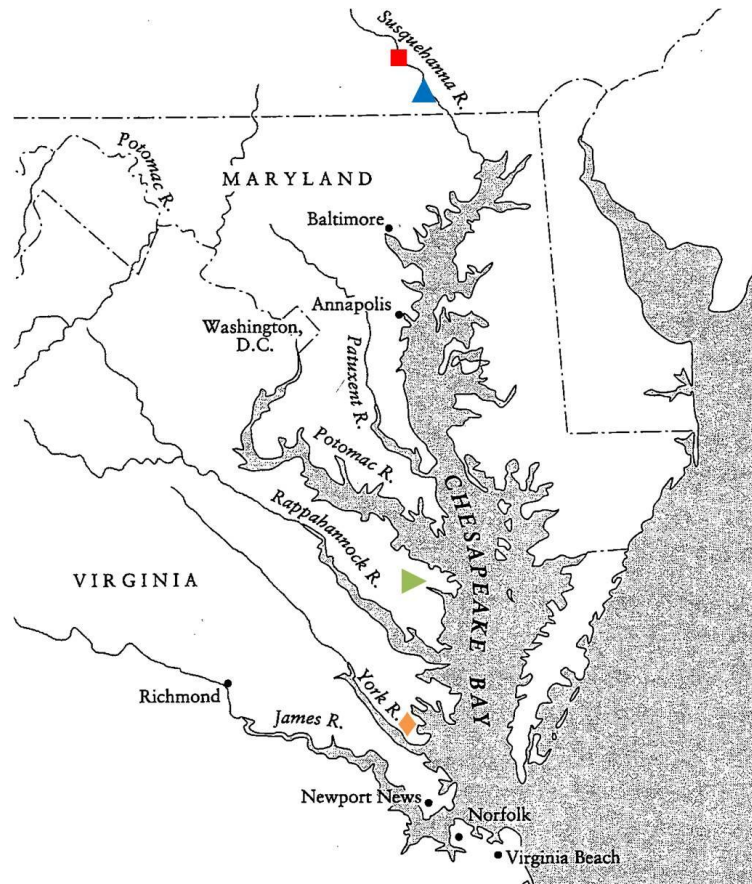


Figure 1.3. Chesapeake Bay with ATSTM sampling sites designated. Pennsylvania: (■) Muddy Run Reservoir (Susquehanna River) and (▲) Peach Bottom Nuclear Power Plant (Susquehanna River); Virginia: (▶) Great Wicomico River and (◆) VIMS, York River. (adapted from Curtin et al., 2001)

The York River is a large tributary to the Chesapeake Bay, located on the southeastern shore of the Chesapeake Bay in the state of Virginia. It is responsible for

3% of the fresh water input into the Chesapeake Bay (Pritchard & Schubel, 2001). This river has bottom salinities that range from 6 to 25 between its mouth and West Point, VA (Friedrichs, 2009). The ATSTM Boat Basin system was installed at the Virginia Institute of Marine Science (VIMS) Boat Basin, located in Gloucester Point, VA (N37°45'17" and W76°19'48"). Water to the floway was thus pumped from the boat basin, whose water originates from the York River, and salinity ranges from 18 to 20.

ATSTM Design

Several different ATSTM designs were used during the study for experiments, as described at the different study sites. To allow for better comparison, these different designs are summarized in Table 1.1.

Table 1.1. The different designs of ATSTM systems used during the study.

	Susquehanna River			Great Wicomico River		York River
	Muddy Run		Peach Bottom			VIMS Boat Basin
	Floway 1	Floway 2		Floway 1	Floway 2	
Floway Dimensions	0.3m x 91.4m	0.3m x 91.4m	0.3m x 91.4m	0.61m x 24.4m	0.61m x 15.24m	1.2m x 24.4m
Slope	2%	1%	2%	1%	2%	1%
Constructed Material	Aluminum	Wood/fiberglass	Aluminum	Wood/fiberglass	Wood/fiberglass	Wood/fiberglass
Substrate	HDPE	-	HDPE	HDPE & 3D	3D	HDPE
Mesh size	0.25 cm ²	0.04 cm ²	0.25 cm ²	0.25 cm ²	-	0.25 cm ²
Mean Input Water Nutrient Concentrations ^a	NO ₃ : 0.89 mg/l TN: 1.38 mg/l PO ₄ : 0.06 mg/l TP: 0.12 mg/l		-	TN: 0.48 mg/l TP: 0.017 mg/l		TN: 0.338 mg/l TP: 0.024 mg/l NH ₃ : 0.04 mg/l

HDPE: High-density polyethylene; 3D: Three dimensional 'carpet' screen.

^aData from Adey et al. (in. rev.), Kangas et al (2010), Canuel & Duffy (2011)

Aims of this Dissertation

The main aim of this dissertation was to describe the periphytic communities growing on ATSTM flowways in select locations along the Chesapeake Bay. In this manner, the general hypothesis was that algal communities differed in composition, abundance, and/or functional-structural makeup at different locations.

This study, therefore, aimed to:

- Provide aggregate descriptions of the algal turf, offering explanations for the structure/composition of these communities;
- Examine longitudinal patterns on long ATSTM units (Muddy Run), focusing on patterns of nutrient uptake into biomass and species composition, while examining putative relationships between these two parameters;
- Provide a phenotypic baseline to identify field populations of cyanobacteria from the Order Oscillatoriales in the Chesapeake Bay region by using morphological features easily recognizable under light microscopy and congruent by ultrastructure and molecular studies, while demonstrating the potential of novel species using a combined polyphasic approach.

The following chapters (Chapter 2, 3, and 4) are select studies, which include the methodology, results, and discussion in pursuit of the aims described above.

Chapter 2: Community composition and dynamics of periphytic algal communities of ATSTM systems along Chesapeake Bay tributaries.

Introduction

Alga(e) is a popular term that unites a polyphyletic group of mostly photosynthetic organisms found in an array of different ecosystems (Round, 1983). Most of the large macroscopic species live in marine waters (e.g. kelps and rock weeds), while the microscopic species have a wider distribution, though these microscopic, basically single-celled species, can accumulate in colonies and filaments forming macroscopic mats or ‘algal turfs’. Many species occur in fresh and brackish waters, though they can also be found in snow, thermal vents, humid soils, desert crusts, in/on plants, animals, rocks, etc. Basically, we live in an algal world. In periphyton, algae are critical since they are a principal producer in the food chain, as well as involved in nutrient cycling (Horne & Goldman, 1994; Lowe & Pan 1996).

Biggs (1996) summarizes that colonization by algae of an aquatic surface is a process of the settlement rate directed by the size and type of the source system (if this is dominated by bedrock, SAVs, sediment, etc.), substratum texture, light intensity, and water velocity; however, it should also be added that these filamentous attached algae can sometimes facilitate the ‘adherence’ of planktonic algae, due to their filamentous nature. Most of the source waters of the ATSTM system in this study are dominated by diatoms, since this group is predominant in sandy bottom rivers (Laughinghouse, 2010). Contrarily, ATSTM systems in Florida on small rocky canals and streams are dominated by filamentous chlorophytes (Adey et al., 1993). Both these groups are important

components of algal communities. In natural short-term communities, a succession usually occurs where first an organic matrix with bacteria will develop on a substrate, with small adnate diatoms following, then larger colonial diatoms, to larger filamentous chlorophytes (Hoagland et al., 1982; Biggs, 1996). Since there is a weekly harvest on ATSTM floways, the system is maintained at the intermediate stage of colonial diatoms. Since the primary objective in ATSTM systems is to maximize algal growth rate, and therefore nutrient removal, leaving algae on the floway too long could cause sloughing and loss in biomass.

The attributes of biological communities most used in ecological studies, such as abundance, richness, evenness, dominance, and species diversity are significantly affected by human activities (Pinto-Coelho et al., 1999). In particular, species diversity and the factors responsible for the maintenance or decline are key issues in ecology, and its decrease by anthropogenic effects has become a concern in science. Recent experiments have highlighted the importance of this issue, since they demonstrated the link between diversity and ecosystem functioning (Hillebrand & Sommer, 2000). According to Primack & Rodrigues (2001), the growing concern over the maintenance of biodiversity is a result of the greater awareness of its value not only as an economic good, but also with implications for the natural quality of life for people themselves.

Odum (1971) stated that communities in unfavorable or polluted environments show reduced diversity. However, data for freshwater aquatic communities are controversial, and there are cases where there is an increase in diversity with enrichment (Marcus, 1980; Pringle, 1990; Vercellino, 2001; Ferragut, 2004) and decrease of diversity

due to increase of nutrients in the supply water (Miller et al., 1992 in Hillebrand & Sommer, 2000).

The algal communities growing on the screens are periphytic turfs that are composed primarily of three life forms: 1) multi-cellular filaments that are attached directly or indirectly to the screen, 2) single-celled epiphytic species that are attached to the filaments and 3) single-celled species that grow unattached within the filamentous matrix. The filamentous species provide three-dimensional structure, analogous to the canopy or overstory in a forest, while the additional single-celled species grow within this structure, in part at least analogous to the understory in a forest. This type of algal community is a complicated sub-set of species that colonize the screen from the larger pool of naturally occurring species that possibly could colonize the screens (Figure 1.1). The screens themselves and the frequent harvesting of the algal growth technologies provide special selective forces that act as a “filter” between the total potential species pool and the sub-set of species that successfully colonizes the systems. Because the screens are made of artificial materials (man-made plastics, etc.), the colonizing species have not evolved to grow on them. The successful colonizers are thought to be pre-adapted to growth on the screens due to chance functional traits, since these have not evolved with them. The main goals of this chapter are to provide aggregate descriptions of the algal turf communities and to offer some explanations for the structure and composition of these communities.

Materials & Methods

Sampling

Samples of periphyton were collected at scheduled intervals in all of the ATSTM systems of this project and subsequently analyzed at the National Museum of Natural History (NMNH), using an Olympus BX50 binocular light microscope (LM). Forty-eight samples were collected at Muddy Run, 74 at Great Wicomico, and 55 at VIMS. For the ‘species-pool/source-communities’ comparison study, undertaken at VIMS, six samples of phytoplankton were obtained, using a phytoplankton net (25 µm), five samples of benthic/sediment samples, and two samples of macroalgae for epiphytic analyses were collected during an annual cycle from 2010-2011 ensuring sampling during all seasonal periods. The sediment samples were taken from the top 3 cm of the sediment in the field, brought back to the lab and left on a lighted shelf, allowing the epipsammic and/or benthic algae to rise to the surface of the sediment. Using a Pasteur pipette, the algae, which had risen was subsampled and analyzed using LM and oxidized for diatom analysis. For epiphytic algae on macroalgae, areas adjacent to the ATSTM at VIMS were scoured for macroalgae, which was brought back to the laboratory for analysis. These were brushed using a sterile toothbrush, and the algae was analyzed using LM and also oxidized for better visualization of the diatoms. These samples were collected during different seasons, and analyzed either live, preserved in 4% formaldehyde or in lugol’s for sedimentation, and samples were frozen for potential molecular studies.

For qualitative analyses, periphyton was scraped at various parts of the floway to have an understanding of the full complexity of the algal community. For quantitative

analyses, areas of 25 cm² located at the top, middle, and bottom sections of the flowways were sampled for analysis.

The procedure for visualizing ‘soft-algae’ and diatoms are different, thus steps undertaken for the qualitative and quantitative analyses of both are noted below.

Qualitative analysis

In preparation for light microscopy (LM) and scanning electron microscopy (SEM), diatoms were oxidized, a different procedure than just direct visualization used for soft-bodied algae (i.e., chlorophytes and cyanobacteria). A 20 ml subsample was separated and boiled in 30% hydrogen peroxide in a 1:1 sample ratio, adding 3 mg of potassium dichromate during the process to speed oxidization, until returning to the original volume of 20 ml. The cleaned material was concentrated in a centrifuge, and rinsed several times until reaching a neutral pH. This material was diluted into 3 different dilutions, air dried on coverslips, and processed for either LM or SEM analysis.

For LM, the coverslips were allowed to dry overnight, and mounted onto glass slides with the high refraction index (1.704) mounting medium Cargille Meltmount™ (Cargille-Sacher Laboratories, NJ). The samples were then analyzed under 400x or 1000x (oil immersion) using an Olympus Bx50 compound microscope with phase contrast. Morphological characteristics were recorded for the taxa for specific delimitation, i.e., valve/cell diameter and length, diameter of central area, striae length, density, and number. For SEM, coverslips were mounted on specimen stubs and sputter-coated with a gold/palladium alloy (10 nm) analyzed using a Leica Stereoscan 440 SEM.

The following specific literature for identification was used for each group: Bacillariophyta (Krammer & Lange-Bertalot, 1986, 1988, 1991, 1991; Cox, 1996; Round et al., 1990); Cyanobacteria (Komárek & Anagnostidis, 1998, 2005); Chlorophyta (Prescott, 1982; Bicudo & Menezes, 2005; John & Williamson, 2009) in addition to using some regional floras (Prescott, 1982).

For species listing of these qualitative data, presence/absence data was used for each specific site and can be seen in the tables in this Chapter.

Quantitative analysis

Samples were quantitatively analyzed with a modified Utermöhl chamber counting method (Utermöhl, 1931; Lund et al., 1958), where thick algal mats were homogenized (blended) in distilled water (or salt water), with the final volume recorded. A subsample of 100 ml out of 800 ml to 1 L was taken and standard lugol's solution was added to sediment and stabilize the samples for analysis, preparing it for counts in the inverted microscope. A second sub-sample of 100 ml was also taken, without adding lugols, and frozen (-4°C) for DNA community analyses in a future work. After 3 hours, or enough time for lugol to penetrate the algal cells in the subsample, the sample was homogenized by shaking slowly back and forth for 1 minute, and 5 ml were placed in a sedimentation chamber of equal volume. After 4 hours, for cell sedimentation to the bottom of the chamber, visualization with a Zeiss inverted microscope for counting was used.

Algal counts of periphyton were analyzed using a Zeiss inverted microscope, counting a minimum of 500 cells/valves (cell cm⁻²). These were recorded and a formula proposed by Wetzel & Likens (1979) modified by Schwarzbald (1992) was used to determine the number of algal cells cm⁻²:

$$N = \frac{n * V}{v * (1/S)}$$

where:

N = number of individuals per cm²

n = total number of individuals counted in the sample

V = volume of the sample with scraped material in ml

v = volume of the counted fields

S = surface of the substrate in cm²

Statistical treatment

The results were initially evaluated using descriptive statistics, with graphs of means and histograms. Percentages were calculated by dividing the group in question by the overall total.

Life History Classification

Each taxon identified in this studied was determined to contain a life form, mode of attachment or absence, habit, and be microscopic or macroscopic. To verify these attributes, the following literature was used: Prescott (1982), Krammer & Lange-Bertalot (1986, 1988, 1991, 1991), Round et al. (1990), Komárek & Anagnostidis (1998, 2005), Bicudo & Menezes (2005), Brodie et al. (2007), and John & Williamson (2009). This classification information is provided in Appendices 1-4.

Diversity

For analyzing the diversity of each of the locations, species-area curves were constructed and compared. Species-area curves show the relationship between the areas of a habitat, in this case an ATSTM, and the cumulative number of species that are found within that area. This representation is relevant since diversity and the shape this curve arise from ecological interactions and adaptations at the community level of organization (Rosenzweig, 1995). Species area curves are an expression of the diversity of a community; they are the most robust phenomena in the ecological literature (Odum, 1971). Diversity is depicted in the species-area curve by the slope of the graph, along with the absolute value of number of species (Rosenzweig, 1995). Based on a subjective assessment of the annual cycle of species diversity, it was decided to the species into two parts. Thus, the year was divided into two parts, Spring-Summer and Autumn-Winter, and the species-lists were randomized, sampled in triplicate and species area curves were constructed to compare the diversity among the sites.

To calculate similarity between sites the number of taxa shared between sites were divided by the total number of taxa from those particular sites. For example, the VIMS ATSTM and the plankton contain a total of 116 total taxa, though they share 31 taxa, thus $31/116 \approx 27\%$ of similarity between these two assemblages.

Results

ATSTM at the Boat Basin of the Virginia Institute of Marine Science

Source communities

With the attempt to understand origin of the taxa which inhabit the algal turf on these engineered systems, the phytoplankton, sediments, and epiphytes on macroalgae at VIMS were sampled (Figure 2.1: showing a conceptual model of species-pool habitats) as described in the Materials and Methods. In Table 2.1, all 112 species found in the VIMS habitats are presented. When analyzing the similarity of the aggregated list among all the sites, it was found that 12.5% of the taxa (14 taxa) are shared among all three sites. Twenty-one taxa (18.8%) are shared between two sites (without distinguishing which sites). Considering sites that share taxa, overall 31.3% (35 taxa) of the taxa are shared among 2 or 3 sites, which means that roughly 69% of the taxa are found in one distinct habitat.

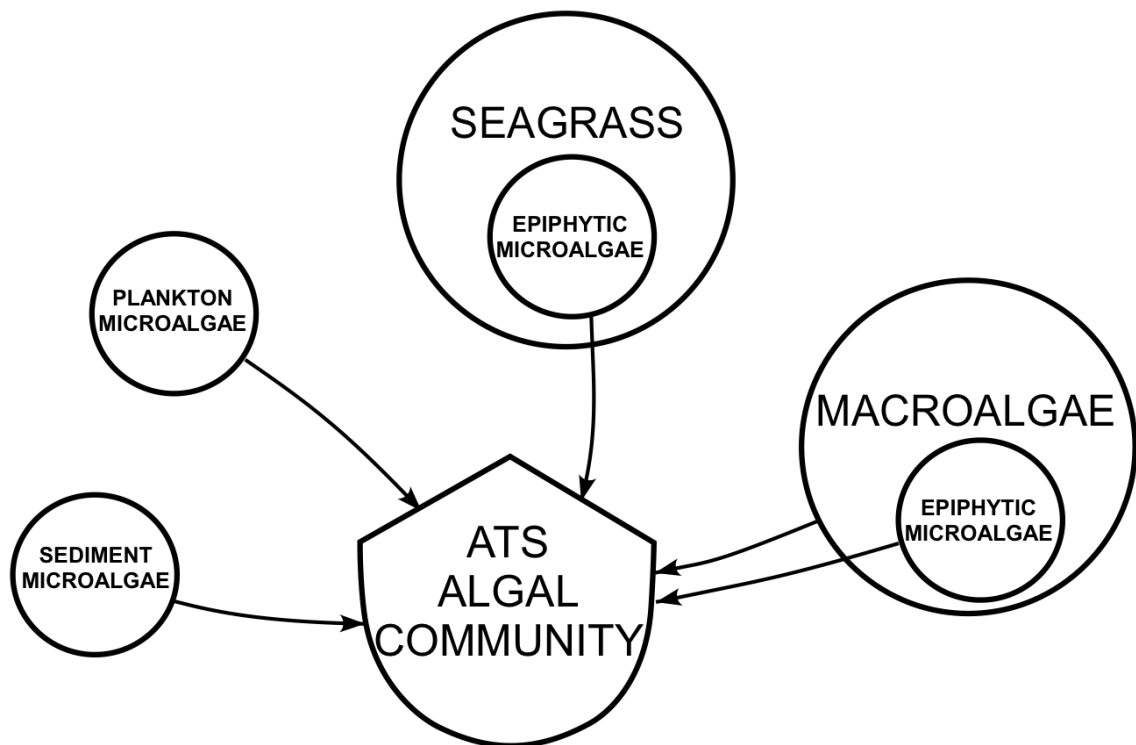


Figure 2.1. Conceptual model of species-pool habitats that can colonize the ATS™.

Table 2.1. List of species found in the source communities ('species-pool') at VIMS.

Species	Plankton	Sediment	Epiphyte
Cyanobacteria			
<i>Aphanothece minutissima</i>	1		
<i>Johannesbaptista pellucida</i>			1
<i>Leptolyngbya</i> sp.		1	1
<i>Lyngbya salina</i>			1
<i>Oscillatoria</i> sp.			1
<i>Pseudanabaena</i> sp.	1		1
Dinophyta			
<i>Protoperidinium</i> sp.	1		
Chlorophyta			
<i>Cladophora</i> sp.			1
<i>Pseudendoclonium submarinum</i>			1
<i>Ulothrix</i> sp.			1
<i>Ulva intestinalis</i>			1
Bacillariophyta			
<i>Achnanthes</i> sp.	1	1	1
<i>Actinocyclus octonarius</i>	1		
<i>Actinocyclus subtilis</i>	1		
<i>Actinopytichus senarius</i>	1		
<i>Amphipleura</i> sp.			1
<i>Amphora</i> sp.	1	1	1
<i>Asterionellopsis</i> sp.	1		
<i>Auliscus</i> cf. <i>sculptus</i>	1		
<i>Auliscus</i> sp.	1		
<i>Bacillaria paxillefer</i>	1	1	1
<i>Bacteriastrum</i> sp.	1		
<i>Berkeleya fennica</i>	1		
<i>Berkeleya rutilans</i>	1		1
<i>Caloneis aemula</i>	1		
<i>Chaetoceros aequatorialus</i>	1		
<i>Chaetoceros compressus</i>	1		
<i>Chaetoceros danicus</i>	1		
<i>Chaetoceros deciepens</i>	1		
<i>Chaetoceros lorenzianus</i>	1		
<i>Chaetoceros</i> spp.	1		1
<i>Cocconeis</i> sp.	1	1	1
<i>Coscinodiscus radiatus</i>	1	1	1
<i>Cyclotella</i> cf. <i>caspia</i>	1		
<i>Cylindrotheca closterium</i>	1	1	1
<i>Cymbella</i> sp.	1		
<i>Cymbellonitzschia</i> sp.	1		

<i>Dactyliosolen</i> sp.	1		
<i>Delphineis</i> sp.	1		
<i>Dimeregramma minor</i>		1	
<i>Diploneis</i> sp.		1	1
<i>Ditylum brightwellii</i>	1	1	1
<i>Entomoneis</i> sp.	1		
<i>Eunotogramma laevis</i>		1	
<i>Fallacia</i> sp.		1	
<i>Fragilaria pulchella</i> var. <i>constricta</i>	1		
<i>Fragilaria</i> sp.	1		1
<i>Grammatophora</i> sp.			1
<i>Gomphonema</i> sp.	1	1	
<i>Guinardia flaccida</i>	1		
<i>Gyrosigma</i> sp.	1	1	1
<i>Gyrosigma</i> sp.2		1	
<i>Leptocylindrus danicus</i>	1		
<i>Licmophora</i> sp. (short)	1	1	1
<i>Licmophora</i> sp. (long)			1
<i>Lyrella</i> sp.		1	
<i>Mastogloia</i> sp.	1	1	
<i>Melosira monoliformes</i>	1		1
<i>Melosira nummuloides</i>	1		1
<i>Meunieria</i> sp.		1	
<i>Navicula arenaria</i> var. <i>rostellata</i>	1	1	
<i>Navicula capitoradiata</i>		1	
<i>Navicula celinei</i>	1		
<i>Navicula duerrenbergiana</i>		1	
<i>Navicula gregaria</i>		1	
<i>Navicula smithii</i>		1	1
<i>Navicula</i> sp.	1	1	1
<i>Navicula vaneii</i>		1	
<i>Neocalyptrella robusta</i>	1		
<i>Nitzschia</i> cf. <i>circumscribita</i>	1		
<i>Nitzschia fasciculata</i>	1		
<i>Nitzschia filiformis</i>		1	
<i>Nitzschia frustulum</i>	1		
<i>Nitzschia longissima</i>		1	
<i>Nitzschia scalpelliformis</i>		1	1
<i>Nitzschia sigma</i>	1	1	
<i>Nitzschia sigmaformis</i>	1		
<i>Nitzschia tryblionella</i>			1
<i>Nitzschia valdestriata</i>	1		
<i>Nitzschia ventricosa</i>		1	
<i>Nitzschia</i> sp.	1	1	
<i>Odontella granulata</i>	1		
<i>Odontella mobilensis</i>	1		
<i>Odontella obtusa</i>			1
<i>Opephora burchardtia</i>	1		
<i>Opephora marina</i>	1	1	

<i>Paralia sulcata</i>	1		
<i>Parlibellus</i> sp.		1	
<i>Planothidium</i> sp.		1	
<i>Pleurosigma</i> sp.	1	1	1
<i>Proboscia alata</i>	1		
<i>Pseudonitzscha pungens</i>	1		1
<i>Pseudonitzschia fraudulenta</i>	1		
<i>Pseudostaurosira</i> sp.			1
<i>Rhaphoneis ampiceros</i>	1	1	
<i>Rhaphoneis</i> sp.	1		
<i>Rhizosolenia pungens</i>	1	1	
<i>Rhizosolenia setigera</i>	1		
<i>Rhopalodia</i> sp.	1		1
<i>Skeletonema costatum</i>	1		
<i>Skeletonema marinoi</i>	1		
<i>Stauroneis</i> sp.	1		
<i>Stephanocyclus meneghiana</i>	1		
<i>Surirella brebissonii</i>	1		
<i>Surirella</i> sp.	1		
<i>Synedra</i> sp.	1	1	1
<i>Tabularia tabulata</i>	1		1
<i>Thalassionema nitzschioides</i>	1	1	1
<i>Thalassiosira nordenskiöldii</i>	1		
<i>Thalassiosira</i> sp.	1	1	1
<i>Trachysphenia acuminata</i>	1		
Rhodophyta			
<i>Ceramium</i> sp.			1

Species Diversity

Sixty-eight taxa were found on the flowway at VIMS. The taxonomic distribution of species by species number and cell abundance is shown in Figure 2.2. Diatoms (Bacillariophyta) dominated the algal flora with 82% of the total diversity. Four other algal phyla were represented in the flora with cyanobacteria and chlorophytes contributing 12% and 3%, respectively, to total diversity. Overall, the diatom genera *Berkeleya* and *Melosira* and the green alga genus *Ulva* are the dominant “canopy” species that structure most of the sampled algal communities.

Analyzing the data by abundance, the diatoms also dominate with 83% of the total cell abundance. Cyanobacteria and Chlorophyta were the following abundant groups, with 10% and 7%, of total relative abundance, respectively. The other phyla accumulated to less than 1% of total cells present.

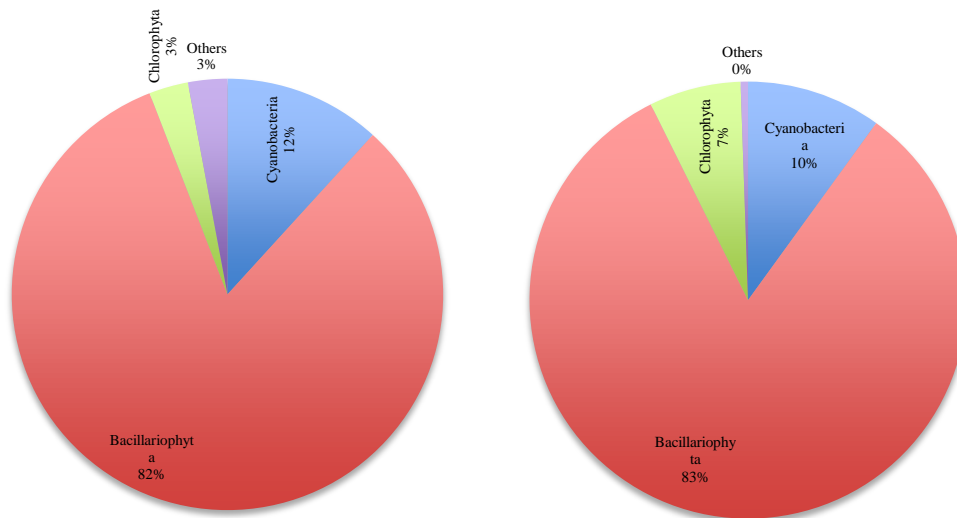


Figure 2.2. Relative composition of different algal phyla at VIMS, (left) by species composition, (right) by cell abundance.

Species-area curves for two seasonal aggregations of samples from the VIMS boat-basin, on-land ATSTTM, are shown in Figure 2.3 (spring-summer samples) and Figure 2.4 (fall-winter samples). In each case the curves have not reached an asymptote after about 400 cm² of sampled area, but they are close to leveling off. Somewhat surprisingly, the shapes of the two curves are similar with a total of about 70 species for the seasonally aggregated communities.

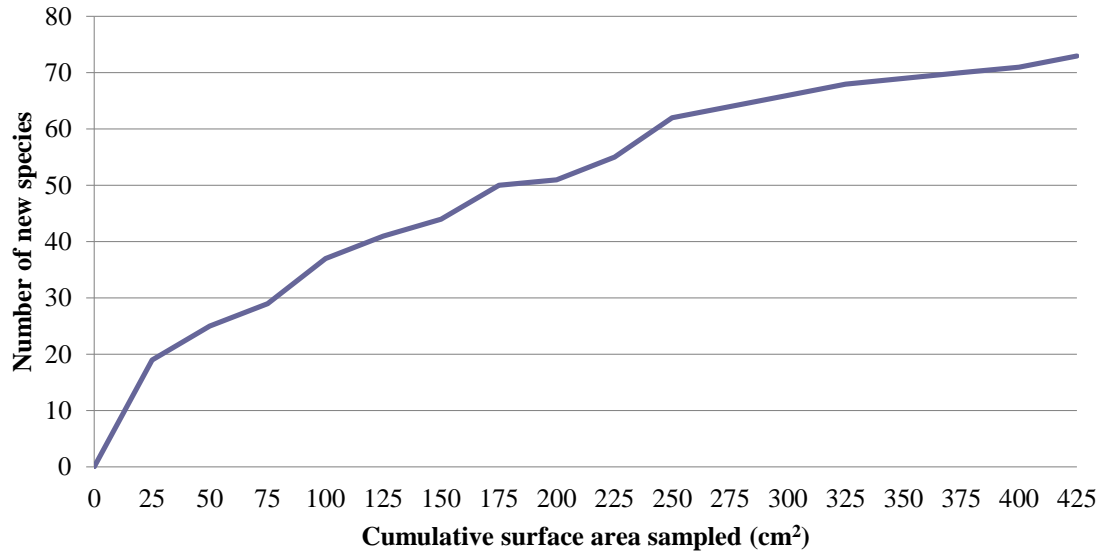


Figure 2.3. Species area curve for the VIMS Boat Basin data set during Spring-Summer.

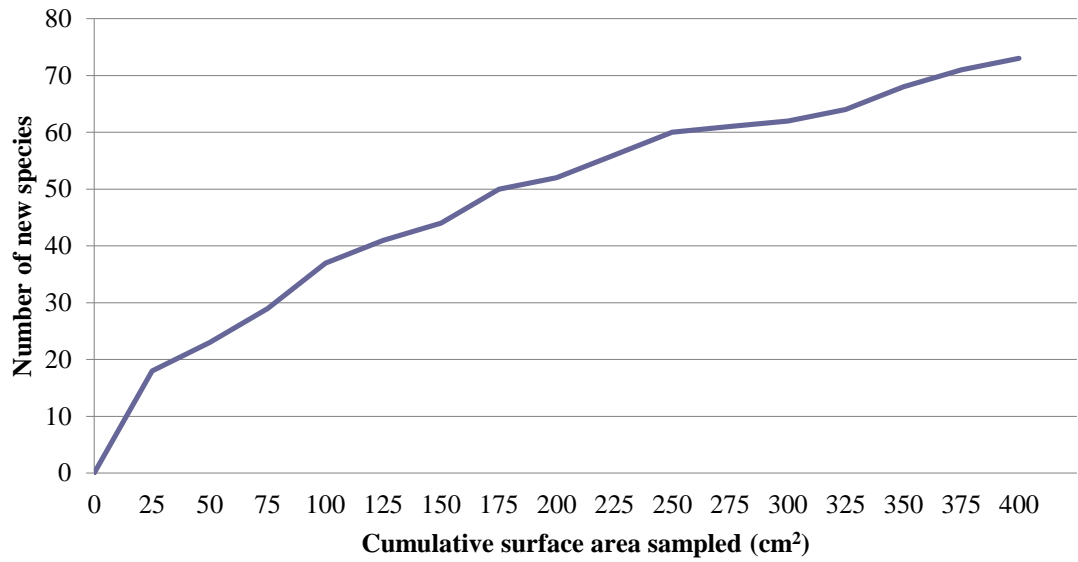


Figure 2.4. Species area curve for the VIMS Boat Basin data set during Fall-Winter.

The distribution of life forms represented in the algal flora is shown in Figure 2.5. Although single-celled, solitary species were the most common at 52% of the total, colonial, filamentous, and chains were well represented.

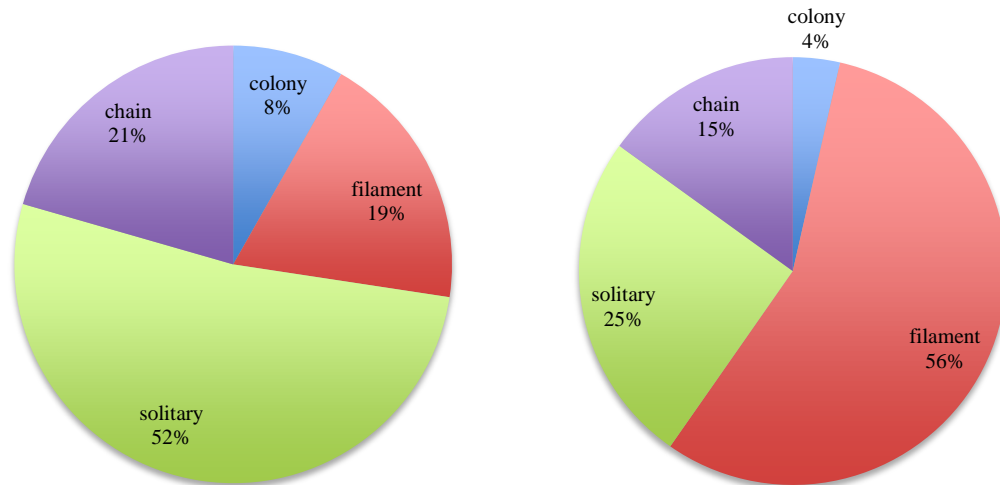


Figure 2.5. Distribution of life forms at VIMS, (left) by species composition, (right) by cell abundance.

Another critical preadaptation of the species that colonize the screen is the mode of attachment. It is important that at least some species become attached to the screen in order to provide stability against the water currents. Several modes of attachment are illustrated in Figure 2.6 and the distribution across the boat basin ATSTM is shown in Figure 2.7. Most species found on the screens lack an attachment adaptation (55%) and those are probably found in the understory of the turf. Mucilage (41%) and special

holdfast cells (4%) are the common attachment preadaptations¹ and these are found in the canopy of the turf.

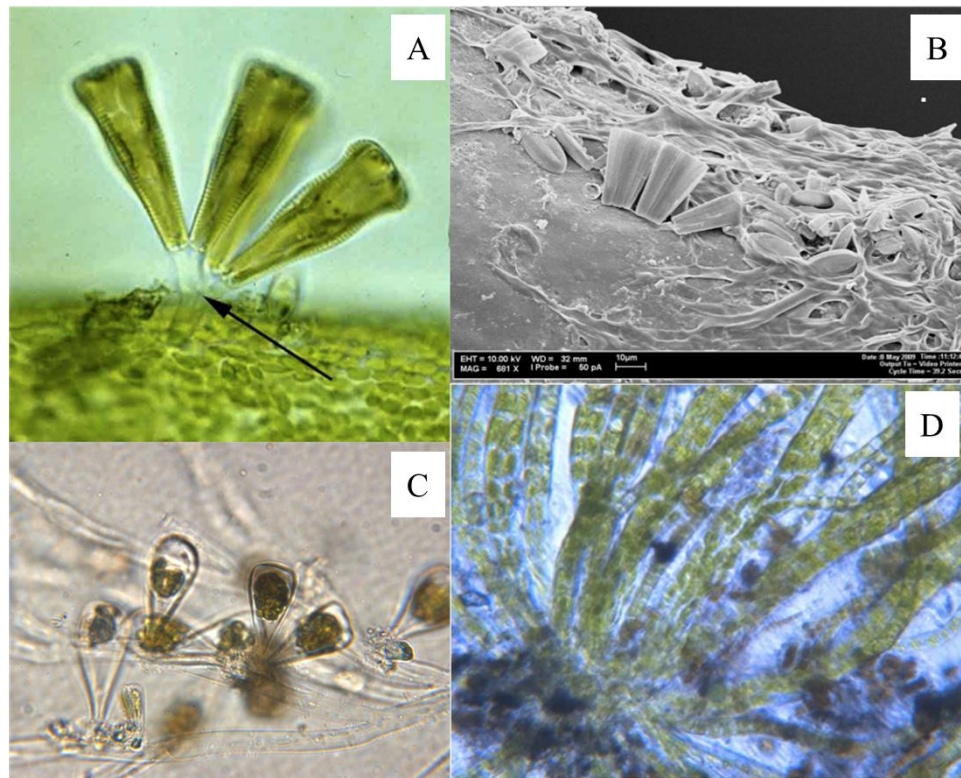


Figure 2.6. Modes of attachment: A) Mucilaginous stalk; B) Mucilage pad and sheath; C) Mucilaginous tube; D) Holdfast.

¹ Attachment pre-adaptations refer to those attachment adaptations in which species have evolved for surviving in their natural habitats over evolutionary time, which they use to their benefit in the artificial ATSTTM flowways.

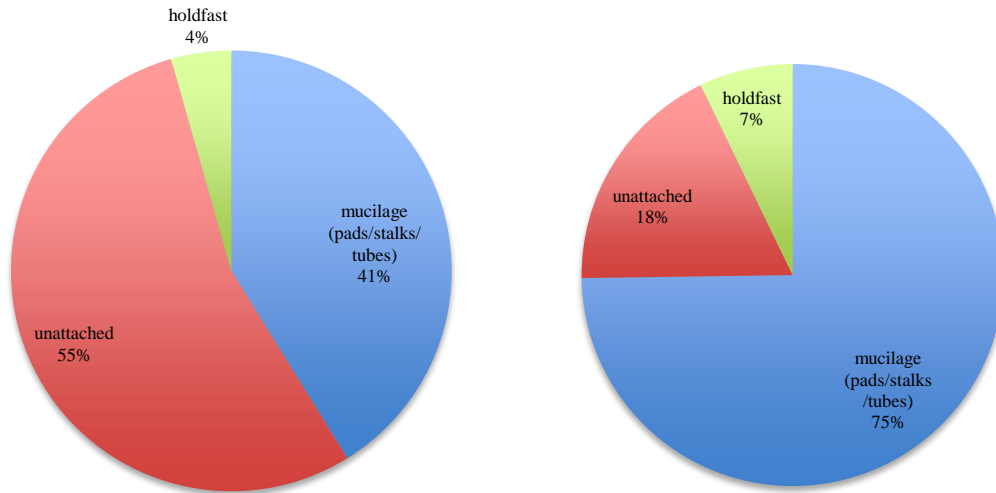


Figure 2.7. Distribution of attachment adaptations at VIMS, (left) by species composition, (right) by cell abundance.

The origins of the algae found on the screens of the algal production systems are shown in Figure 2.8 with names used to describe the habitats of the species. The definitions of the terms are as follows: Benthic – growing on the bottom of a water body, Periphytic – growing attached to a substrate, Metaphytic – growing among the periphyton, Epiphytic – growing on a plant, Planktonic – growing suspended in the water column, Epilithic – growing on rock/stone, Epipellic – growing on mud, and Epipsammic – growing on sand. Although algae on the screens of the production systems come from a variety of habitats, the dominant species (filamentous diatoms and chlorophytes) are either epiphytic (36%) or benthic (53%).

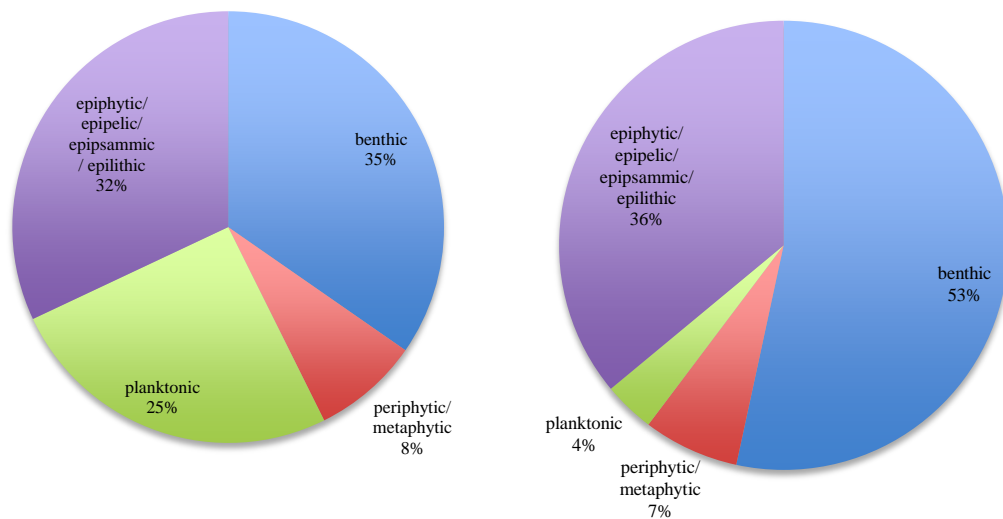


Figure 2.8. Distribution of types of habits of the algal associated to the VIMS algal turf systems, (left) by species composition, (right) by cell abundance.

A final characteristic of the flora relates to the relative size of the taxa – macroscopic versus microscopic. Figure 2.9 shows the distribution of sizes with a strong dominance of microalgae on the screens. Some of the dominant macroalgae from the intertidal zone of the Chesapeake Bay (see Discussion) are found on the screens, but they seldom dominate the communities, and possibly the frequent harvesting inhibits their development.

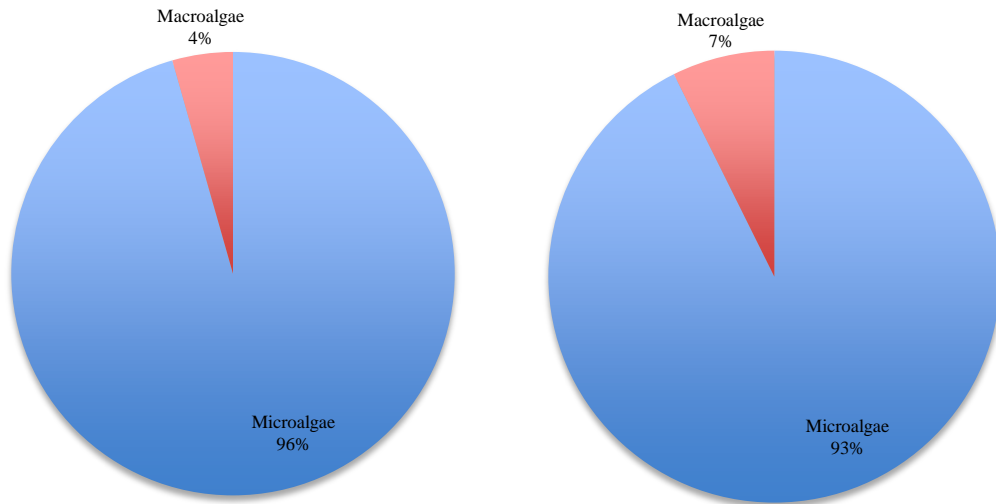


Figure 2.9. Relative contribution of microalgae vs. macroalgae at VIMS, (left) by species composition, (right) by cell abundance.

Algal abundance

The most abundant algal group on the system during the study period was Bacillariophyta (diatoms) with 83% of total relative abundance (Figures 2.10 & 2.11). Cyanobacteria and Chlorophyta were the next most abundant groups, with 10% and 7%, of total abundance, respectively. The other phyla accumulated to less than 1% of total cell numbers.

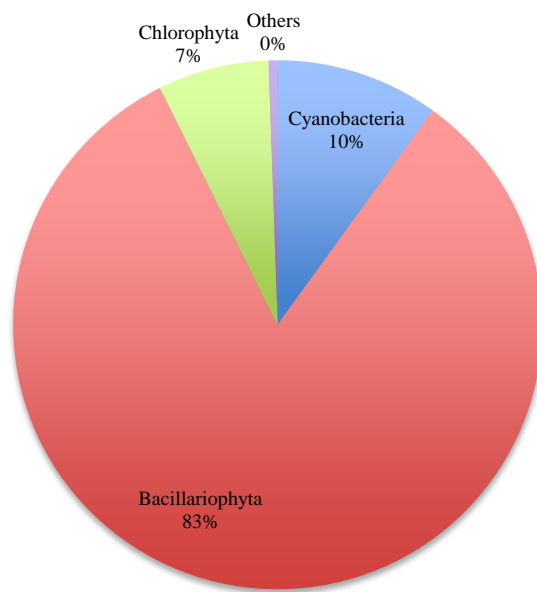


Figure 2.10. Relative abundance of algal species by phyla on the VIMS ATS™.

The average community structure data is shown in Table 2.2. Raw data by sample date can be found in Appendices 5-11. The most abundant taxa (by relative abundance values) were *Berkeleya* spp. (*B. fennica* and *B. rutilans*) (40%), *Melosira* spp. (*M. monoliformis* and *M. nummuloides*) (9%), *Ulva intestinalis* (7%), *Nitzschia* spp. (6%), *Stauronella* sp. (5%), *Navicula* spp. (4%), and *Calothrix* sp. (4%). The other taxa occurring on the flowway accounted for 3% or less of total abundance each.

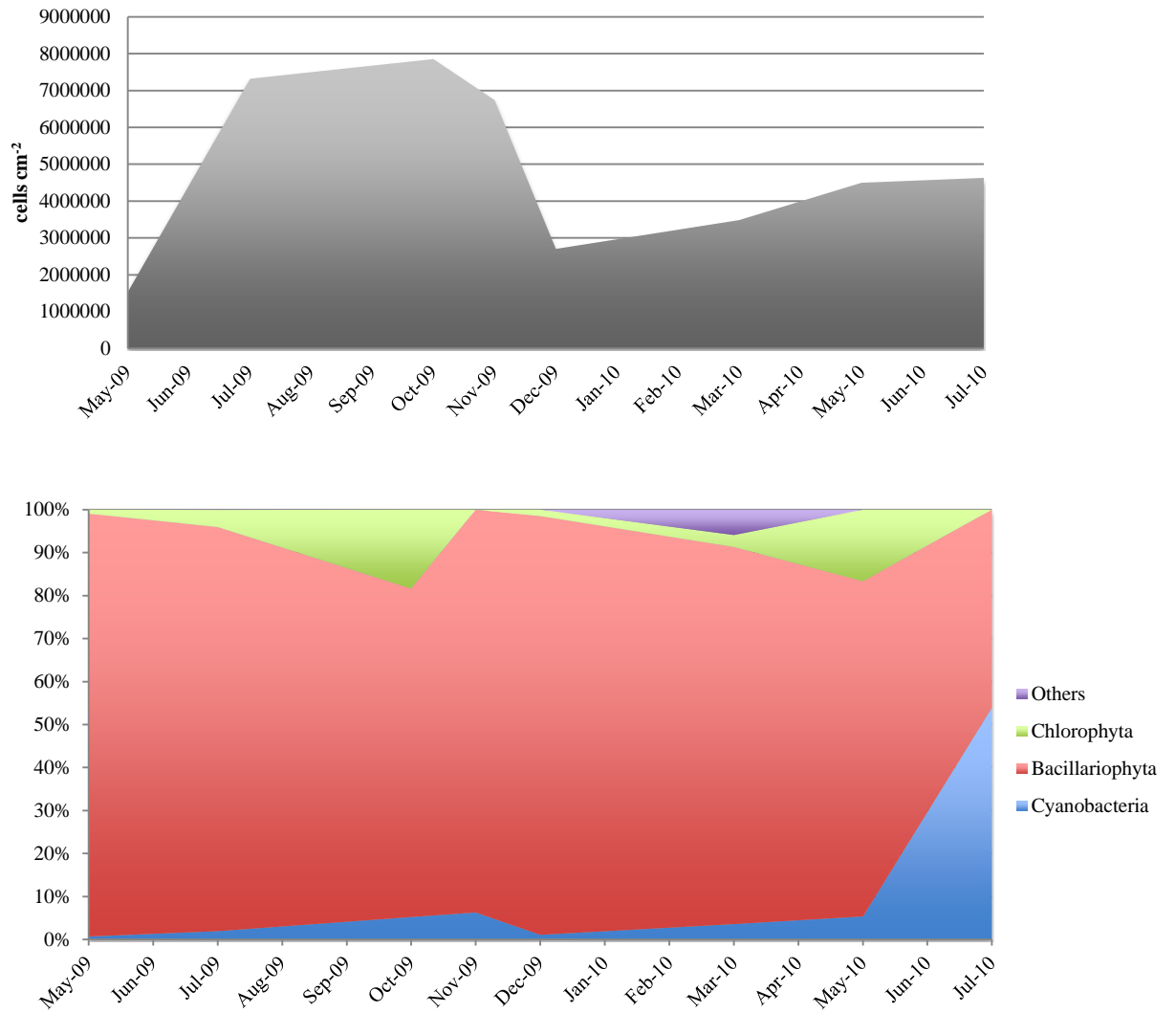


Figure 2.11. Change with time (May 2009 – July 2010) of (top) total community abundance and (bottom) of algal relative abundance, by phyla for the VIMS ATSTM.

Table 2.2. Algal community structure on the VIMS Boat Basin floway during 2009-2010. Density values are numbers of individuals x 10³ per square centimeter of screen surface. Numbers in parentheses are percentage of the total (diatom + non-diatom) average density. Frequency is the number of occurrence among the 7 sample dates.

Species	Average Density	Frequency
Diatoms		
<i>Berkeleya rutilans</i>	955 (49)	7/7
<i>Melosira nummuloides</i>	162 (8)	7/7
<i>Stauronella</i> sp.	88 (5)	1/7
<i>Navicula</i> sp.	58 (3)	7/7
<i>Melosira monoliformes</i>	49 (3)	5/7
<i>Nitzschia</i> sp.	40 (2)	7/7
<i>Nitzschia</i> sp. (long)	38 (2)	1/7
<i>Licmophora</i> sp. 1	34 (2)	5/7
<i>Achnanthes brevipes</i>	29 (2)	2/7
<i>Entomoneis</i> sp.	25 (1)	4/7
<i>Achnanthes</i> sp.	21 (1)	6/7
<i>Gyrosigma</i> sp.	21 (1)	3/7
<i>Fragilariopsis</i> sp.	19 (1)	3/7
<i>Amphora</i> sp.	19 (1)	7/7
<i>Grammatophora</i> sp.	15 (1)	3/7
<i>Nitzschia nana</i>	11 (1)	2/7
<i>Thalassosira</i> sp.	10 (1)	5/7
<i>Coscinodiscus</i> sp.	9 (<1)	7/7
<i>Navicula smithii</i>	9 (<1)	2/7
<i>Pseudonitzschia</i> cf. <i>multiseries</i>	9 (<1)	1/7
<i>Tabularia</i> sp.	7 (<1)	4/7
<i>Licmophora</i> sp. 2	7 (<1)	3/7
<i>Actinoptychus</i> sp.	7 (<1)	2/7
<i>Navicula</i> sp. (small)	7 (<1)	1/7
<i>Skeletonema costatum</i>	6 (<1)	3/7
<i>Pseudonitzschia</i> sp.	6 (<1)	2/7
<i>Bacillaria paxillifer</i>	5 (<1)	3/7
<i>Pseudonitzschia</i> cf. <i>pungens</i>	5 (<1)	1/7
<i>Plagiotropis</i> sp.	5 (<1)	1/7
<i>Cyclotella</i> sp.	4 (<1)	6/7
<i>Minidiscus</i> sp.	4 (<1)	5/7
<i>Stauroneis</i> sp.	4 (<1)	2/7
<i>Nitzschia</i> sp. 2	4 (<1)	1/7
<i>Nitzschia</i> sp. (small)	3 (<1)	1/7
<i>Cocconeis</i> sp.	2 (<1)	4/7
<i>Haslea</i> sp.	2 (<1)	1/7
<i>Cymbella</i> sp.	1 (<1)	4/7
<i>Fragilaria</i> sp.	1 (<1)	2/7
Unidentified diatom	1 (<1)	2/7
<i>Amphora</i> sp. (small)	1 (<1)	1/7
<i>Nitzschia</i> sp. (mid)	1 (<1)	1/7

<i>Pinnularia</i> sp. (small)	1 (<1)	1/7
<i>Eucampia</i> sp.	1 (<1)	1/7
<i>Melosira</i> sp.	1 (<1)	1/7
<i>Cylindrotheca closterium</i>	1 (<1)	1/7
<i>Pinnularia</i> sp.	1 (<1)	1/7
<i>Navicula</i> sp. (mid)	1 (<1)	1/7
<i>Chaetoceros</i> sp.	1 (<1)	1/7
<i>Diploneis</i> sp.	<1 (<1)	2/7
<i>Nitzschia</i> sp. 3	<1 (<1)	1/7
<i>Caloneis/Luticola</i> sp.	<1 (<1)	1/7
<i>Hantzschia</i> sp.	<1 (<1)	1/7
<i>Staurosira</i> sp.	<1 (<1)	1/7
<i>Gomphenema</i> sp.	<1 (<1)	1/7
<i>Luticola</i> sp.	<1 (<1)	1/7
<i>Surirella</i> sp.	<1 (<1)	1/7
<i>Ctenophora</i> sp.	<1 (<1)	1/7
Unidentified pennate diatom	<1 (<1)	1/7
<i>Tabularia tabulata</i>	<1 (<1)	1/7
<i>Sellaphora</i> sp.	<1 (<1)	1/7
<i>Pleurosigma</i> cf. <i>fasciola</i>	<1 (<1)	1/7
<i>Achnantheidium minutissimum</i>	<1 (<1)	1/7
<i>Cylindrotheca</i> sp.	<1 (<1)	1/7
<i>Opephora</i> sp.	<1 (<1)	1/7
Total	1711 (87)	

Non-Diatoms

<i>Ulva intestinalis</i>	149 (8)	6/7
<i>Calothrix</i> sp.	37 (2)	3/7
<i>Oscillatoria</i> sp.	14 (1)	3/7
<i>Ceramium</i> sp.	10 (1)	1/7
<i>Pseudanabaena</i>	6 (<1)	1/7
<i>Ulothrix</i> sp.	2 (<1)	1/7
<i>Nodularia</i> sp.	1 (<1)	1/7
<i>Peridinium</i> sp.	<1 (<1)	1/7
<i>Cyanosarcira</i> sp.	<1 (<1)	1/7
<i>Leptolyngbya</i> sp.	<1 (<1)	1/7
<i>Phormidium</i> sp.	<1 (<1)	1/7
Total	220 (13)	

Great Wicomico River ATSTM

Algal Turf Scrubber Floway 1

Species Diversity

One hundred twenty species were found at the Great Wicomico River ATSTM over both floways. The taxonomic distribution of species by species number and cell abundance found on Floway 1 of the Great Wicomico River ATSTM is shown in Figure 2.12. Diatoms (Bacillariophyta) dominate the diversity of the algal flora with 77 % of the total diversity. Six other algal phyla were represented in the flora with cyanobacteria and chlorophytes contributing 13% and 5%, respectively, of total diversity.

Although the diversity of diatoms reached 75%, its relative abundance values were only 51% of the total biomass. Another interesting fact is that chlorophytes and cyanobacteria were 27% and 21% of the total abundance, respectively, with the other phyla roughly 1%. Comparing these two charts, it is noticed that even though the cyanobacteria and chlorophytes were not so diverse, their abundance was high.

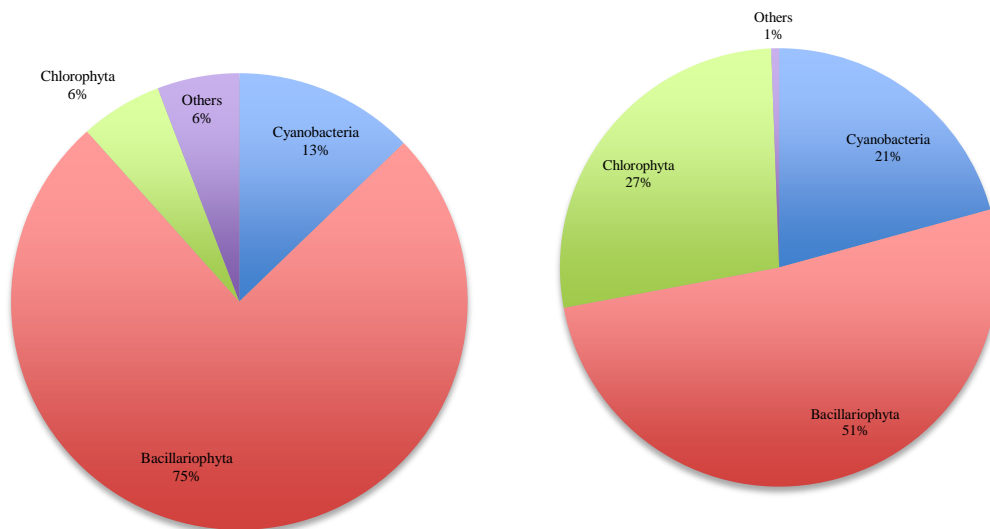


Figure 2.12. Relative composition of different algal phyla on Floway 1 at Wicomico, (left) by species composition, (right) by cell abundance.

As previously stated, species-area curves can be used to examine the diversity of a particular community. Species-area curves for two seasonal aggregations of samples from the Great Wicomico River ATSTM Floway 1 are shown in Figure 2.13 (spring-summer samples) and Figure 2.14 (fall-winter samples). In each case the curves have not reached an asymptote after about 400 cm² of sampled area (spring-summer) and 125 cm² (fall-winter), though the prior is close.

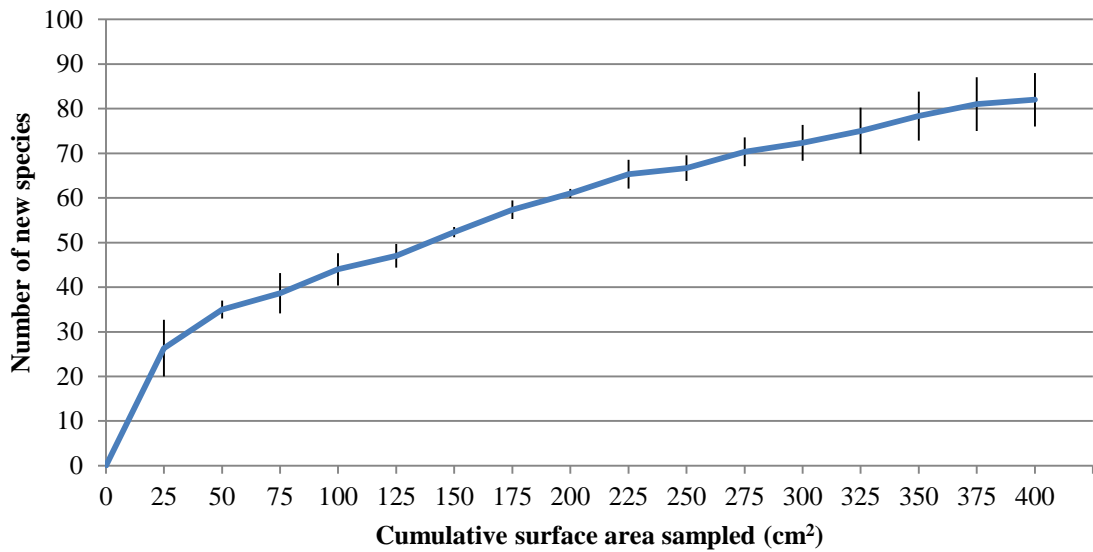


Figure 2.13. Species area curve for the Wicomico Floway 1 data set during Spring-Summer.

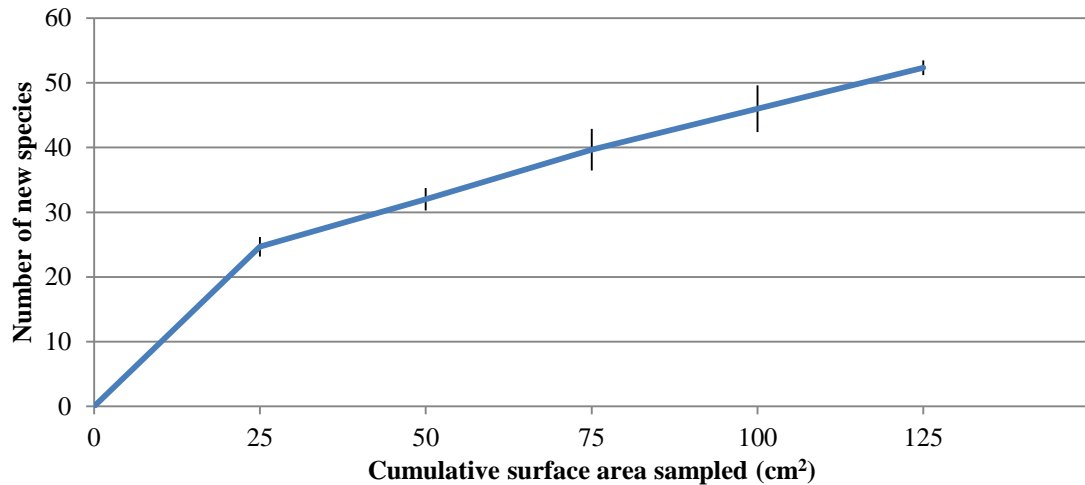


Figure 2.14. Species area curve for the Wicomico Floway 1 data set during Fall-Winter.

The distribution of life forms represented in the algal flora is shown in Figure 2.15. Although single-celled, solitary species were the most common at 55% of the total, colonial, filamentous, and colonies were well represented. As previously stated, life forms are important in determining the structure of the turf communities. The filamentous species along with the chain-forming species to a lesser degree comprise the overstory of the turf, which generally give the physical character to the turf. The remaining life forms are found in the understory.

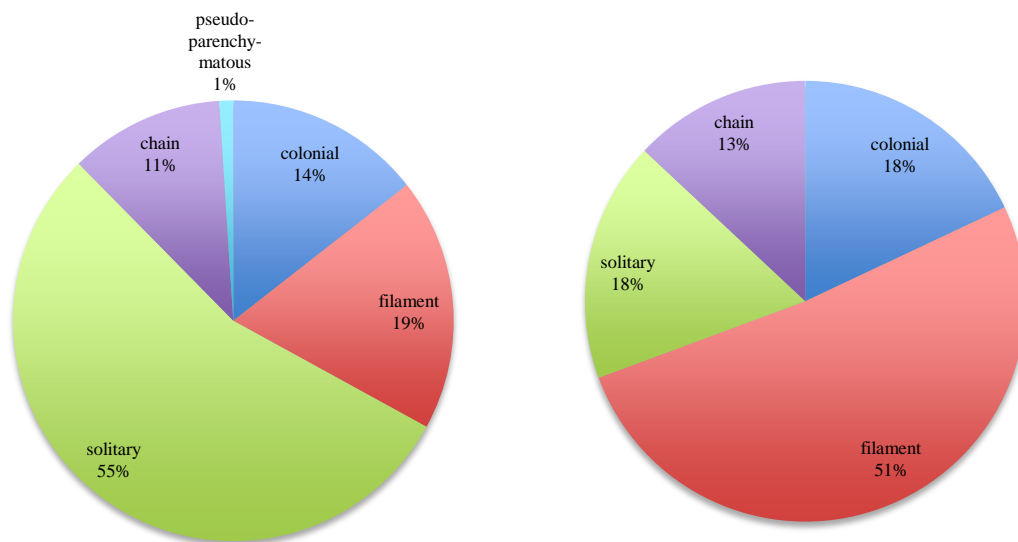


Figure 2.15. Distribution of life forms at Floway 1 at Wicomico, (left) by species composition, (right) by cell abundance.

Species that colonize the screen possess a mode of attachment, and it is important that at least some species become physically attached to the screen for stability. Most

species found on the screens lack an attachment adaptation (52%) and those are probably found in the understory of the turf. Mucilage (41%) and special holdfast cells (7%) are common attachment pre-adaptations and these are found in the canopy of the turf (Figure 2.16).

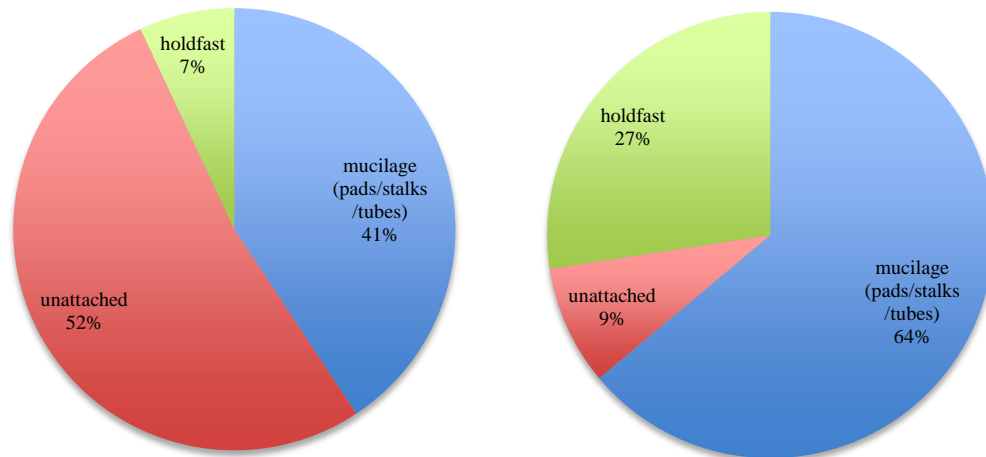


Figure 2.16. Distribution of attachment adaptations on Floway 1 at Wicomico, (left) by species composition, (right) by cell abundance.

The origins of the algae found on the screens of the algal production systems are shown in Figure 2.17 with names used to describe the habitats of the species. Most species are either benthic or grow attached to a substrate.

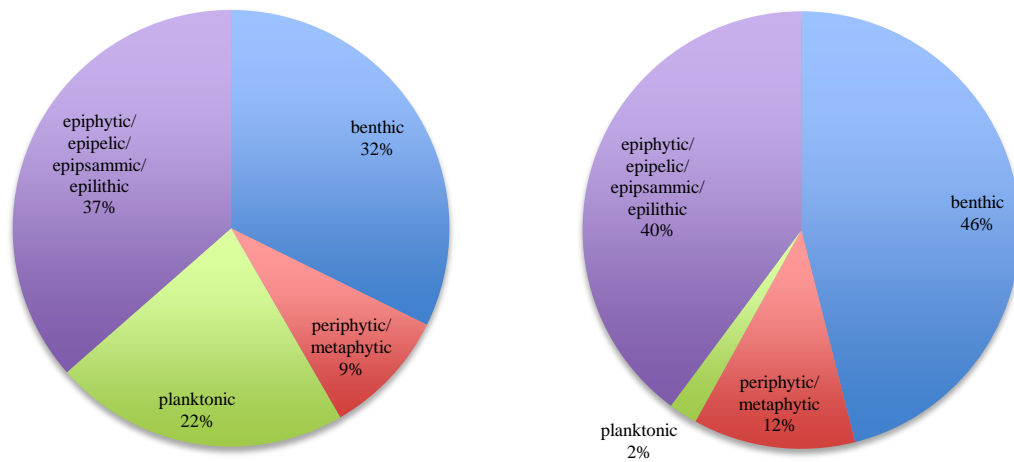


Figure 2.17. Distribution of types of habitats of the algae associated to Floway 1 at Wicomico.

A final characteristic of the flora relates to the relative size of the taxa – macroscopic versus microscopic. Figure 2.18 shows the distribution of sizes with a strong dominance of microalgae on the screens. Some of the dominant macroalgae from the intertidal zone of the Chesapeake Bay (Orris, 1980) are also found on these screens, e.g. species of *Ceramium*, *Cladophora*, *Polysiphonia*, and *Ulva*, but they seldom dominate the communities.

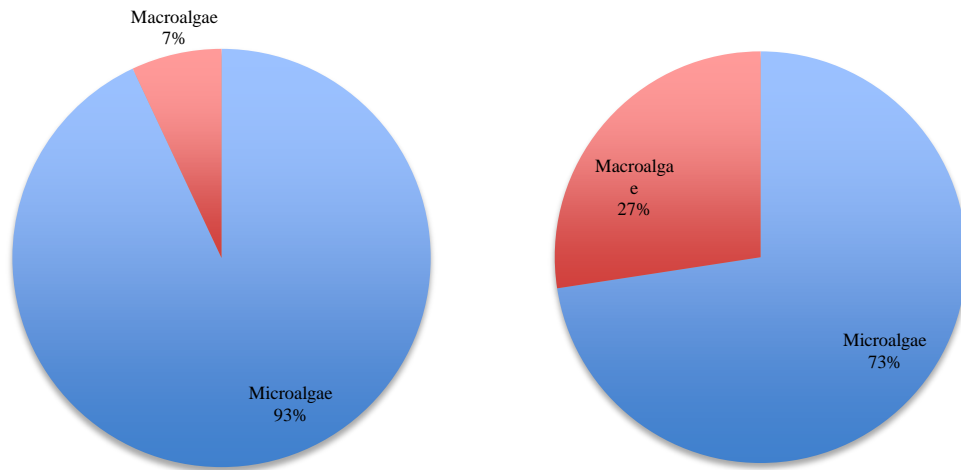


Figure 2.18. Relative contribution of microalgae vs. macroalgae on Floway 1 at Wicomico.

Algal Abundance

The most abundant algal group on Floway 1 during the study period was Bacillariophyta (diatoms) with 53% of total relative abundance (Figures 2.19 & 2.20). Chlorophyta and Cyanobacteria followed as the next most abundant groups, with 24% and 22%, of total abundance, respectively. The other phyla accumulated to roughly 1% of total relative abundance.

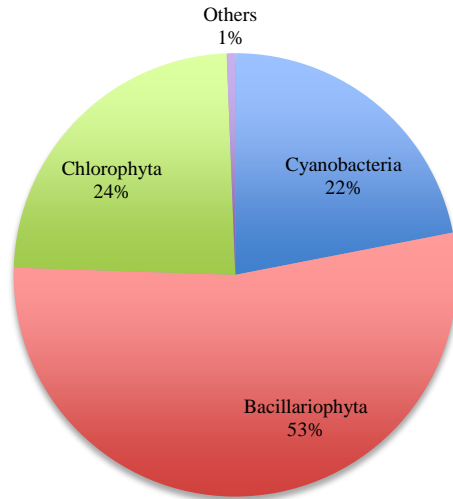


Figure 2.19. Relative abundance of algal species by phyla on Floway 1.

The average community structure data is shown in Table 2.3. Raw data by sample date can be found in Appendix 12. The most abundant taxa (by relative abundance values) were *Berkeleya* spp. (*B. fennica*, *B. fragilis*, and *B. rutilans*) (20%), *Gloeotheca* sp. (13%), *Ulva intestinalis* (10%), *Ulothrix* sp. (9%), *Melosira* spp. (*M. moniliformis* and *M. nummuloides*) (9%), *Lyngbya* cf. *salina* (7%) and *Achrochaete* sp. (7%). The other taxa occurring on the floway each accounted for 2% or less of total abundance. The most frequent taxa (occurring >84% of samplings) were *Achnanthes* spp. (i.e., *Achnanthes brevipes*), *Amphora* spp., *Berkeleya rutilans*, *Mastogloia* spp., *Melosira nummuloides*, *Stauronella* sp., *Navicula* spp., and *Grammatophora* spp.

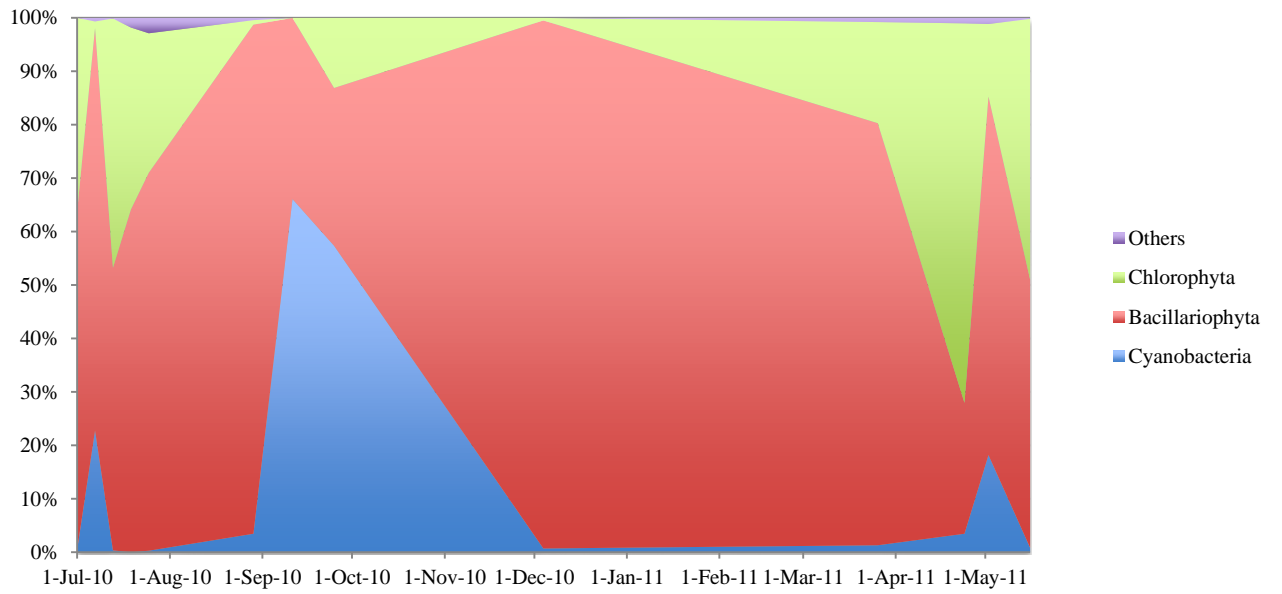
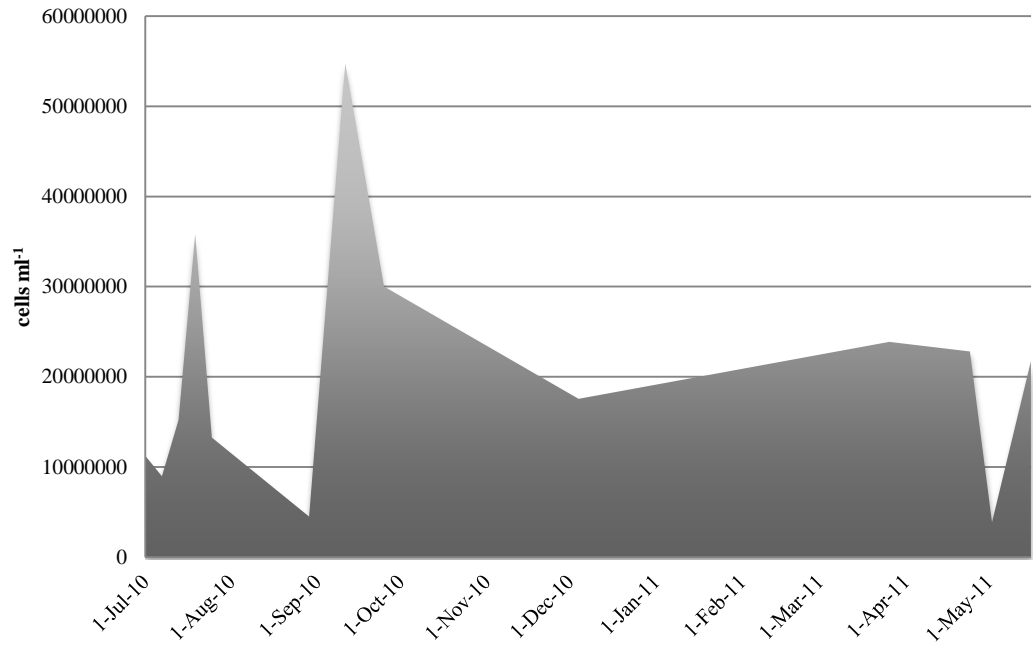


Figure 2.20. Change with time (July 2010 – June 2011) of (top) total community abundance and (bottom) of algal relative abundance, by phyla for Floway 1.

Table 2.3. Algal community structure on the Great Wicomico Floway 1 during 2010-2011. Density values are numbers of individuals per milliliter. Numbers in parentheses are percentage of the total (diatom + non-diatom) average density. Frequency is the number of occurrence among the 13 sample dates.

Species	Total Average	Frequency
Diatoms		
<i>Berkeleya rutilans</i>	3638296 (17)	13/13
<i>Melosira nummuloides</i>	1165780 (5)	12/13
<i>Melosira monoliformes</i>	938483 (4)	7/13
<i>Amphora</i> sp.	535882 (2)	13/13
<i>Licmophora</i> sp. (short)	504087 (2)	8/13
<i>Nitzschia sigma</i>	429808 (2)	3/13
<i>Stauronella</i> sp.	359995 (2)	13/13
<i>Berkeleya fennica</i>	357531 (2)	1/13
<i>Achnanthes</i> sp.	356268 (2)	13/13
<i>Licmophora</i> sp. (long)	325694 (2)	7/13
<i>Tabularia tabulata</i>	279569 (2)	9/13
<i>Achnantheidium minutissimum</i>	264197 (1)	4/13
<i>Nitzschia sigmoidea</i>	231126 (1)	4/13
<i>Grammatophora</i> sp.	207207 (1)	12/13
<i>Berkeleya fragilis</i>	180789 (1)	2/13
<i>Nitzschia</i> sp.	162396 (1)	10/13
<i>Thalassionema nitzschiodes</i>	154625 (1)	3/13
<i>Navicula</i> sp.	133385 (1)	11/13
<i>Thalassiosira</i> sp.	114222 (1)	7/13
<i>Mastogloia</i> sp.	92254 (<1)	13/13
<i>Nitzschia nana</i>	67072 (<1)	5/13
<i>Nitzschia sigmaformis</i>	51568 (<1)	3/13
<i>Fragilaria</i> sp.	49012 (<1)	4/13
Centrales	38789 (<1)	1/13
<i>Cocconeis</i> sp.	36950 (<1)	7/13
<i>Cylindrotheca closterium</i>	28161 (<1)	5/13
<i>Rhopaloidia</i> sp.	22743 (<1)	3/13
<i>Navicula smithii</i>	22093 (<1)	3/13
<i>Coscinodiscus</i> sp.	20695 (<1)	7/13
<i>Nitzschia fusiliformis</i>	20238 (<1)	1/13
<i>Fogedia</i> sp.	14166 (<1)	2/13
<i>Nitzschia filiformis</i>	14166 (<1)	1/13
<i>Catenula</i> sp.	14054 (<1)	2/13
<i>Neodelphineis</i> sp.	13792 (<1)	2/13
<i>Cymatosira</i> sp.	13492 (<1)	1/13
<i>Nitzschia scalpelliformis</i>	10793 (<1)	1/13
<i>Epithemia</i> sp.	10456 (<1)	3/13
<i>Bacillaria paxillifer</i>	9123 (<1)	3/13
<i>Lyrella</i> sp.	8770 (<1)	2/13
<i>Psammothidium</i> sp.	8095 (<1)	1/13
<i>Nitzschia longissima</i>	8095 (<1)	1/13
<i>Opephora</i> sp.	7830 (<1)	3/13
<i>Parlibellus</i> sp.	7495 (<1)	1/13

<i>Pinnularia</i> sp.	6558	(<1)	4/13
<i>Skelatonema costatum</i>	6071	(<1)	1/13
<i>Synedra</i> sp.	6071	(<1)	1/13
<i>Cyclotella</i> sp.	6020	(<1)	3/13
<i>Diploneis</i> sp.	5895	(<1)	3/13
<i>Rhizosolenia</i> sp.	5782	(<1)	1/13
<i>Achnanthes brevippes</i>	5397	(<1)	2/13
<i>Gyrosigma</i> sp.	5118	(<1)	3/13
<i>Podocystis</i> sp.	4818	(<1)	2/13
<i>Denticula</i> sp.	4553	(<1)	2/13
<i>Entomoneis</i> sp.	4497	(<1)	1/13
<i>Actinoptychus senarius</i>	3855	(<1)	2/13
<i>Staurosirella</i> sp.	3148	(<1)	2/13
<i>Fragilaria martyii</i>	2998	(<1)	1/13
<i>Camplyodiscus</i> sp.	2530	(<1)	1/13
<i>Ditylum brightwellii</i>	2024	(<1)	1/13
<i>Minidiscus</i> sp.	1927	(<1)	1/13
<i>Rhaphoneis</i> sp.	1927	(<1)	1/13
Unidentified diatom	1927	(<1)	1/13
<i>Eunotogramma laevis</i>	1499	(<1)	1/13
<i>Caloneis</i> sp.	1446	(<1)	1/13
<i>Sieminskia</i> sp.	1446	(<1)	1/13
Total	11014749		

Non-Diatoms

<i>Gloeothece</i> sp.	2695647	(13)	1/13
<i>Ulva intestinalis</i>	2238898	(10)	8/13
<i>Ulothrix</i> sp.	2008243	(9)	3/13
<i>Achrochaete</i> sp.	1453359	(7)	3/13
<i>Lyngbya salina</i>	1438893	(7)	3/13
<i>Cladophora</i> sp.	166551	(1)	7/13
<i>Cyanodictyon</i> sp.	88956	(<1)	1/13
<i>Pseudanabaena</i> sp.	64286	(<1)	4/13
<i>Chromulina</i> sp.	62961	(<1)	3/13
<i>Spirulina</i> sp.	62528	(<1)	4/13
<i>Leptolyngbya</i> sp.	38765	(<1)	4/13
<i>Prorocentrum</i> sp.	32699	(<1)	4/13
<i>Aphanocapsa</i> sp.	31930	(<1)	2/13
Dino cysts	14070	(<1)	4/13
<i>Johannesbaptista pellucida</i>	11993	(<1)	1/13
<i>Cyanobium</i> sp.	11564	(<1)	1/13
<i>Polysiphonia</i> sp.	10793	(<1)	2/13
<i>Pseudendoclonium marinum</i>	7710	(<1)	1/13
<i>Phacus</i> sp.	4272	(<1)	2/13
<i>Oscillatoria</i> sp.	4216	(<1)	2/13
<i>Phormidium</i> sp.	2530	(<1)	1/13
Total	10450864		

The periphyton growing on these engineered systems are dynamic. Diatoms are always present and abundant, although different species become dominant during different times of the year. For example, *Tabularia tabulata*, *Nitzschia sigmaidea*, and *N. sigma* are most abundant from July to September, but when it becomes colder these species are not found, and other taxa, such as *Nitzschia nana*, *Thalassionema nitzschiodes*, and *Thalassiosira* sp. increase. However, as a group, chlorophytes tend to increase during late spring and late summer, reaching 70% of total abundance (Figure 2.20). The cyanobacteria were abundant in fall due to the large amount of two taxa: first, in mid-September, *Gloeothece* sp. was dominating the periphyton; later in the fall, *Lyngbya salina* dominated.

Algal Turf Scrubber Floway 2

Species Diversity

The taxonomic distribution of species by species number and cell abundance found on Floway 2 of the Great Wicomico River ATS™ is shown in Figure 2.21. Diatoms (Bacillariophyta) dominate the diversity of the algal flora with 72% of the total diversity. Six other algal phyla were represented in the flora with cyanobacteria, dinoflagellates, and chlorophytes having 12%, 7%, and 6%, respectively of the total diversity.

Using cell abundance values, it was verified that diatoms also dominated with 66% of total abundance. Cyanobacteria and chlorophytes followed with 25% and 7%,

respectively, with the other phyla, though diverse, only amounting to 2% of total diversity.

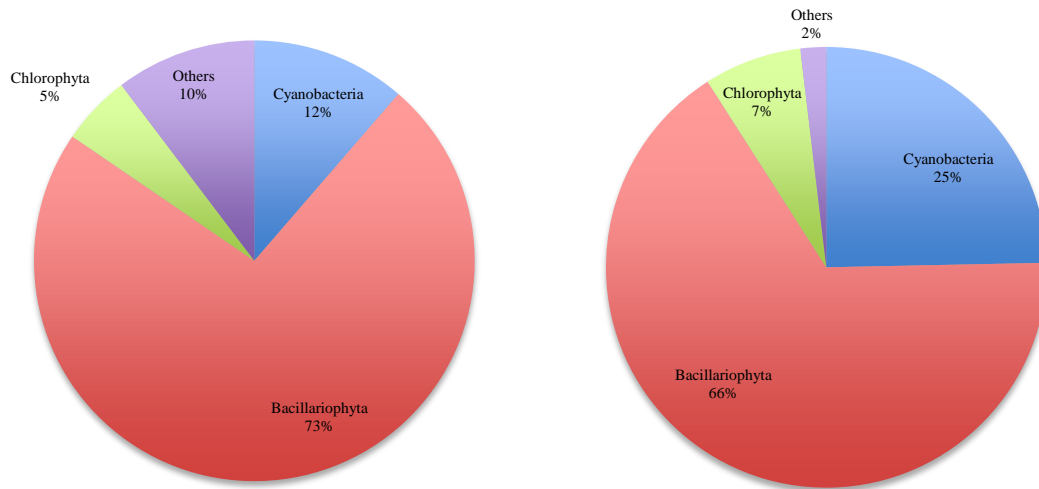


Figure 2.21. Relative composition of different algal phyla on Floway 2 at Wicomico, (left) by species composition, (right) by cell abundance.

Species-area curves for two seasonal aggregations of samples from the Great Wicomico River ATSTTM Floway 2 are shown in Figure 2.22 (spring-summer samples) and Figure 2.23 (fall-winter samples). In each case the slopes of the curves have not reached an asymptote after about 275 cm² of sampled area (spring-summer) and 300 cm² (fall-winter), though both are close to leveling off.

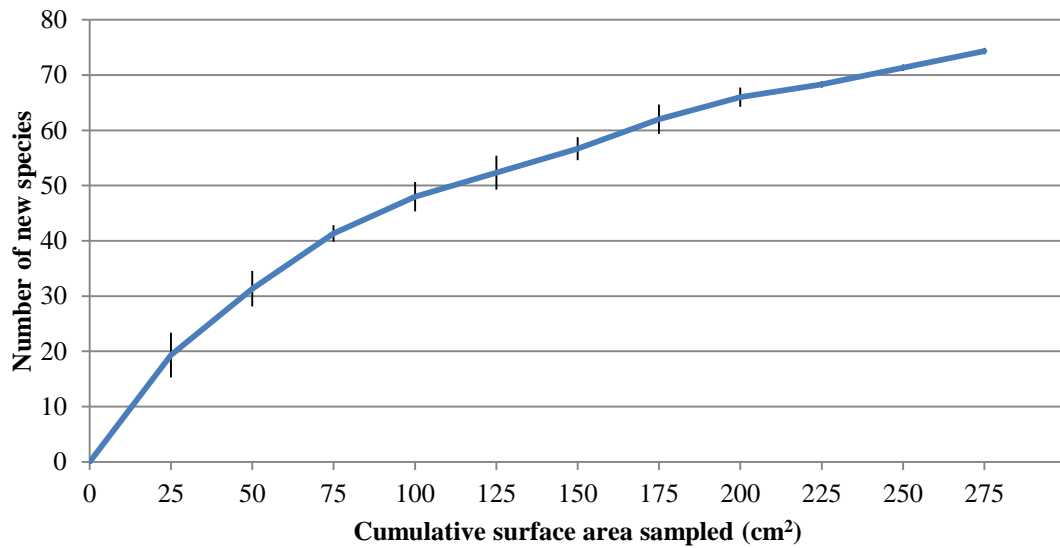


Figure 2.22. Species area curve for the Wicomico Floway 2 data set during Spring-Summer.

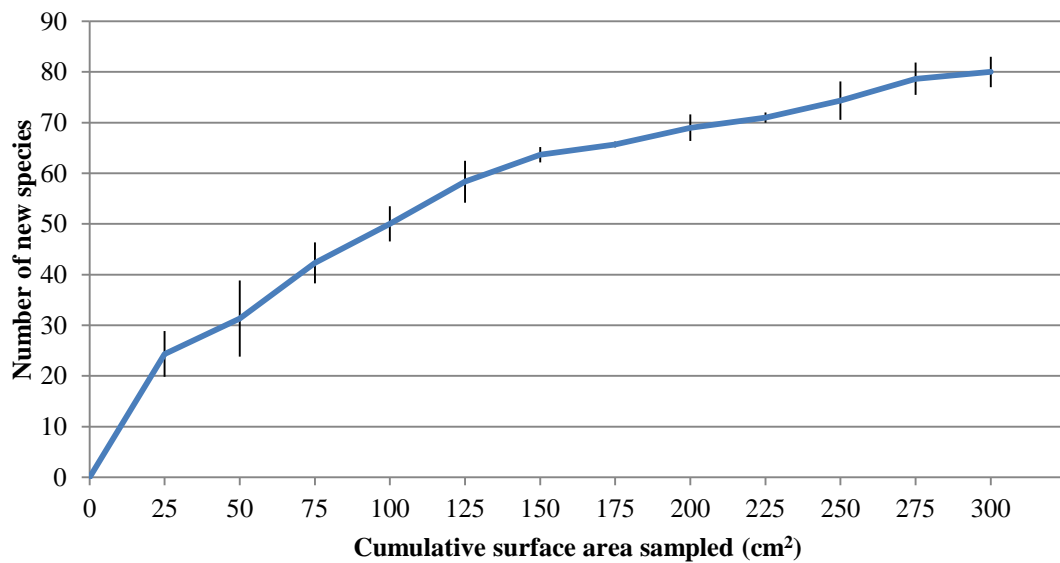


Figure 2.23. Species area curve for the Wicomico Floway 2 data set during Fall-Winter.

The distribution of life forms is presented in Figure 2.24. Single-celled, solitary species were the most common at 50% of the total, though filamentous, colonial, and chain-forming species were well represented.

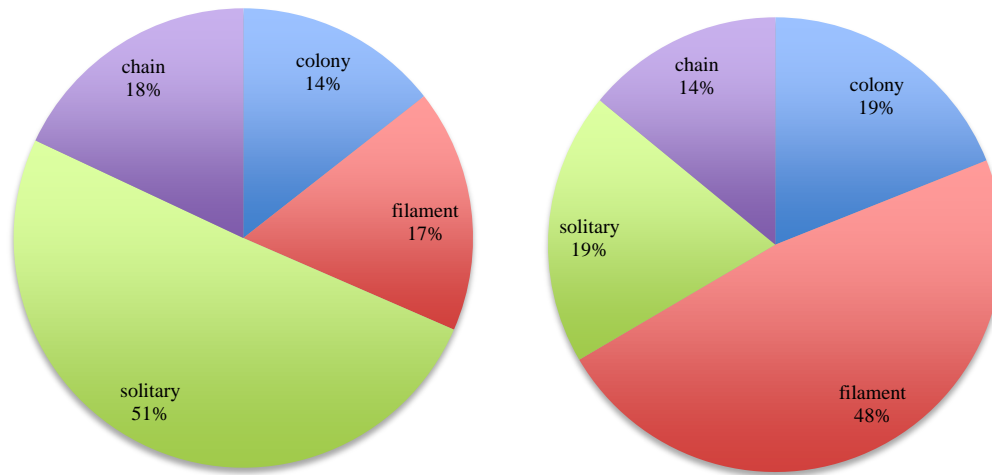


Figure 2.24. Distribution of life forms at Floway 2 at Wicomico, (left) by species composition, (right) by cell abundance.

Most species found on the screens lack an attachment adaptation (53%), and are probably found in the understory of the turf. Mucilage (40%) and special holdfast cells (6%) were also present in the turf (Figure 2.25).

The original habitats of the algal species encountered on the screens of the algal production systems are shown in Figure 2.26. Most species are either benthic (41%) or epiphytic (21%).

Most species found on Floway 2 are considered microalgae, as can be seen in Figure 2.27, which compares the distribution of microalgae versus macroalgae.

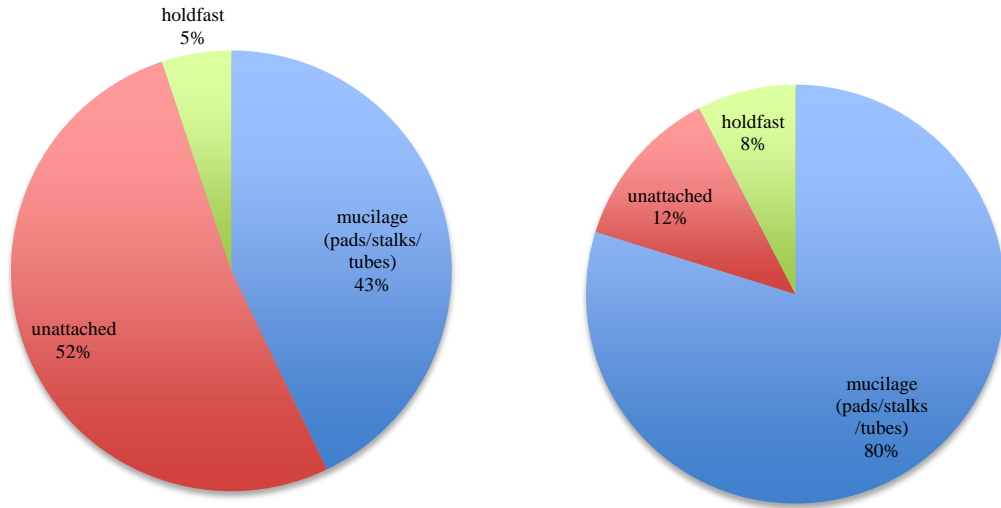


Figure 2.25. Distribution of attachment adaptations on Floway 2 at Wicomico, (left) by species composition, (right) by cell abundance.

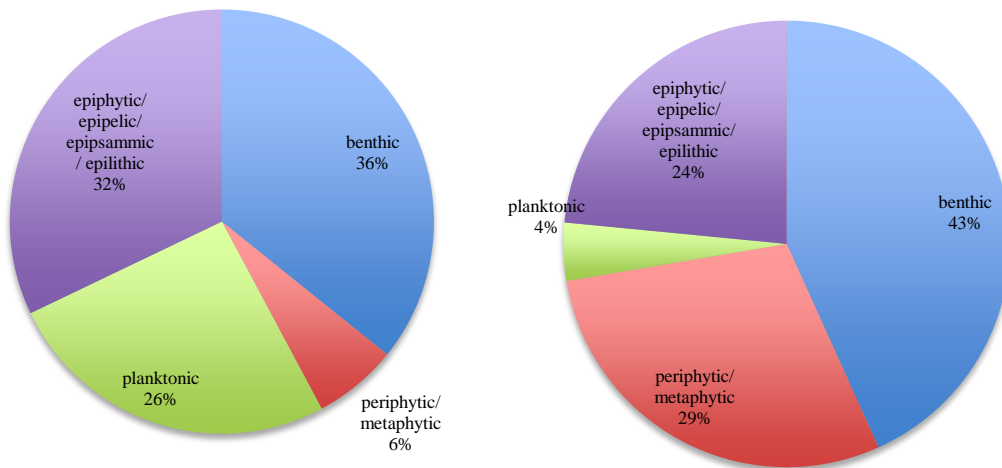


Figure 2.26. Distribution of types of habitats of the algae associated to Floway 2 on Wicomico, (left) by species composition, (right) by cell abundance.

Algal Abundance

On this floway, 98 algal taxa, belonging to seven different phyla (Bacillariophyta, Chlorophyta, Cyanobacteria, Rhodophyta, Dinophyta, and Chrysophyta) were found. The most abundant algal group on the system during the study period was Bacillariophyta (diatoms) with 67% of total relative abundance (Figure 2.28). Cyanobacteria and Chlorophyta were the following most abundant groups, with 24% and 7%, of total relative abundance, respectively. The other phyla accumulate to roughly 2% of total abundance. Different than seen on Floway 1, there were 7 taxa of dinoflagellates compared to only 2 taxa on Floway 1.

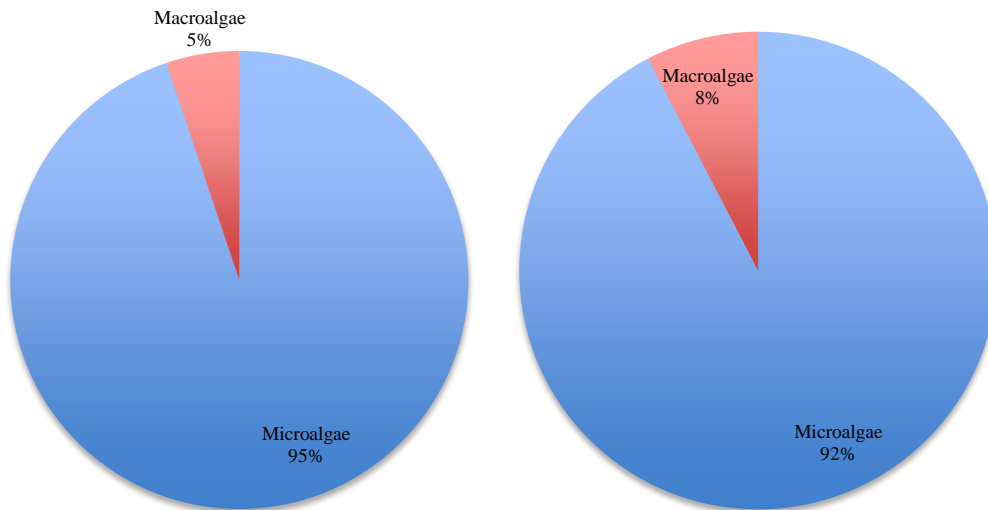


Figure 2.27. Relative contribution of microalgae vs. macroalgae on Floway 1 at Wicomico, (left) by species composition, (right) by cell abundance.

The average community structure data is shown in Table 2.4. Raw data by sample date can be found in Appendix 13. The most frequent taxa (occurring >85% of

samplings) were *Achnanthes* spp. (i.e. *Achnanthes brevipes*), *Amphora* spp., *Berkeleya rutilans*, *Grammatophora* spp., *Licmophora* spp., *Melosira nummuloides*, *Navicula* spp., and *Tabularia tabulata*.

The most abundant taxa were *Berkeleya* spp. (*B. fennica* and *B. rutilans*) (19%), *Lyngbya* cf. *salina* (19%), *Thalassionema nitzschiodes* (14%), *Melosira nummuloides* (7%), and *Ulva intestinalis* (6%). The other taxa occurring on the floway accounted for 3% or less of total abundance each.

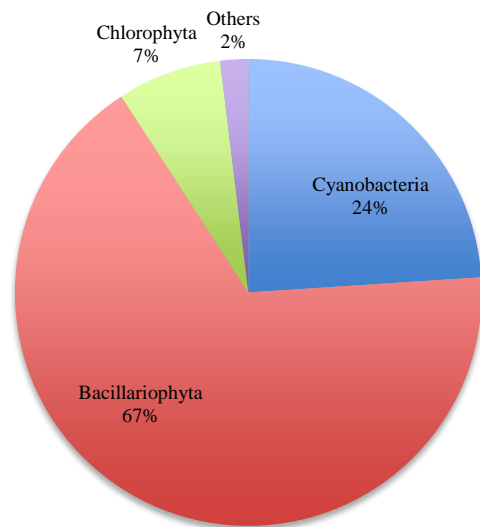


Figure 2.28. Total cumulative relative abundance of periphyton growing on Floway 2.

Figure 2.29 illustrates how the periphytic community on this system is dynamic. As in Floway 1, diatoms are always present, though there are changes in community structure occurring throughout the year. Cyanobacteria tend to have an increase from August to November (up to 60%) of total abundance, dominated by *Lyngbya salina*. Although present several times during the year, chlorophytes have their highest

abundance in the late springtime, reaching up to 40% of the total abundance. Both *Ulva intestinalis* and *Ulothrix* are responsible for this abundance.

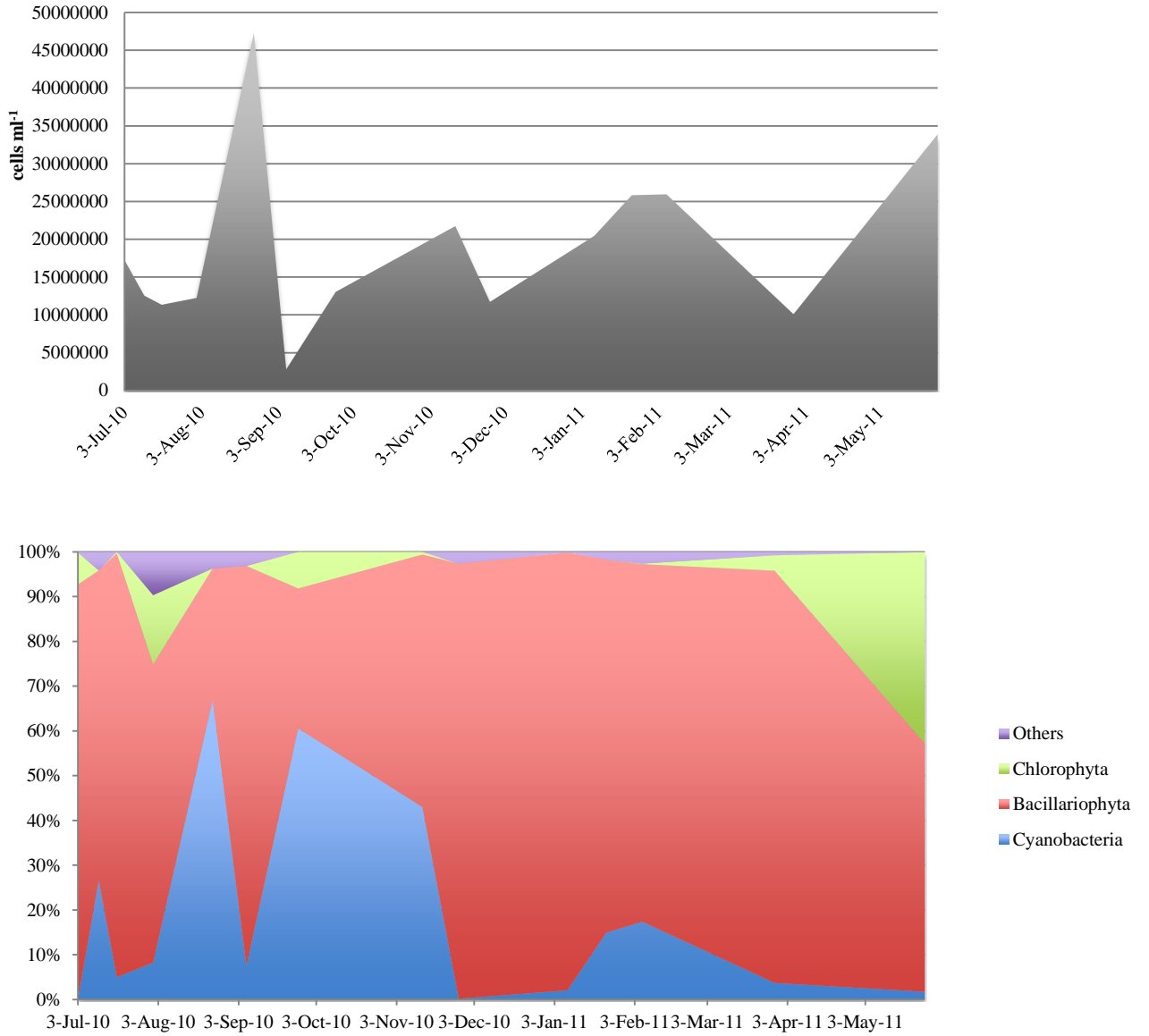


Figure 2.29. Change with time (July 2010 – May 2011) of (top) total community abundance and (bottom) of algal relative abundance, by phyla for Floway 2.

Table 2.4. Algal community structure on the Great Wicomico Floway 2 during 2010-2011. Density values are numbers of individuals per milliliter. Numbers in parentheses are percentage of the total (diatom + non-diatom) average density. Frequency is the number of occurrence among the 14 sample dates.

Species	Average Density	Frequency
Diatoms		
<i>Berkeleya rutilans</i>	3562991 (18)	14/14
<i>Thalassionema nitzschiodes</i>	2673047 (14)	7/14
<i>Melosira nummuloides</i>	1429793 (7)	14/14
<i>Amphora</i> sp.	513209 (3)	14/14
<i>Grammatophora</i> sp.	474750 (2)	14/14
<i>Skelatonema costatum</i>	418280 (2)	3/14
<i>Nitzschia nana</i>	393681 (2)	8/14
<i>Tabularia tabulata</i>	340480 (2)	13/14
<i>Achnanthes</i> sp.	294937 (1)	14/14
<i>Stauronella</i> sp.	290520 (1)	11/14
<i>Thalassiosira</i> sp.	284926 (1)	5/14
<i>Nitzschia sigmoidea</i>	221627 (1)	2/14
<i>Nitzschia</i> cf. <i>longissima</i>	218266 (1)	2/14
<i>Berkeleya fennica</i>	217283 (1)	4/14
<i>Licmophora</i> sp. (short)	203194 (1)	10/14
<i>Navicula</i> sp.	156288 (1)	14/14
<i>Mastogloia</i> sp.	154203 (1)	12/14
<i>Achnantheidium minutissimum</i>	107062 (1)	4/14
<i>Nitzschia</i> sp.	101016 (1)	9/14
<i>Cocconeis</i> sp.	99257 (1)	8/14
<i>Nitzschia sigmaformis</i>	79692 (<1)	4/14
<i>Nitzschia</i> sp. (tube)	72819 (<1)	2/14
<i>Staurosirella</i> sp.	72036 (<1)	4/14
<i>Rhopaloidia</i> sp.	70470 (<1)	5/14
<i>Licmophora</i> sp. (long)	67768 (<1)	10/14
<i>Melosira monoliformes</i>	46911 (<1)	6/14
<i>Navicula smithii</i>	46756 (<1)	4/14
<i>Fragilariopsis</i> sp.	46566 (<1)	5/14
cf. <i>Diademsis</i> sp.	34452 (<1)	2/14
<i>Nitzschia filiformis</i>	33495 (<1)	3/14
<i>Nitzschia sigma</i>	29729 (<1)	2/14
<i>Leptocylindrus minimus</i>	28971 (<1)	2/14
<i>Cylindrotheca closterium</i>	24534 (<1)	5/14
<i>Berkeleya fragilis</i>	22272 (<1)	1/14
<i>Cyclotella</i> sp.	16835 (<1)	4/14
<i>Fragilaria</i> sp.	16833 (<1)	3/14
<i>Gyrosigma</i> sp.	16391 (<1)	5/14
<i>Eunotia</i> sp.	14094 (<1)	2/14
<i>Chaetoceros</i> sp.	12702 (<1)	4/14
<i>Coscinodiscus</i> sp.	12667 (<1)	5/14
<i>Frustulia</i> sp.	12528 (<1)	1/14
<i>Achnanthes brevipes</i>	9396 (<1)	1/14
<i>Paralia</i> sp.	9396 (<1)	1/14

<i>Bacillaria paxillifer</i>	8829	(<1)	4/14
<i>Amphipleura</i> sp.	8613	(<1)	2/14
<i>Navicula gregaria</i>	7569	(<1)	2/14
<i>Nitzschia scalpelliformis</i>	6890	(<1)	2/14
<i>Catenula</i> sp.	6264	(<1)	1/14
<i>Opephora</i> sp.	5906	(<1)	3/14
<i>Fogedia</i> sp.	5011	(<1)	2/14
<i>Entomoneis</i> sp.	4698	(<1)	1/14
<i>Meuniera</i> sp.	4698	(<1)	1/14
<i>Diploneis</i> sp.	4549	(<1)	3/14
<i>Plagiogramma</i> sp.	4176	(<1)	1/14
<i>Pinnularia</i> sp.	3967	(<1)	2/14
<i>Denticula</i> sp.	3758	(<1)	1/14
<i>Ditylum brightwellii</i>	3445	(<1)	2/14
<i>Dactyliosolen</i> sp.	3132	(<1)	1/14
<i>Nitzschia ventricosa</i>	3132	(<1)	1/14
<i>Plagiotropis</i> sp.	3132	(<1)	1/14
<i>Neodelphineis</i> sp.	2784	(<1)	1/14
<i>Hippodonta</i> sp.	2088	(<1)	1/14
<i>Actinoptychus senarius</i>	1566	(<1)	1/14
<i>Caloneis</i> sp.	1566	(<1)	1/14
<i>Epithemia</i> sp.	1566	(<1)	1/14
<i>Meridion</i> sp.	1566	(<1)	1/14
<i>Nitzschia tryblionella</i>	1566	(<1)	1/14
<i>Pseudostaurosira</i> sp.	1566	(<1)	1/14
<i>Striatella</i> sp.	1566	(<1)	1/14
<i>Surirella</i> sp.	1566	(<1)	1/14
<i>Pleurosigma</i> sp.	1392	(<1)	1/14
<i>Synedropsis</i> sp.	894	(<1)	1/14
Total	13059578	(66)	

Non-Diatoms

<i>Lyngbya salina</i>	3756244	(19)	9/14
<i>Ulva intestinalis</i>	1252664	(6)	6/14
<i>Pseudanabaena</i> sp.	473908	(2)	4/14
<i>Aphanocapsa</i> sp.	277078	(1)	2/14
<i>Chromulina</i> sp.	198360	(1)	5/14
<i>Polysiphonia</i> sp.	121452	(1)	3/14
<i>Calothrix</i> sp.	89332	(<1)	2/14
<i>Ulothrix</i> sp.	86443	(<1)	2/14
<i>Leptolyngbya</i> sp.	73567	(<1)	4/14
<i>Geitlerinema</i> sp.	53244	(<1)	1/14
<i>Jaaginema</i> sp.	41891	(<1)	2/14
<i>Johannesbaptista pellucida</i>	38976	(<1)	1/14
<i>Aphanothece</i> sp.	34452	(<1)	1/14
<i>Cocoid green</i>	32886	(<1)	1/14
<i>Prorocentrum</i> sp.	32234	(<1)	5/14
<i>Cladophora</i> sp.	31477	(<1)	2/14
<i>Chroococcus</i> sp.	14198	(<1)	2/14
<i>Spirulina</i> sp.	9396	(<1)	2/14

Unknown green #2	9396	(<1)	1/14
Dino cysts	7516	(<1)	1/14
<i>Katodinium</i> sp.	3132	(<1)	1/14
<i>Gyrodinium</i> sp.	3132	(<1)	1/14
<i>Euglena</i> sp.	2349	(<1)	1/14
<i>Alexandrium</i> sp.	1566	(<1)	1/14
<i>Ceratium</i> sp.	1566	(<1)	1/14
<i>Dinophysis</i> sp.	1566	(<1)	1/14
Total	6648025	(34)	

Muddy Run Reservoir ATSTM

Aluminum Floway

Species Diversity

Two hundred twelve taxa were found on the ATSTM floways at Muddy Run, which is considerably higher than the other locations. The algal community structure on the aluminum floway at the Muddy Run Reservoir ATSTM is presented in Table 2.5. The taxonomic distribution of species found on the aluminum floway at the Muddy Run Reservoir is shown in Figure 2.30. Diatoms (Bacillariophyta) dominated the algal flora with 46 % of total diversity. Six other algal phyla were represented in the flora with chlorophytes and cyanobacteria contributing 36% and 14%, respectively, of total diversity.

Table 2.5. Algal community structure on the aluminum floway at the Muddy Run Reservoir ATS™, 2008-2009.

Taxa	Sample Frequency	Date Frequency
Cyanobacteria		
<i>Aphanocapsa holsatica</i>	1	1
<i>Aphanocapsa rivularis</i>	0	0
<i>Aphanothece</i> sp.	0	0
<i>Asterocapsa</i> sp.	0	0
<i>Bacularia vermicularis</i>	1	1
<i>Chroococcus minor</i>	3	2
<i>Chroococcus minutus</i>	0	0
<i>Eucapsis carpatica</i>	0	0
<i>Eucapsis parallelepipedon</i>	1	1
<i>Geitierinema amphibium</i>	2	1
<i>Leibleinia epiphytica</i>	6	1
<i>Leptolyngbya boryana</i>	0	0
<i>Leptolyngbya subtilis</i>	2	1
<i>Lyngbya martesiana</i>	1	1
<i>Merismopedia tenuissima</i>	3	3
<i>Oscillatoria curviceps</i>	1	1
<i>Oscillatoria froelichii</i>	5	3
<i>Oscillatoria limosa</i>	1	1
<i>Oscillatoria princeps</i>	0	0
<i>Phormidium autumnale</i>	10	6
<i>Phormidium fonticulum</i>	0	0
<i>Phormidium interruptum</i>	1	1
<i>Phormidium retzii</i>	3	2
<i>Phormidium simplicissimum</i>	0	0
<i>Phormidium stagninum</i>	2	2
<i>Phormidium teryestinum</i>	5	2
<i>Planktolyngbya limnetica</i>	2	1
<i>Pseudanabaena galeata</i>	3	2
<i>Pseudanabaena limnetica</i>	0	0
<i>Pseudanabaena</i> sp.	3	1
Chlorophyta		
<i>Ankistrodesmus convolutus</i>	1	1
<i>Botryococcus braunii</i>	2	2
<i>Bulbochaete</i> sp.	1	1
<i>Characiopsis</i> sp.	0	0
<i>Chlorella</i> sp.	2	2
<i>Cladophora glomerata</i>	4	3
<i>Closteriopsis acicularis</i>	3	1
<i>Closterium</i> cf. <i>sublaterale</i>	0	0
<i>Closterium</i> sp.	1	1
<i>Coelastrum astroideum</i>	2	2
<i>Coelastrum</i> cf. <i>cabricum</i>	0	0
<i>Coelastrum</i> cf. <i>microporum</i>	1	1
<i>Cosmarium</i> cf. <i>margaritatum</i>	0	0

<i>Cosmarium</i> cf. <i>pseudocconnatum</i>	0	0
<i>Cosmarium</i> cf. <i>pseudoexiguum</i>	0	0
<i>Cosmarium</i> cf. <i>sublobulatum</i>	0	0
<i>Cosmarium</i> cf. <i>subtumidum</i>	1	1
<i>Cosmarium formosulum</i>	1	1
<i>Cosmarium granatum</i>	0	0
<i>Cosmarium monomazum</i> var. <i>polymazum</i>	1	1
<i>Cosmarium perforatum</i>	0	0
<i>Cosmarium</i> spp.	10	5
<i>Cosmarium trilobulatum</i>	0	0
<i>Cosmarium vexatum</i> var. <i>lacustre</i>	1	1
<i>Desmodesmus balatonicus</i>	1	1
<i>Desmodesmus bicaudatus</i>	0	0
<i>Desmodesmus communis</i>	14	5
<i>Desmodesmus denticulatus</i>	0	0
<i>Desmodesmus gutwinskii</i>	1	1
<i>Desmodesmus intermedius</i>	2	2
<i>Desmodesmus opoliensis</i>	0	0
<i>Desmodesmus polyspinosis</i>	2	1
<i>Desmodesmus</i> sp.	1	1
<i>Diacanthos belenophorus</i>	1	1
<i>Dictyosphaerium pulchellum</i>	1	1
<i>Gloecystis</i> sp.	2	1
<i>Hydrodictyon reticulatum</i>	0	0
<i>Kirchneriella lunaris</i>	1	1
<i>Klebsormidium</i> sp.	0	0
<i>Lagerheimia quadriseta</i>	0	0
<i>Microspora floccosa</i>	1	1
<i>Microspora quadrata</i>	1	1
<i>Microspora wittrockii</i>	1	1
<i>Monoraphidium arcuatum</i>	5	2
<i>Monoraphidium contortum</i>	8	4
<i>Monoraphidium griffithii</i>	1	1
<i>Netrium interruptum</i>	0	0
<i>Netrium</i> sp.	0	0
<i>Oedogonium pluvioporum</i>	8	5
<i>Pediastrum biradiatum</i>	1	1
<i>Pediastrum boryanum</i>	6	3
<i>Pediastrum duplex</i>	5	2
<i>Pediastrum simplex</i>	0	0
<i>Pediastrum tetras</i>	5	3
<i>Pseudocharacium</i> sp.	1	1
<i>Quadricoccus verrococus</i>	0	0
<i>Rhizoclonium heroglyphicum</i>	3	2
<i>Scenedesmus acuminatus</i>	2	2
<i>Scenedesmus acutus</i>	4	4
<i>Scenedesmus alternans</i>	3	3
<i>Scenedesmus arcuatus</i>	0	0
<i>Scenedesmus brevispina</i>	1	1
<i>Scenedesmus</i> cf. <i>granulatus</i>	0	0

<i>Scenedesmus cf. overternus</i>	0	0
<i>Scenedesmus dimorphus</i>	1	1
<i>Scenedesmus ecornis</i>	1	1
<i>Scenedesmus linearis</i>	1	1
<i>Scenedesmus sp.</i>	6	3
<i>Schroederia sp.</i>	1	1
<i>Sphaerocystis schroeteri</i>	1	1
<i>Spirogyra cf. rivularis</i>	15	4
<i>Staurastrum alternans</i>	0	0
<i>Staurastrum sp.</i>	2	2
<i>Stigeoclonium tenue</i>	2	2
<i>Tetraedron caudatum</i>	1	1
<i>Ulothrix cf. tenerrima</i>	1	1
<i>Ulothrix cf. variabilis</i>	1	1
<i>Ulothrix sp.</i>	3	1
<i>Ulothrix zonata</i>	1	1
<i>Uronema elongatum</i>	3	2
Bacillariophyta		
<i>Achnathidium minutissimum</i>	1	1
<i>Amphora cf. pediculus</i>	0	0
<i>Amphora libyca</i>	1	1
<i>Amphora ovalis</i>	0	0
<i>Amphora sp.</i>	3	2
<i>Aulacoseira granulate</i>	2	1
<i>Aulacoseira italica</i>	1	1
<i>Aulacoseira planctonica</i>	2	1
<i>Brachysira brebissonii</i>	1	1
<i>Caloneis sp.</i>	0	0
<i>Cocconeis pediculus</i>	2	1
<i>Cocconeis placentula</i>	3	3
<i>Cymatopleura solea</i>	1	1
<i>Cymbella affine</i>	2	1
<i>Cymbella cistula</i>	1	1
<i>Cymbella lanceolata</i>	3	3
<i>Cymbella leptoceras</i>	0	0
<i>Cymbella parva</i>	2	1
<i>Cymbella spp.</i>	11	6
<i>Cymbella tumida</i>	3	2
<i>Diadismis contenta</i>	7	4
<i>Diatoma ehrenbergii</i>	1	1
<i>Diatoma mesodon</i>	0	0
<i>Diatoma monoliformis</i>	3	2
<i>Diatoma tenue</i>	3	1
<i>Diatoma vulgare</i>	11	4
<i>Encyonema caespitosum</i>	2	1
<i>Encyonema gracile</i>	0	0
<i>Encyonema minutum</i>	1	1
<i>Encyonema prostratum</i>	1	1
<i>Encyonema sp.</i>	2	1

<i>Eunotia</i> sp.	1	1
<i>Fragilaria capucina</i>	8	4
<i>Fragilaria vaucheriae</i>	3	2
<i>Frustulia rhomboides</i>	1	1
<i>Frustulia</i> sp.	6	4
<i>Frustulia vulgaris</i>	1	1
<i>Gomphoneis minuta</i>	1	1
<i>Gomphonema angustatum</i>	1	1
<i>Gomphonema capitatum</i>	0	0
<i>Gomphonema</i> cf. <i>brasiliense</i>	3	1
<i>Gomphonema</i> cf. <i>hastatum</i>	0	0
<i>Gomphonema olivaceum</i>	0	0
<i>Gomphonema</i> sp.	7	3
<i>Gomphonema truncatum</i>	4	2
<i>Gyrosigma attenuatum</i>	1	1
<i>Gyrosigma</i> sp.	2	2
<i>Luticola geoppertiana</i>	3	2
<i>Melosira varians</i>	23	6
<i>Meridion circulare</i>	1	1
<i>Navicula capitata</i>	1	1
<i>Navicula capitoradiata</i>	2	1
<i>Navicula</i> cf. <i>drouetiana</i>	2	1
<i>Navicula</i> cf. <i>fonticola</i>	0	0
<i>Navicula</i> cf. <i>hungarica</i>	1	1
<i>Navicula</i> cf. <i>margalithi</i>	0	0
<i>Navicula cryptocephala</i>	5	3
<i>Navicula gregaria</i>	7	3
<i>Navicula lanceolata</i>	2	2
<i>Navicula rhyncocephala</i>	2	2
<i>Navicula</i> spp.	13	6
<i>Neidum</i> sp.	0	0
<i>Nitzschia acicularis</i>	0	0
<i>Nitzschia</i> spp.	10	5
<i>Nitzschia amphibia</i>	0	0
<i>Nitzschia angustatula</i>	1	1
<i>Nitzschia brevissima</i>	1	1
<i>Nitzschia</i> cf. <i>agnita</i>	0	0
<i>Nitzschia</i> cf. <i>radicula</i>	1	1
<i>Nitzschia</i> cf. <i>vermicularis</i>	1	1
<i>Nitzschia dissipata</i>	5	3
<i>Nitzschia draveillensis</i>	0	0
<i>Nitzschia filiformis</i>	0	0
<i>Nitzschia linearis</i>	1	1
<i>Nitzschia obtusa</i>	0	0
<i>Nitzschia palea</i>	2	2
<i>Nitzschia paleacea</i>	1	1
<i>Nitzschia sigmoidea</i>	1	1
<i>Pinnularia</i> sp.	0	0
<i>Rhoicosphenia abbreviata</i>	8	5
<i>Rhopalodia</i> sp.	1	1

<i>Sellaphora</i> sp.	1	1
<i>Staurosirella leptostauron</i>	0	0
<i>Stephanocyclus meneghiana</i>	13	6
<i>Surirella elegans</i> f. <i>elongata</i>	1	1
<i>Surirella minuta</i>	1	1
<i>Surirella</i> sp.	3	2
<i>Surirella tenera</i>	1	1
<i>Synedra acus</i>	2	2
<i>Synedra</i> cf. <i>affinis</i>	0	0
<i>Synedra formosa</i>	1	1
<i>Synedra</i> spp.	7	3
<i>Tabellaria flocculosa</i>	4	4
<i>Thalassiosira</i> sp.	1	1
<i>Ulnaria ulna</i>	19	6
Chrysophyceae		
<i>Ochromonas</i>	0	0
Chlamydomphyceae		
<i>Chlamydomonas</i> sp.	1	1
<i>Pandorina</i> sp.	0	0
Raphidophyceae		
<i>Colponema</i> sp.	1	1
Euglenophyta		
cf. <i>Parmidium</i>	0	0
<i>Lepocinclis</i> cf. <i>ovum</i>	0	0
<i>Phacus</i> sp.	1	1
<i>Trachelomonas volvocina</i>	2	2
Dinophyta		
<i>Peridinium</i> sp.	1	1
<i>Sphaerodinium cinctum</i>	1	1

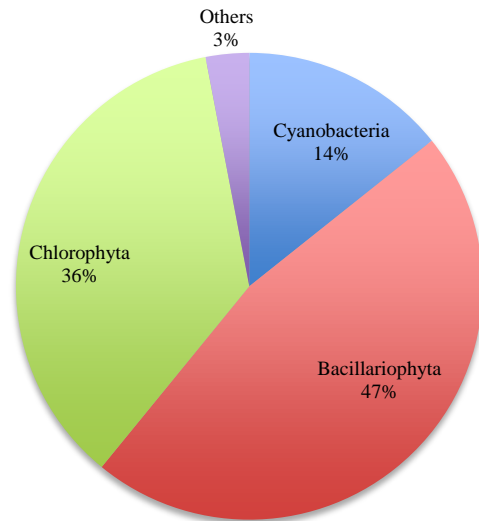


Figure 2.30. Relative composition of different algal phyla on the aluminum flowway at Muddy Run (by species composition).

Species-area curves for two seasonal aggregations of samples from the aluminum flowway at the Muddy Run Reservoir ATS™ are shown in Figures 2.31 and 2.32. In neither have the slopes reached an asymptote after about 325 cm² of sampled area (spring-summer) and 150 cm² (fall-winter).

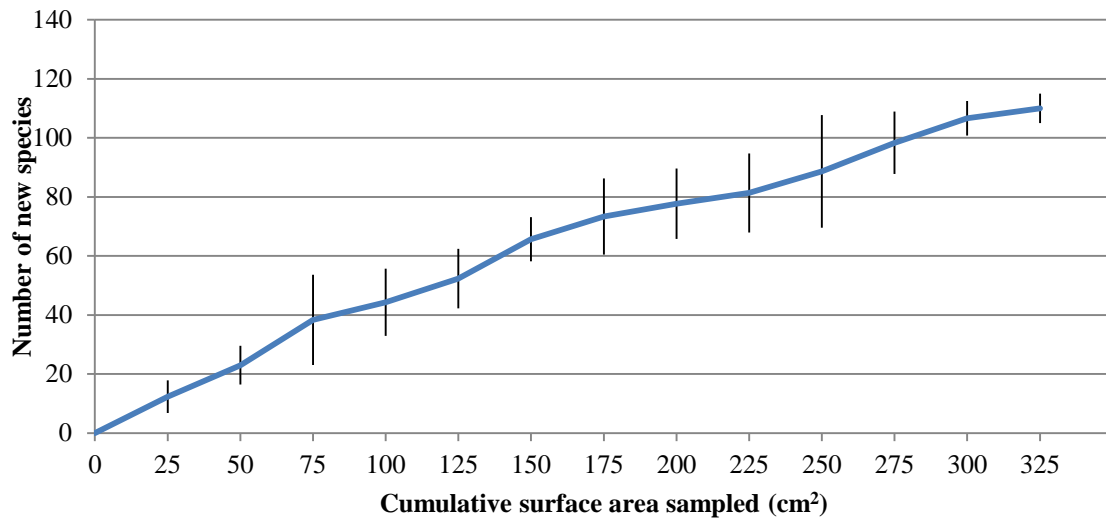


Figure 2.31. Species area curve for the Aluminum Flowway data set during Spring-Summer.

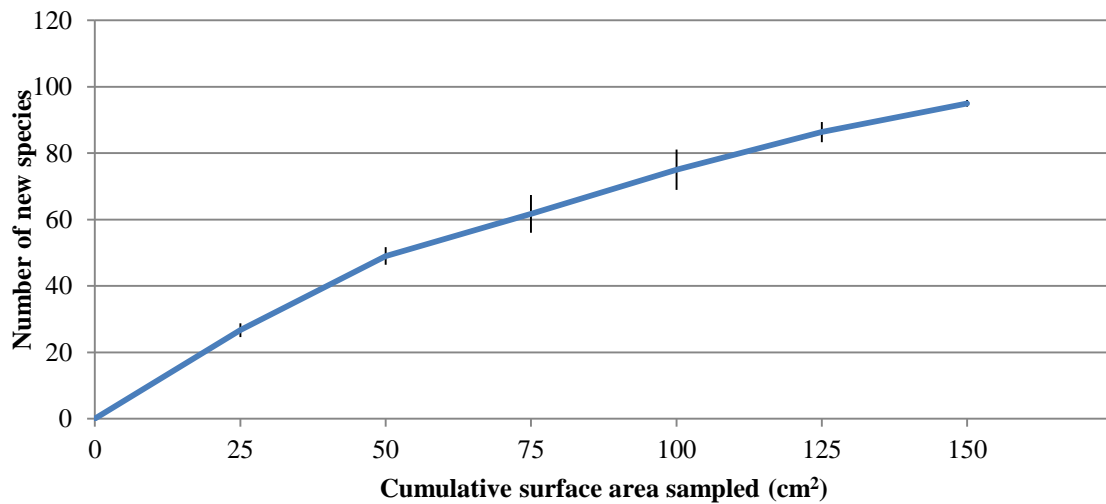


Figure 2.32. Species area curve for the Aluminum Flowway data set during Fall-Winter.

Life form distributions are presented in Figure 2.33. Single-celled, solitary species were the most common at 46% of the total, though filamentous, colonial, and coenobial species were well represented, with 18%, 18%, and 14%, respectively, of the total diversity.

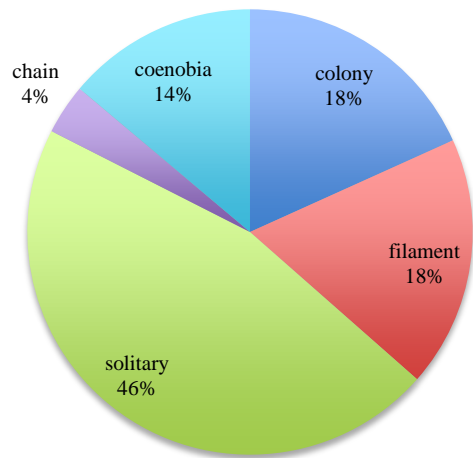


Figure 2.33. Distribution of life forms on the aluminum flowway at Muddy Run (by species composition).

Most species found on the screens lack an attachment adaptation (55%), and are probably found in the understory of the turf. Mucilage (36%) and holdfast cells (9%) were also present in the turf (Figure 2.34).

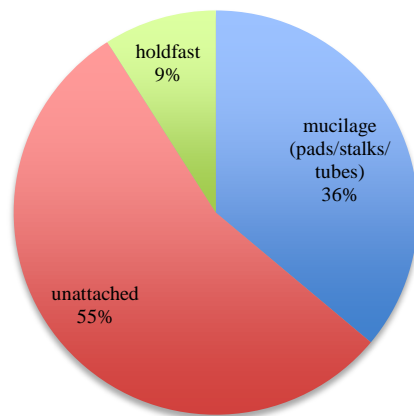


Figure 2.34. Distribution of attachment adaptations on the aluminum flowway at Muddy Run (by species composition).

The original habitats of the algal species encountered on the aluminum screens at Muddy Run are shown in Figure 2.35. Different than at the other sites, most species were planktonic (28%), followed by those benthic (27%).

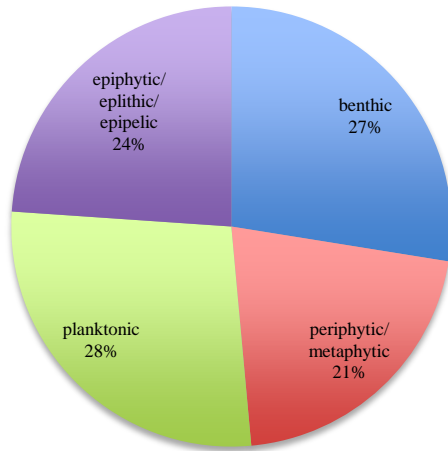


Figure 2.35. Distribution of types of habitats of the algae associated to the aluminum flowway at Muddy Run (by species composition).

As in the other ATSTM systems in these studies, most species found on the aluminum flowway are considered microalgae, as can be seen in Figure 2.36.

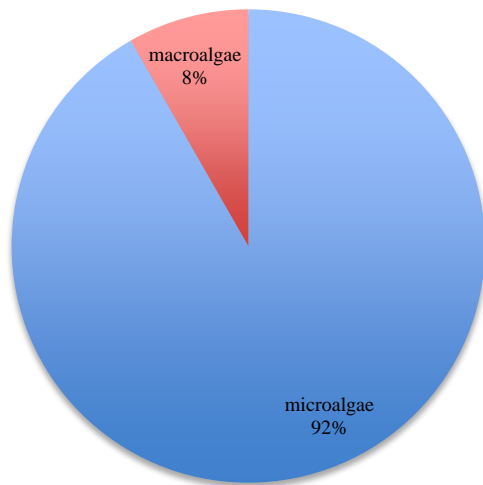


Figure 2.36. Relative contribution of microalgae vs. macroalgae on the aluminum flow of Muddy Run.

Wood Floway

Species Diversity

The algal community structure on the wood floway at the Muddy Run Reservoir ATS™ is presented in Table 2.6. The taxonomic distribution of species found on the wood floway at the Muddy Run is shown in Figure 2.37. Diatoms (Bacillariophyta) dominated the algal flora comprising 46 % of total diversity. Six other algal phyla were represented in the flora with chlorophytes and cyanobacteria comprising 39% and 11%, respectively, of total diversity.

Table 2.6. Algal community structure on the wood floway at the Muddy Run Reservoir ATS™, 2008-2009.

Taxa	Sample Frequency	Date Frequency
Cyanobacteria		
<i>Aphanocapsa holsatica</i>	1	1
<i>Aphanocapsa rivularis</i>	1	1
<i>Aphanothece</i> sp.	2	1
<i>Asterocapsa</i> sp.	1	1
<i>Bacularia vermicularis</i>	0	0
<i>Chroococcus minor</i>	0	0
<i>Chroococcus minutus</i>	1	1
<i>Eucapsis carpatica</i>	1	1
<i>Eucapsis parallelepipedon</i>	0	0
<i>Geitierinema amphibium</i>	0	0
<i>Leibleinia epiphytica</i>	0	0
<i>Leptolyngbya boryana</i>	2	1
<i>Leptolyngbya subtilis</i>	11	4
<i>Lyngbya martensiana</i>	0	0
<i>Merismopedia tenuissima</i>	0	0
<i>Oscillatoria curviceps</i>	1	1
<i>Oscillatoria limosa</i>	0	0
<i>Oscillatoria princeps</i>	1	1
<i>Oscillatoria</i> sp. <i>froelichii</i>	0	0
<i>Phormidium autumnale</i>	4	3
<i>Phormidium fonticulum</i>	2	1
<i>Phormidium interruptum</i>	0	0
<i>Phormidium retzii</i>	11	3
<i>Phormidium simplicissimum</i>	1	1
<i>Phormidium stagninum</i>	1	1
<i>Phormidium tergestinum</i>	1	1
<i>Planktolyngbya limnetica</i>	1	1
<i>Pseudanabaena galeata</i>	2	2
<i>Pseudanabaena limnetica</i>	6	1
<i>Pseudanabaena</i> sp.	2	2
Chlorophyta		
<i>Ankistrodesmus convolutus</i>	1	1
<i>Botryococcus braunii</i>	0	0
<i>Bulbochaete</i> sp.	0	0
<i>Characiopsis</i> sp.	1	1
<i>Chlorella</i> sp.	1	1
<i>Cladophora glomerata</i>	4	2
<i>Closteriopsis acicularis</i>	0	0
<i>Closterium</i> cf. <i>sublaterale</i>	1	1
<i>Closterium</i> sp.	9	5
<i>Coelastrum astroideum</i>	3	2
<i>Coelastrum</i> cf. <i>cabricum</i>	1	1
<i>Coelastrum</i> cf. <i>microporum</i>	3	2
<i>Cosmarium</i> cf. <i>margaritatum</i>	1	1

<i>Cosmarium</i> cf. <i>pseudocconnatum</i>	2	1
<i>Cosmarium</i> cf. <i>pseudoexiguum</i>	1	1
<i>Cosmarium</i> cf. <i>sublobulatum</i>	3	1
<i>Cosmarium</i> cf. <i>subtumidum</i>	0	0
<i>Cosmarium formosulum</i>	0	0
<i>Cosmarium granatum</i>	1	1
<i>Cosmarium monomazum</i> var. <i>polymazum</i>	0	0
<i>Cosmarium perforatum</i>	1	1
<i>Cosmarium</i> spp.	8	5
<i>Cosmarium trilobulatum</i>	2	2
<i>Cosmarium vexatum</i> var. <i>lacustre</i>	0	0
<i>Desmodesmus balatonicus</i>	1	1
<i>Desmodesmus bicaudatus</i>	1	1
<i>Desmodesmus communis</i>	14	5
<i>Desmodesmus denticulatus</i>	2	1
<i>Desmodesmus gutwinskii</i>	0	0
<i>Desmodesmus intermedius</i>	4	1
<i>Desmodesmus opoliensis</i>	1	1
<i>Desmodesmus</i> sp.	3	2
<i>Desmodesmuspolyspinosis</i>	1	1
<i>Diacanthos belenophorus</i>	1	1
<i>Dictyosphaerium pulchellum</i>	1	1
<i>Gloeocystis</i> sp.	1	1
<i>Hydrodictyon reticulatum</i>	1	1
<i>Kirchneriella lunaris</i>	0	0
<i>Klebsormidium</i> sp.	2	2
<i>Lagerheimia quadriseta</i>	1	1
<i>Microspora floccosa</i>	1	1
<i>Microspora quadrata</i>	2	2
<i>Microspora wittrockii</i>	0	0
<i>Monoraphidium arcuatum</i>	16	4
<i>Monoraphidium contortum</i>	10	3
<i>Monoraphidium griffithii</i>	4	3
<i>Netrium interruptum</i>	1	1
<i>Netrium</i> sp.	1	1
<i>Oedogonium pluvioporum</i>	10	4
<i>Pediastrum biradiatum</i>	0	0
<i>Pediastrum boryanum</i>	7	3
<i>Pediastrum duplex</i>	9	4
<i>Pediastrum simplex</i>	4	2
<i>Pediastrum tetras</i>	8	3
<i>Pseudocharacium</i> sp.	0	0
<i>Quadricoccus verrococus</i>	1	1
<i>Rhizoclonium heroglyphicum</i>	3	1
<i>Scenedesmus acuminatus</i>	2	2
<i>Scenedesmus acutus</i>	8	2
<i>Scenedesmus alternans</i>	3	2
<i>Scenedesmus arcuatus</i>	1	1
<i>Scenedesmus brevispina</i>	0	0
<i>Scenedesmus</i> cf. <i>granulatus</i>	1	1

<i>Scenedesmus cf. ovelternus</i>	2	1
<i>Scenedesmus dimorphus</i>	4	1
<i>Scenedesmus ecornis</i>	4	3
<i>Scenedesmus linearis</i>	0	0
<i>Scenedesmus sp.</i>	3	2
<i>Schroederia sp.</i>	0	0
<i>Sphaerocystis schroeteri</i>	1	1
<i>Spirogyra cf. rivularis</i>	13	5
<i>Staurastrum alternans</i>	3	2
<i>Staurastrum sp.</i>	1	1
<i>Stigeoclonium tenue</i>	4	3
<i>Tetraedron caudatum</i>	6	2
<i>Ulothrix cf. tenerrima</i>	2	2
<i>Ulothrix cf. variabilis</i>	2	1
<i>Ulothrix sp.</i>	5	2
<i>Ulothrix zonata</i>	0	0
<i>Uronema elongatum</i>	1	1
Bacillariophyta		
<i>Achnathidium minutissimum</i>	1	1
<i>Amphora cf. pediculus</i>	1	1
<i>Amphora libyca</i>	0	0
<i>Amphora ovalis</i>	1	1
<i>Amphora sp.</i>	4	4
<i>Aulacoseira granulata</i>	2	2
<i>Aulacoseira italica</i>	1	1
<i>Aulacoseira planctonica</i>	5	2
<i>Brachysira brebissonii</i>	1	1
<i>Caloneis sp.</i>	6	2
<i>Cocconeis pediculus</i>	1	1
<i>Cocconeis placentula</i>	4	3
<i>Cymatopleura solea</i>	2	2
<i>Cymbella cistula</i>	3	2
<i>Cymbella lanceolata</i>	3	1
<i>Cymbella leptoceras</i>	1	1
<i>Cymbella parva</i>	1	1
<i>Cymbella spp.</i>	10	4
<i>Cymbella tumida</i>	7	3
<i>Diadismus contenta</i>	5	3
<i>Diatoma ehrenbergii</i>	2	1
<i>Diatoma mesodon</i>	1	1
<i>Diatoma monoliformis</i>	3	1
<i>Diatoma tenue</i>	2	2
<i>Diatoma vulgare</i>	11	5
<i>Encyonema caespitosum</i>	1	1
<i>Encyonema gracile</i>	1	1
<i>Encyonema minutum</i>	3	2
<i>Encyonema prostratum</i>	3	3
<i>Encyonema sp.</i>	4	2
<i>Eunotia sp.</i>	0	0

<i>Fragilaria capucina</i>	9	4
<i>Fragilaria vaucheriae</i>	10	3
<i>Frustulia rhomboides</i>	5	1
<i>Frustulia</i> sp.	9	3
<i>Frustulia vulgaris</i>	2	1
<i>Gomphoneis minuta</i>	4	2
<i>Gomphonema angustatum</i>	1	1
<i>Gomphonema capitatum</i>	1	1
<i>Gomphonema</i> cf. <i>brasiliense</i>	0	0
<i>Gomphonema</i> cf. <i>hastatum</i>	1	1
<i>Gomphonema olivaceum</i>	3	1
<i>Gomphonema</i> sp.	9	3
<i>Gomphonema truncatum</i>	8	5
<i>Gyrosigma attenuatum</i>	0	0
<i>Gyrosigma</i> sp.	0	0
<i>Luticola geoppertiana</i>	0	0
<i>Melosira varians</i>	12	5
<i>Meridion circulare</i>	2	1
<i>Navicula capitata</i>	0	0
<i>Navicula capitoradiata</i>	2	2
<i>Navicula</i> cf. <i>drouetiana</i>	0	0
<i>Navicula</i> cf. <i>fonticola</i>	1	1
<i>Navicula</i> cf. <i>hungarica</i>	0	0
<i>Navicula</i> cf. <i>margalithi</i>	3	1
<i>Navicula cryptocephala</i>	3	1
<i>Navicula gregaria</i>	11	4
<i>Navicula lanceolata</i>	4	3
<i>Navicula rhyncocephala</i>	4	2
<i>Navicula</i> spp.	8	3
<i>Neidium</i> sp.	1	1
<i>Nitzschia acicularis</i>	1	1
<i>Nitzschia amphibia</i>	3	1
<i>Nitzschia angustatula</i>	0	0
<i>Nitzschia brevissima</i>	0	0
<i>Nitzschia</i> cf. <i>agnita</i>	2	1
<i>Nitzschia</i> cf. <i>radicula</i>	1	1
<i>Nitzschia</i> cf. <i>vermicularis</i>	0	0
<i>Nitzschia dissipata</i>	3	2
<i>Nitzschia draveillensis</i>	1	1
<i>Nitzschia filiformis</i>	1	1
<i>Nitzschia linearis</i>	0	0
<i>Nitzschia obtusa</i>	1	1
<i>Nitzschia palea</i>	4	1
<i>Nitzschia paleacea</i>	1	1
<i>Nitzschia sigmoidea</i>	2	2
<i>Nitzschia</i> spp.	12	4
<i>Pinnularia</i> sp.	9	2
<i>Rhoicosphenia abbreviata</i>	1	1
<i>Rhopalodia</i> sp.	0	0
<i>Sellaphora</i> sp.	0	0

<i>Staurosirella leptostauron</i>	1	1
<i>Stephanocyclus meneghiana</i>	2	7
<i>Surirella</i> cf. <i>tenera</i>	0	0
<i>Surirella elegans</i> f. <i>elongata</i>	0	0
<i>Surirella minuta</i>	0	0
<i>Surirella</i> sp.	2	2
<i>Synedra acus</i>	2	2
<i>Synedra</i> cf. <i>affinis</i>	1	1
<i>Synedra formosa</i>	0	0
<i>Synedra</i> spp.	15	5
<i>Tabellaria flocculosa</i>	0	0
<i>Thalassiosira</i> sp.	0	0
<i>Ulnaria ulna</i>	11	5
Chrysophyceae		
<i>Ochromonas</i>	1	1
Chlamydomphyceae		
<i>Chlamydomonas</i> sp.	0	0
<i>Pandorina</i> sp.	5	1
Raphidophyceae		
<i>Colponema</i> sp.	0	0
Euglenophyta		
<i>Lepocinclis ovum</i>	1	1
<i>Parmidium</i> sp.	1	1
<i>Phacus</i> sp.	0	0
<i>Trachelomonas volvocina</i>	2	2
Dinophyta		
<i>Peridinium</i> sp.	0	0
<i>Sphaerodinium cinctum</i>	0	0

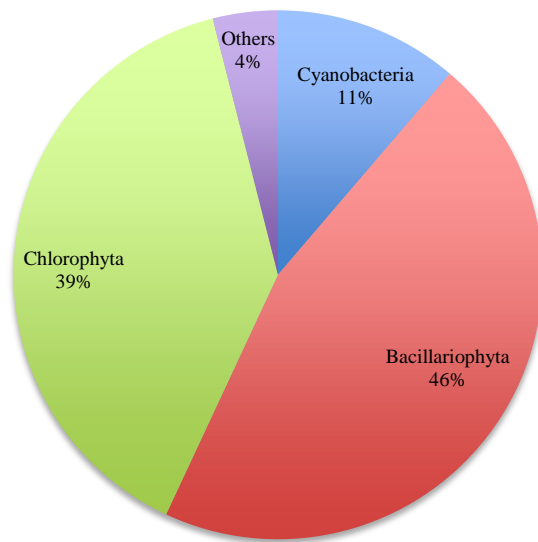


Figure 2.37. Relative composition of different algal phyla on the wooden flowway at Muddy Run.

Species-area curves for two seasonal aggregations of samples from the wood flowway at the Muddy Run Reservoir ATSTM are shown in Figures 2.38 and 2.39. In neither have the slopes reached an asymptote after about 150 cm² of sampled area (spring-summer) and 325 cm² (fall-winter). Moreover, both aggregated seasons present a high number of species, achieving about 100 species in a little over 150 cm² of screen.

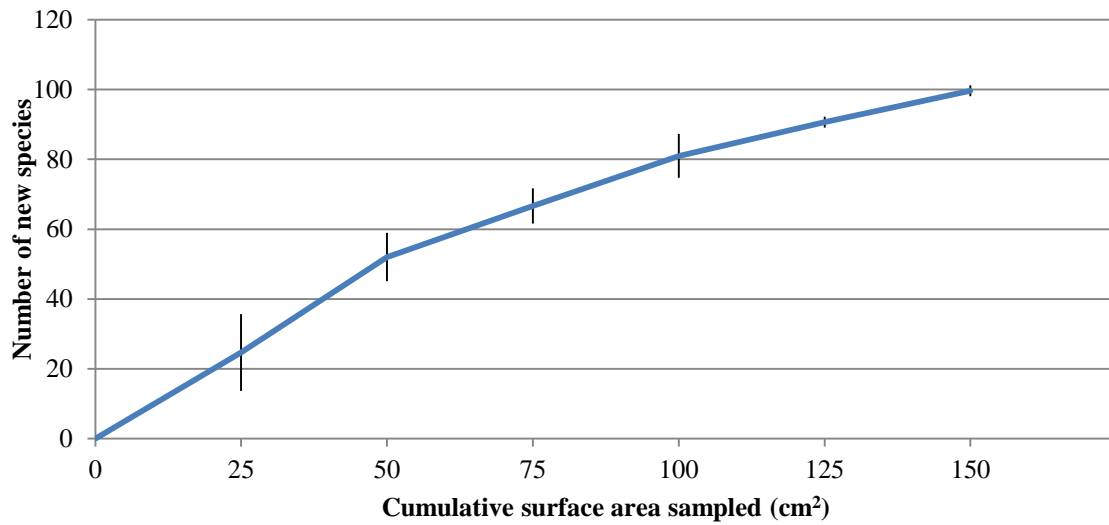


Figure 2.38. Species area curve for the wooden floway data set during Spring-Summer.

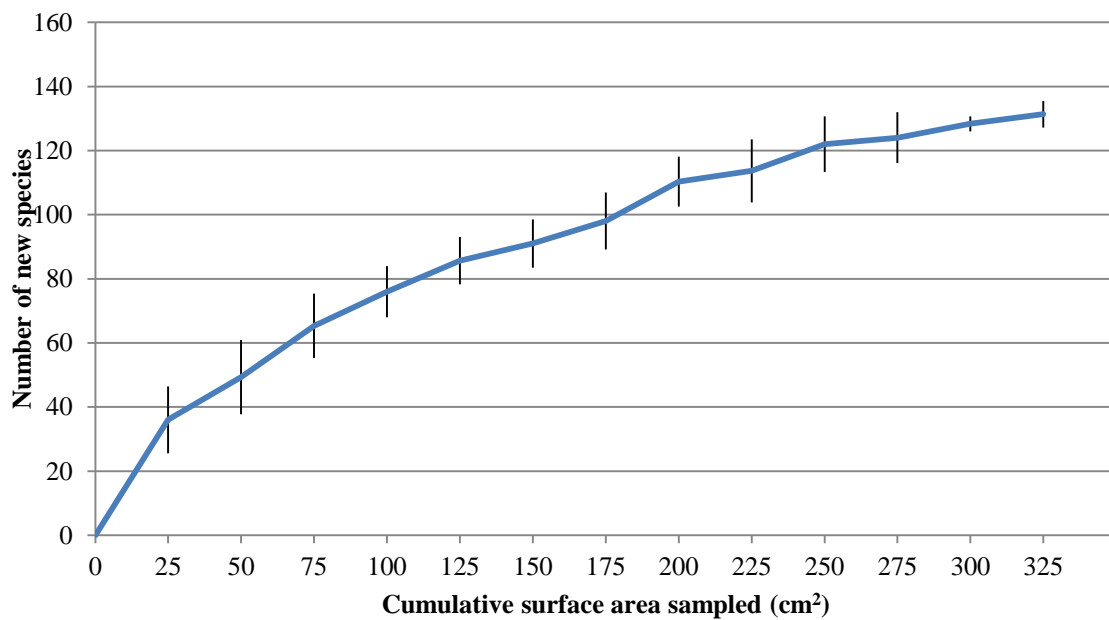


Figure 2.39. Species area curve for the wooden floway data set during Fall-Winter.

Life form distributions are presented in Figure 2.40. Solitary was most common at 48% of the total, though colonial, coenobial, and filamentous species were well represented, with 17%, 17%, and 15% of the total diversity, respectively.

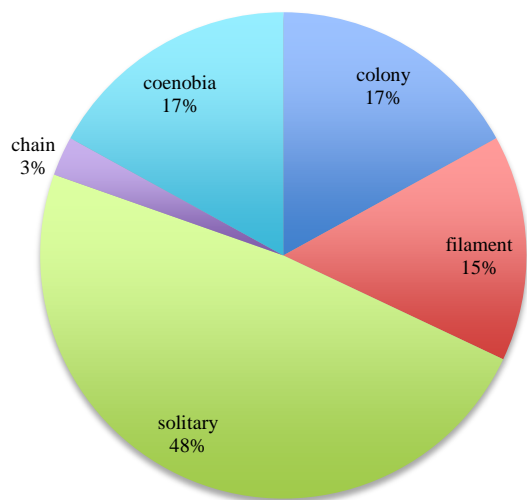


Figure 2.40. Distribution of life forms on the wooden flowway at Muddy Run (by species composition).

Having some species that physically attach to the screen is important for formation of the turf structure. However, only 42% of species attach to the screen, by a mucilaginous structure or holdfast cell, while most species (58%) lack an attachment adaptation (Figure 2.41).

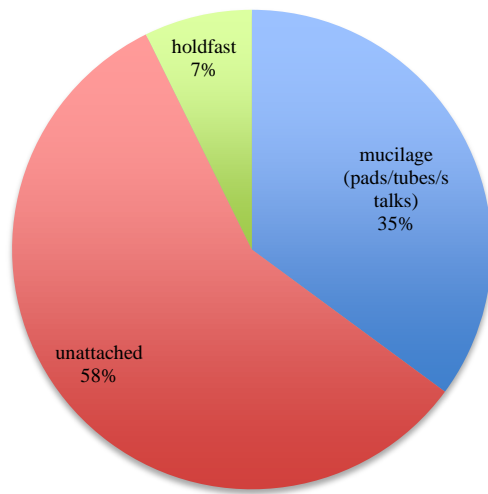


Figure 2.41. Distribution of attachment adaptations on the wooden flowway at Muddy Run (by species composition).

The original habitats of the algal species encountered on the aluminum screens at Muddy Run are shown in Figure 2.42. While most species were benthic (29%), a larger percentage derives from the plankton (28%), showing an important role of this habitat on the community growing on this ATSTM.

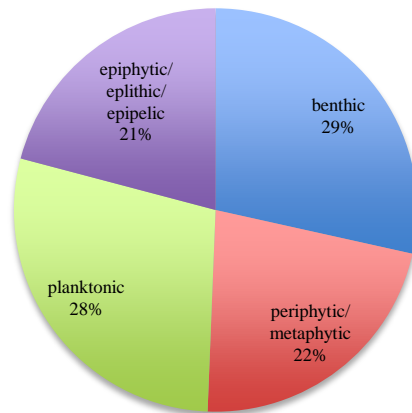


Figure 2.42. Distribution of types of habits of the algae associated to the wooden flowway at Muddy Run (by species composition).

Figure 2.43 compares the relative contribution of microalgae to macroalgae found on the wooden flowway. It was the same percentage as seen on the aluminum flowway, following the pattern as all the other sites in this study.

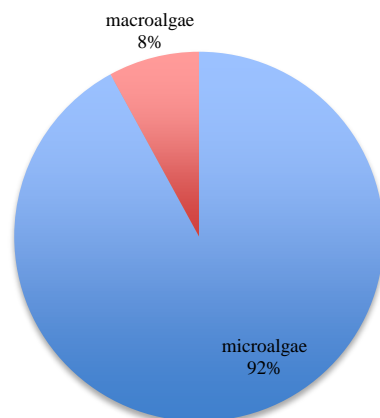


Figure 2.43. Relative contribution of microalgae vs. macroalgae on the wooden flowway of Muddy Run (by species composition).

Similarity among sites

In Table 2.7, lists of species at each site are presented. The studied Chesapeake Bay ATSTM community was compared between each site, and among all three sites, to determine how closely the periphytic community resembles another site's community. It was found that only 4.3% (14 taxa of the 324 total) of the algal community is shared among all three sites (Muddy Run ATSTM, Great Wicomo ATSTM, and VIMS ATSTM). Each site was also compared between each other (pairwise comparison). The Muddy Run algal community was compared to both Great Wicomico and VIMS, and it was found that they share 7.8% (24 shared from 307 taxa) and 6.9% (18 shared from 262) of the total algal community, respectively. The two brackish communities resemble each other more by sharing 34.3% (48 taxa of 140) of their aggregated community. Interesting is that most of the 4.3% of the total shared among the three sites were those taxa that were only identified to genus level (*Amphora* sp., *Caloneis* sp., *Cocconeis* sp., *Gyrosigma* sp., *Leptolyngbya* sp., *Navicula* spp., *Nitzschia* spp., *Pinnularia* sp., *Rhopalodia* sp., *Surirella* sp., *Synedra* sp., *Thalassiosira* sp.) – except for one, *Stephanocyclus meneghiana* – demonstrating the nuances which are lost when higher taxonomic resolution is not achieved.

Table 2.7. List of the periphytic community at the ATS™ floways located at Muddy Run, Great Wicomico, and VIMS.

Species	Muddy Run	Wicomico	VIMS
CYANOBACTERIA			
<i>Aphanocapsa holsatica</i>	1	1	0
<i>Aphanocapsa rivularis</i>	1	0	0
<i>Aphanothece</i> sp.	1	1	0
<i>Asterocapsa</i> sp.	1	0	0
<i>Bacularia vermicularis</i>	1	0	0
<i>Calothrix</i> sp.	0	1	1
<i>Chroococcus minor</i>	1	0	0
<i>Chroococcus minutus</i>	1	0	0
<i>Chroococcus</i> sp.	0	1	0
<i>Cyanobium</i> sp.	0	1	0
<i>Cyanodictyon</i> sp.	0	1	0
<i>Cyanosarcina</i> sp.	0	0	1
<i>Eucapsis carpatica</i>	1	0	0
<i>Eucapsis parallelepipedon</i>	1	0	0
<i>Geitlerinema amphibium</i>	1	0	0
<i>Geitlerinema</i> sp.	0	1	0
<i>Gloethece</i> sp.	0	1	0
<i>Jaaginema</i> sp.	0	1	0
<i>Johannesbaptista pellucida</i>	0	1	0
<i>Leibleinia epiphytica</i>	1	0	0
<i>Komvophoron minutum</i>	1	0	0
<i>Leptolyngbya boryana</i>	1	0	0
<i>Leptolyngbya</i> sp.	1	1	1
<i>Leptolyngbya subtilis</i>	1	0	0
<i>Lyngbya giussepei</i>	1	0	0
<i>Lyngbya martensiana</i>	1	0	0
<i>Lyngbya major</i>	1	0	0
<i>Lyngbya nigra</i>	1	0	0
<i>Lyngbya salina</i>	0	1	1
<i>Merismopedia tenuissima</i>	1	0	0
<i>Nodularia</i> sp.	0	0	1
<i>Oscillatoria curviceps</i>	1	0	0
<i>Oscillatoria froelichii</i>	1	0	0
<i>Oscillatoria princeps</i>	1	0	0
<i>Oscillatoria limosa</i>	1	0	0
<i>Oscillatoria</i> sp.	0	1	1
<i>Phormidium autumnale</i>	1	0	0
<i>Phormidium fonticolum</i>	1	0	0
<i>Phormidium interruptum</i>	1	0	0
<i>Phormidium retzii</i>	1	0	0
<i>Phormidium simplicissimum</i>	1	0	0
<i>Phormidium</i> sp.	0	1	0
<i>Phormidium stagninum</i>	1	0	0
<i>Phormidium tergestinum</i>	1	0	0
<i>Planktolyngbya limnetica</i>	1	0	0
<i>Pseudanabaena galeata</i>	1	0	0
<i>Pseudanabaena limnetica</i>	1	0	0

<i>Pseudanabaena</i> sp.	0	1	1
<i>Spirulina subsala</i>	0	1	1

CHLAMYDOPHYTA

<i>Chlamydomonas</i> sp.	1	0	0
<i>Pandorina</i> sp.	1	0	0

CHLOROPHYTA

<i>Achrochaete</i> sp.	0	1	0
<i>Ankistrodesmus convolutus</i>	1	0	0
<i>Botryococcus braunii</i>	1	0	0
<i>Bulbochaete</i> sp.	1	0	0
<i>Chlorella</i> sp.	1	0	0
<i>Cladophora glomerata</i>	1	0	0
<i>Cladophora</i> sp.	0	1	0
<i>Closteriopsis acicularis</i> var. <i>acicularis</i>	1	0	0
<i>Closterium</i> cf. <i>sublaterale</i>	1	0	0
<i>Closterium</i> sp.	1	0	0
<i>Coelastrum astroideum</i>	1	0	0
<i>Coelastrum</i> cf. <i>cambricum</i>	1	0	0
<i>Coelastrum</i> cf. <i>microporum</i>	1	0	0
<i>Cosmarium</i> cf. <i>margaritatum</i>	1	0	0
<i>Cosmarium</i> cf. <i>pseudoconnatum</i>	1	0	0
<i>Cosmarium</i> cf. <i>pseudoexiguum</i>	1	0	0
<i>Cosmarium</i> cf. <i>sublobulatum</i>	1	0	0
<i>Cosmarium</i> cf. <i>subtumidum</i> var. <i>subtumidum</i> f. <i>minor</i>	1	0	0
<i>Cosmarium formosulum</i>	1	0	0
<i>Cosmarium monomazum</i> var. <i>polymazum</i>	1	0	0
<i>Cosmarium perforatum</i>	1	0	0
<i>Cosmarium</i> sp.	1	0	0
<i>Cosmarium trilobulatum</i>	1	0	0
<i>Cosmarium vexatum</i> var. <i>lacustre</i>	1	0	0
<i>Cylindrocapsa</i> sp.	1	0	0
<i>Desmodesmus alternans</i>	1	0	0
<i>Desmodesmus balatonicus</i>	1	0	0
<i>Desmodesmus bicaudatus</i>	1	0	0
<i>Desmodesmus communis</i>	1	0	0
<i>Desmodesmus denticulatus</i>	1	0	0
<i>Desmodesmus gutwinskii</i>	1	0	0
<i>Desmodesmus intermedius</i>	1	0	0
<i>Desmodesmus opoliensis</i>	1	0	0
<i>Desmodesmus polyspinosus</i>	1	0	0
<i>Desmodesmus</i> sp.	1	0	0
<i>Diacanthos belenophorus</i>	1	0	0
<i>Dictyosphaerium pulchellum</i>	1	0	0
<i>Gloeocystis</i> sp.	1	0	0
<i>Hydrodictyon reticulatum</i>	1	0	0
<i>Kirchneriella lunaris</i>	1	0	0
<i>Klebsormidium</i> sp.	1	0	0
<i>Lagerheimia quadriseta</i>	1	0	0
<i>Microspora floccosa</i>	1	0	0
<i>Microspora quadrata</i>	1	0	0
<i>Microspora wittrockii</i>	1	0	0

<i>Monoraphidium arcuatum</i>	1	0	0
<i>Monoraphidium contortum</i>	1	0	0
<i>Monoraphidium griffithii</i>	1	0	0
<i>Netrium interruptum</i>	1	0	0
<i>Netrium</i> sp.	1	0	0
<i>Oedogonium</i> cf. <i>pluvioporum</i>	1	0	0
<i>Pediastrum biradiatum</i>	1	0	0
<i>Pediastrum boryanum</i>	1	0	0
<i>Pediastrum duplex</i>	1	0	0
<i>Pediastrum simplex</i>	1	0	0
<i>Pediastrum tetras</i>	1	0	0
<i>Pseudendoconium marinum</i>	0	1	0
<i>Pseudocharacium</i> sp.	1	0	0
<i>Quadricoccus verrococus</i>	1	0	0
<i>Rhizoclonium hieroglyphicum</i>	1	0	0
<i>Scenedesmus acuminatus</i>	1	0	0
<i>Scenedesmus acutus</i>	1	0	0
<i>Scenedesmus alternans</i>	1	0	0
<i>Scenedesmus arcuatus</i>	1	0	0
<i>Scenedesmus brevispina</i>	1	0	0
<i>Scenedesmus</i> cf. <i>granulatus</i>	1	0	0
<i>Scenedesmus</i> cf. <i>ovalternus</i>	1	0	0
<i>Scenedesmus dimorphus</i>	1	0	0
<i>Scenedesmus linearis</i>	1	0	0
<i>Scenedesmus</i> sp.	1	0	0
<i>Scenedesmus ecornis</i>	1	0	0
<i>Schroederia</i> sp.	1	0	0
<i>Sphaerocystis schroeteri</i>	1	0	0
<i>Spirogyra</i> cf. <i>rivularis</i>	1	0	0
<i>Staurastrum alternans</i>	1	0	0
<i>Staurastrum</i> sp.	1	0	0
<i>Stigeoclonium tenue</i>	1	0	0
<i>Tetraedron caudatum</i>	1	0	0
<i>Ulothrix</i> cf. <i>tenerrima</i>	1	0	0
<i>Ulothrix</i> cf. <i>variabilis</i>	1	0	0
<i>Ulothrix</i> sp.	0	1	1
<i>Ulothrix zonata</i>	1	0	0
<i>Ulva intestinalis</i>	0	1	1
<i>Uronema elongatum</i>	1	0	0
Unknown green #2	0	1	0
Coccoid green	0	1	0
EUGLENOPHYCEAE			
<i>Euglena</i> sp.	0	1	0
<i>Lepocinclis</i> cf. <i>ovum</i>	1	0	0
<i>Parmidium</i> sp.	1		0
<i>Phacus</i> sp.	1	1	0
<i>Trachelomonas</i> sp.	1	0	0
DINOPHYTA			
<i>Alexandrium</i> sp.	0	1	0
<i>Ceratium</i> sp.	0	1	0
Dino cysts	0	1	0
<i>Dinophysis</i> sp.	0	1	0

<i>Gyrodinium</i> sp.	0	1	0
<i>Katodinium</i> sp.	0	1	0
<i>Peridinium</i> sp.	1	0	1
<i>Prorocentrum</i> sp.	0	1	0
<i>Sphaerodinium cinctum</i>	1	0	0
RAPHIDOPHYCEAE			
<i>Colponema</i> sp.	1	0	0
CRYSOPHYCEAE			
<i>Ochromonas</i> sp.	1	0	0
<i>Chromulina</i> sp.	0	1	0
BACILLARIOPHYTA			
<i>Achnanthes brevipes</i>	0	1	1
<i>Achnanthes</i> sp.	0	1	1
<i>Achnanthidium minutissimum</i>	1	1	1
<i>Actinoptychus senarius</i>	0	1	1
<i>Amphipleura</i> sp.	0	1	1
<i>Amphora</i> cf. <i>pediculus</i>	1	0	0
<i>Amphora libyca</i>	1	0	0
<i>Amphora ovalis</i>	1	0	0
<i>Amphora</i> sp.	1	1	1
<i>Anaulus</i> sp.	0	0	1
<i>Aulacoseira</i> cf. <i>granulata</i>	1	0	0
<i>Bacillaria paxillifer</i>	0	1	1
<i>Brachysira brebissonii</i>	1	0	0
<i>Berkeleya fennica</i>	0	1	1
<i>Berkeleya fragilis</i>	0	1	0
<i>Berkeleya rutilans</i>	0	1	1
<i>Caloneis</i> sp.	1	1	1
<i>Camplyodiscus</i> sp.	0	1	0
<i>Catenula</i> sp.	0	1	0
<i>Chaetoceros</i> sp.	0	1	1
<i>Cocconeis placentula</i>	1	0	0
<i>Cocconeis pediculus</i>	1	1	1
<i>Coscinodiscus</i> sp.	0	1	1
<i>Ctenophora</i> sp.	0	0	1
<i>Cymatopleura solea</i>	1	0	0
<i>Cymatosira</i> sp.	0	1	0
<i>Cymbella</i> cf. <i>affine</i>	1	0	0
<i>Cymbella parva</i>	1	0	0
<i>Cymbella cistula</i>	1	0	0
<i>Cymbella lanceolata</i>	1	0	0
<i>Cymbella leptoceras</i>	1	0	0
<i>Cymbella</i> spp.	1	0	1
<i>Cymbella tumida</i>	1	0	0
<i>Cymbopleura</i> sp.	1	0	0
<i>Cylindrotheca closterium</i>	0	1	1
<i>Dactyliosolen</i> sp.	0	1	0
<i>Denticula</i> sp.	0	1	0
<i>Diademsis</i> cf. <i>contenta</i>	1	1	0
<i>Diatoma</i> cf. <i>mesodon</i>	1	0	0
<i>Diatoma ehrenbergii</i>	1	0	0

<i>Diatoma monoliformis</i>	1	0	1
<i>Diatoma tenuis</i>	1	0	0
<i>Diatoma vulgare</i>	1	0	0
<i>Diploneis</i> sp.	0	1	1
<i>Ditylum brightwellii</i>	0	1	0
<i>Encyonema caespitosum</i>	1	0	0
<i>Encyonema gracile</i>	1	0	0
<i>Encyonema minutum</i>	1	0	0
<i>Encyonema prostratum</i>	1	0	0
<i>Encyonema</i> sp.	1	0	0
<i>Entomoneis</i> sp.	0	1	1
<i>Epithemia</i> sp.	0	1	0
<i>Eucampia</i> sp.	0	0	1
<i>Eunotia</i> sp.	1	1	0
<i>Eunotogramma laevis</i>	0	1	0
<i>Fogedia</i> sp.	0	1	0
<i>Fragilaria capucina</i>	1	0	0
<i>Fragilaria vaucheriae</i>	1	0	0
<i>Fragilaria martyii</i>	0	1	0
<i>Fragilaria</i> sp.	0	1	1
<i>Fragilariopsis</i> sp.	0	0	1
<i>Frustulia vulgaris</i>	1	0	0
<i>Frustulia rhomboides</i>	1	0	0
<i>Frustulia</i> sp.	1	0	0
<i>Gomphoneis</i> cf. <i>minuta</i>	1	0	0
<i>Gomphonema capitatum</i>	1	0	0
<i>Gomphonema</i> cf. <i>angustatum</i>	1	0	0
<i>Gomphonema</i> cf. <i>brasiliense</i>	1	0	0
<i>Gomphonema</i> cf. <i>hastatum</i>	1	0	0
<i>Gomphonema</i> cf. <i>olivaceum</i>	1	0	0
<i>Gomphonema truncatum</i>	1	0	0
<i>Gomphonema</i> sp.	0	0	1
<i>Grammatophora</i> sp.	0	1	1
<i>Gyrosigma attenuatum</i>	1	0	0
<i>Gyrosigma</i> sp.	1	1	1
<i>Hantzschia</i> sp.	0	0	1
<i>Haslea</i> sp.	0	0	1
<i>Hippodonta</i> sp.	0	1	0
<i>Leptocylindrus minimus</i>	0	1	0
<i>Licmophora</i> sp. (long)	0	1	0
<i>Licmophora</i> sp. (short)	0	1	0
<i>Licmophora</i> sp. complex	0	1	1
<i>Luticola</i> cf. <i>geoppertiana</i>	1	0	0
<i>Luticola</i> sp.	0	0	1
<i>Lunella</i> sp.	0	0	1
<i>Lyrella</i> sp.	0	1	0
<i>Mastogloia</i> sp.	0	1	1
<i>Melosira monoliformes</i>	0	1	1
<i>Melosira nummuloides</i>	0	1	1
<i>Melosira</i> cf. <i>italica</i>	1	0	0
<i>Melosira varians</i>	1	0	0
<i>Meridion</i> cf. <i>circularis</i>	1	1	0
<i>Meuniera membranacea</i>	0	1	0
<i>Minidiscus</i> sp.	0	1	1

<i>Navicula capitata</i>	1	0	0
<i>Navicula capitoradiata</i>	1	0	0
<i>Navicula</i> cf. <i>drouetiana</i>	1	0	0
<i>Navicula</i> cf. <i>fonticola</i>	1	0	0
<i>Navicula</i> cf. <i>hungarica</i>	1	0	0
<i>Navicula</i> cf. <i>margalithi</i>	1	0	0
<i>Navicula cryptocephala</i>	1	0	0
<i>Navicula gregaria</i>	1	1	0
<i>Navicula lanceolata</i>	1	0	0
<i>Navicula rhynccephala</i>	1	0	0
<i>Navicula smithii</i>	0	1	0
<i>Navicula</i> spp.	1	1	1
<i>Neidium</i> sp.	1	0	0
<i>Neodelphineis</i> sp.	0	1	0
<i>Nitzschia acicularis</i>	1	0	0
<i>Nitzschia amphibia</i>	1	0	0
<i>Nitzschia angustatula</i>	1	0	0
<i>Nitzschia brevissima</i>	1	0	0
<i>Nitzschia</i> cf. <i>agnita</i>	1	0	0
<i>Nitzschia</i> cf. <i>radicula</i>	1	0	0
<i>Nitzschia vermicularis</i>	1	0	0
<i>Nitzschia dissipata</i>	1	0	0
<i>Nitzschia draveillensis</i>	1	0	0
<i>Nitzschia filiformis</i>	1	1	0
<i>Nitzschia fusiliformis</i>	0	1	0
<i>Nitzschia linearis</i>	1	0	0
<i>Nitzschia longissima</i>	0	1	0
<i>Nitzschia nana</i>	0	1	0
<i>Nitzschia obtusa</i>	1	0	0
<i>Nitzschia palea</i>	1	0	0
<i>Nitzschia paleacea</i>	1	0	0
<i>Nitzschia scalpelliformis</i>	0	1	0
<i>Nitzschia sigma</i>	0	1	0
<i>Nitzschia sigmaformis</i>	0	1	0
<i>Nitzschia sigmoidea</i>	1	1	0
<i>Nitzschia tryblionella</i>	0	1	0
<i>Nitzschia ventricosa</i>	0	1	0
<i>Nitzschia</i> spp.	1	1	1
<i>Opephora</i> sp.	0	1	1
<i>Paralia sulcata</i>	0	1	0
<i>Parlibellus</i> sp.	0	1	1
<i>Pinnularia</i> sp.	1	1	1
<i>Plagiogramma</i> sp.	0	1	0
<i>Plagiotropis</i> sp.	0	1	1
<i>Pleurosigma</i> cf. <i>fasciola</i>	0	1	1
<i>Podocystis</i> sp.	0	1	0
<i>Psammothidium</i> sp.	0	1	0
<i>Pseudonitzschia</i> cf. <i>multiseries</i>	0	0	1
<i>Pseudonitzschia</i> cf. <i>pungens</i>	0	0	1
<i>Pseudonitzschia</i> sp.	0	0	1
<i>Pseudostaurosira</i> sp.	0	1	0
<i>Rhaphoneis</i> sp.	0	1	0
<i>Rhizosolenia</i> sp.	0	1	0
<i>Rhoicosphenia abbreviata</i>	1	0	0

<i>Rhopalodia</i> sp.	1	1	1
<i>Sellaphora</i> sp.	1	0	1
<i>Sieminskia</i> sp.	0	1	0
<i>Skelatonema costatum</i>	0	1	1
<i>Stauroneis</i> sp.	0	0	1
<i>Stauronella</i> sp.	0	1	1
<i>Staurosirella leptostauron</i>	1	1	0
<i>Stephanocyclus (Cyclotella) meneghiana</i>	1	1	1
<i>Striatella</i> sp.	0	1	0
<i>Surirella</i> cf. <i>tenera</i>	1	0	0
<i>Surirella elegans</i> f. <i>elongata</i>	1	0	0
<i>Surirella minuta</i>	1	0	0
<i>Surirella</i> sp.	1	1	1
<i>Synedra acus</i>	1	0	0
<i>Synedra</i> cf. <i>affinis</i>	1	0	0
<i>Synedra formosa</i>	1	0	0
<i>Synedra</i> sp.	1	1	1
<i>Synedropsis</i> sp.	0	1	0
<i>Tabellaria flocculosa</i>	1	0	0
<i>Tabellaria</i> sp.	1	0	0
<i>Tabularia tabulata</i> .	0	1	1
<i>Thalassionema nitzschiodes</i>	0	1	0
<i>Thalassiosira</i> sp.	1	1	1
<i>Ulnaria ulna</i>	1	0	0
Unidentified diatom	0	1	1
Centrales	0	1	0
RHODOPHYTA			
<i>Ceramium</i> sp.	0	0	1
<i>Polysiphonia</i> sp.	0	1	0

Discussion

In the aquatic environment algae are typically planktonic or benthic. Benthic algae are mostly cyanobacteria, chlorophytes, diatoms, rhodophytes, and/or phaeophytes. Previous work carried out by researchers on ATSTM systems in Florida and in California demonstrated that the systems were dominated by filamentous green algae in both diversity and abundance (Craggs et al., 1996; Adey et al., 2011). When comparing the VIMS ‘species-pool’ data with the ATSTM taxa (Tables 2.1 & 2.7), 27% of the taxa (31 of 116 total) are shared with the plankton, 21% (19 of 89 total) was shared with the sediment, and 40% (31 of 78 total) with the macroalgal epiphytes. Thus, these data

demonstrate that these ATSTM systems are actually dominated by microalgal epiphytes growing on macroalgae growing in the source waters, which are carried through the plankton, and then attach to the screen. The mechanism of attachment in which they attach is mostly through mucilaginous structures. Researchers have demonstrated that the epiphytic algae on macrophytes are capable of accumulating 40-70% of the phosphorus added to the water column in controlled mesocosms (Havens et al., 1999b), which is important since this demonstrates that although these are not the ‘periphytic/benthic’ algae, they still are functionally capable to ‘scrub’ the water of nutrients, which is the principal application of ATSTM (Adey et al., 2011). Mucilage is also fascinating since Whitton et al. (2009) demonstrate the importance of the mucilage in diatoms as the site of most phosphatase activity in the organism.

The differences in the community structure analyzed during this study can be attributed in part to the artificial substrate (ATSTM screen) continuously undergoing colonization and succession of species, from the time it was exposed to the aquatic environment and after each harvest, when it is a partially empty habitat for species to colonize, while other species maintain their basal cells or whole cells attached to the substratum after every harvest. According to Ricklefs (1996), creating a new habitat invites numerous species, especially those well adapted, considered invasive, to inhabit. According to this author, these first colonizers are followed by others that are slower in taking advantage of the new habitat, but are eventually more successful than the pioneer-species. With this characteristic, the community changes over time. Due to the harvest of the ATSTM, a distinct characteristic that maximizes productivity, these subsequent species are sometimes not allowed to colonize the screens.

Algal turfs are dynamic, as seen in Fig. 2.11. Diatoms are always present and abundant, although different species become dominant during different times of the year. *Tabularia tabulata*, *Nitzschia sigmaidea*, and *N. sigma* are most abundant from July to September, but when winter comes these species are not found, while other taxa, such as *Nitzschia nana*, *Thalassionema nitzschioides*, and *Thalassiosira* sp. are found. However, as a group, chlorophytes increase during late spring and late summer at Wicomico, though at VIMS this happened differently. Since the system encountered at VIMS contained a high amount of silt (data not shown), it could have influenced the algal dynamics (van Vuuren & Pieterse, 2005). The cyanobacteria were abundant in fall due to the large amount of two taxa at Wicomico, first, in mid-September, *Gloeothece* sp. was dominating the periphyton and afterwards *Lyngbya salina* was present. This same species increased at VIMS, though was found at the end of the experiment, thus it was not possible to verify if this was an anomaly or would maintain stable throughout the season (Figs. 2.11, 2.20, and 2.29).

Species of *Pseudonitzschia* increased during October/November 2009. These were probably filtered from the plankton, since these do not have an attachment mechanism. *Skeletonema costatum* peaked between March and July/2010, while *Stauronella* sp. was most abundant between May/July 2010. *Ulva intestinalis* had two small 'peaks' during the yearly cycle on the ATSTM, one in late fall and the other in late spring, while the large increase in cyanobacteria towards the end of the study period was mainly due to two species of cyanobacteria readily present during the study, though exponentially grew towards the end, *Lyngbya salina* and a nostocalean species capable of fixing atmospheric nitrogen, *Calothrix*.

Life forms (Figs. 2.5, 2.15, 2.24, 2.33, and 2.40) are important in determining the structure of the turf communities. The filamentous species along with the chain-forming species to a lesser degree comprise the overstory of the turf, which generally give physical character to the turf. These species can be thought of as “ecosystem engineers” (Kangas, 2004) due to their role in structuring the system. The remaining life forms are found in the understory. These species generally have a more passive role in the structure of the turf since they exist as mostly single-cells in the multicellular, mucilaginous matrix of the filaments. In all likelihood, the matrix of filaments creates microzones of reduced flow rates that act as refuges for the solitary cells that might otherwise be swept away by currents. Also, the filaments may physically filter suspended cells from the passing currents.

Overall, the ATSTM flowways in this study were dominated by diatom communities (Figs. 2.2, 2.10, 2.11, 2.12, 2.19, 2.20, 2.21, 2.28, 2.29, 2.30, and 2.37) specialized to living on the benthos and by those organisms adapted to living attached to other substrata by mucilage (epiphytes), rather than periphyton and hard bottom algal turf communities. Predominance of diatoms, can be related, in part, to the higher quantity of ubiquitous and opportunistic species that possess a variety of mechanisms to adapt to life on diverse substrates, such as mucilaginous stalks that fix to the substrate (Achnanthes, Cymbellales, and Tabellariales) and pores of mucilage capable of facilitating adhesion to the substrate (Naviculales and Fragilariales). Diatoms represent the most important component of the periphytic community during the initial stages of succession on glass slides (Lam & Lei, 1999; Sheath & Wehr, 2003), as well as on plastic plants (Cattaneo & Kalff, 1978). Studies have also shown (Hoagland et al., 1982; Biggs, 1996) that due to

constant grazing (in natural communities) or periodic harvesting (ATSTM) (Laughinghouse, 2010), which happens weekly to biweekly on the ATSTM flowways (dependent on seasons), the system is expected to be dominated by rapidly growing diatoms, since the more morphologically ‘complex’ chlorophytes only occur in those systems which have longer periods for growth, and freshwater rhodophytes and phaeophytes are rare, found mostly in oligotrophic conditions or those with a slight influx of salinity. The periodic harvest maintained both the species abundance and species richness in the diatoms. In addition, several studies of periphyton using glass/plastic slides have shown how diatoms are the group that copes best on artificial substrates (Ács & Kiss, 1993; Albay & Akcaalan, 2003). The species which attach to the substrate, if found in the plankton, are not ‘true’ plankters, being mixed from the benthic habitat in which they occur.

Of the studied sites, the most diverse was Muddy Run, followed by Wicomico then VIMS (Table 2.8). The largest difference noted in this comparison is that Muddy Run was much more diverse than the other two sites, especially concerning chlorophytes. The Muddy Run site was different than Wicomico and VIMS since it was freshwater, and there is a natural ‘dip’ in species diversity towards estuarine systems (Remane & Schlieper, 1971), which can be attributed in part to the species’ capability of osmoregulation, both freshwater species to salt and marine species to fresh waters. Also, Muddy Run was different in the way the incoming water entered the systems, which could also partly explain this large diversity. As was explained in Chapter 1, incoming water for the flowways located here came from the bottom of the Muddy Run Reservoir, which is filled from and drains back into the Susquehanna River daily during the

operation of Exelon’s pumped-storage hydroelectric facility. Thus, the water input into the ATSTM is modified from ambient river conditions by a retention time in this reservoir, providing more source communities of both lentic and lotic environments to the ATSTM flowways. However, the most pertinent factor observed for the increase in Chlorophyta for Muddy Run is attributed to the more species-rich (freshwater) Chlorococcales, Sphaeropleales, and Zygnematales. These were readily present on the ATSTM and are groups that do not survive in waters with salt.

Surprisingly the two estuarine locations – Wicomico and VIMS – had large differences in total taxa. While salinity did not differ greatly at both locations, only by 3-4, this is not ascribed as the factor causing this major difference. Most likely, the difference in these two locations is caused by sampling effort, since there were 74 samples taken at Wicomico and only 55 samples at VIMS, hence the possibility of finding more species. Furthermore, two ATSTM flowways were sampled at Wicomico, just one at VIMS, which had variations in construction and could have favored the growth of different taxa. However, local environmental factors could also have influenced these differences.

Table 2.8. Total taxa of each algal group on the ATSTM flowways at the different studied sites.

	Muddy Run	Wicomico	VIMS
CYANOBACTERIA	34	16	8
CHLAMYDOPHYTA	2	0	0
CHLOROPHYTA	79	7	2
EUGLENOPHYCEAE	4	2	0
DINOPHYTA	2	7	1
RAPHIDOPHYCEAE	1	0	0
CHRYSOPHYCEAE	1	1	0
BACILLARIOPHYTA	95	86	56
RHODOPHYTA	0	1	1
TOTAL	218	120	68

The periphytic community showed seasonal successions throughout the year (Figs. 2.11, 2.20, and 2.29), with the most dramatic changes from a spring-summer flora to an autumn-winter flora at all sites, since this reflects the own physiological preferences of the species capable of functioning at these different times. Seasonal successions usually depend on seasonal variations of the physical environment, such as temperature and light, but can also be caused by nutrient changes. In freshwater systems, *Spirogyra* and *Melosira varians* are the most dominant species found during the summer, while *Diatoma vulgare*, *Fragilaria capucina* and *Tabellaria flocculosa* are the most abundant during the winter months. This is probably due to seasonal preferences of these species. Also, there was a drastic shift from the freshwater to the brackish water species, likely due to the species' capability of osmoregulating the salt content (Table 2.7).

As commented previously, diatoms dominate the flowways in all of the ATSTM systems studied from the Chesapeake Bay, in both biomass and species richness, oscillating from 51% to over 83% of the total abundance during harvest periods and 46% to 82% of species richness depending on the system and/or the season (2.2, 2.10, 2.11, 2.12, 2.19, 2.20, 2.21, 2.28, 2.29, 2.30, and 2.37). However, there were certain 'zones' in the flowways, which were dominated by other groups. *Ulva intestinalis* was dominant at the top of the flowways in the estuarine systems, especially on the dump buckets (used to promote the wave actions). It is true that these dump buckets were not harvested as routinely as the flowway, thus allowing *Ulva intestinalis* to grow thicker, but the higher energy of the top portions of these systems favored its growth (Brodie et al., 2007), and these were routinely harvested. Furthermore, in the freshwater flowways, the thick

cyanobacterial mats are abundant at the highest water turbulence, possibly partly due to the mucilaginous matrix capable of holding the filamentous together, while other taxa without this secretory ability would be displaced down screen. In the freshwater systems, species of *Ulothrix* were readily found dominating at the top.

Understanding the mode in which algae attach to the systems can support future changes in design parameters to favor a certain community. Both the diversity and abundance are greatest in the diatoms, which do not have a specialized holdfast cell, such as the morphologically complex chlorophytes, adapted to a more turbulent environment. The diatoms attach by mucilage, mucilaginous stalks, pads, or forming tubes. Figures 2.7, 2.16, 2.25, and 2.34 compare the attachment mechanisms in which the turf algae ‘fix’ themselves to the screen. By diversity, most species are ‘unattached’, or those species that are not fixed; however, by abundance most species (64%-80%) attach using mucilage. This mucilage is composed of complex polysaccharides, which secrete in certain groups of diatoms through ocelli and adhere to the substrate, fixing the diatom (Daniel et al., 1987). Mucilage in diatoms has even been shown to protect against erosion, when dense populations form pellicles over the sand, protecting it against wave action (Holland et al., 1974).

Some of the most abundant and frequent species of diatoms found in the freshwater ATSTM systems are *Melosira varians*, *Diatoma vulgare*, *Fragilaria* spp. (e.g. *F. capucina*), *Gomphonema* spp. (e.g. *G. olivaceum* and *G. truncatum*), *Navicula* spp. (e.g. *N. gregaria*, *N. lanceolata*), and *Nitzschia* spp. (e.g. *N. dissipata*). In the estuarine systems, the diatoms encountered are the tube-forming *Berkeleya rutilans* and *Navicula smithii*, *Melosira nummoloides*, and species of *Licmophora*, *Gyrosigma*, and *Nitzschia*.

As commented previously, diatoms, like other algae, can be found naturally in many environments, though the genera *Gyrosigma*, *Navicula*, and *Nitzschia* are common on the sediment or strictly part of the silt flora, also on rocks, which are covered with fine sediment. *Diatoma vulgare* and *Gomphonema* spp. are commonly found growing on rocks (sometimes plants) in rivers, and are capable of massive growths (Biggs, 1996; Kelly, 2000). *Fragilaria* are found in various habitats, like the plankton in lakes or on sediments and plants in rivers. *Melosira varians* forms 'loose-flocs' on riverbanks especially in the slower moving parts of the river (Kelly, 2000). These are easily broken apart, since the filaments lack the tensile strength to consistently remain attached in the moderate energy environments, releasing the frustules into the water column of the river, where they are able to move downstream and re-colonize. *M. varians* is a freshwater species; however, in brackish environments species such as *M. nummuloides* can be found in similar habitats (Kelly, 2000). *Berkeleya rutilans* grows in estuarine-marine environments, attached to the rocks, forming colonies resembling macroscopic seaweeds, though having a free living state during times of the year (Lobban, 1984).

Chapter 3: Longitudinal patterns of periphytic algal communities of ATS™ systems at Muddy Run Reservoir, PA

Introduction

Throughout the 21st century, water quality will be an important factor for the survival of humanity and the biosphere as a whole. Population growth and extreme demands on aquatic resources are some of the fundamental causes of the crises with water, which have arisen (Tundisi, 2005). In this sense, Wetzel (2001) highlights the need for detailed knowledge on the functional properties of waters to assess the influence that human activities have on their characteristics, maximizing the need for management of water resources. This author, among many others, recognizes anthropogenic eutrophication as one of the most apparent impacts of mankind on aquatic ecosystems.

Enrichment by phosphorus and/or nitrogen is considered one of the main causes of eutrophication (Tundisi & Matsumara-Tundisi, 1992). At low concentrations, these nutrients limit algal growth, including periphyton, and when available in larger quantities, are rapidly assimilated stimulating structural and functional alterations in the aquatic communities (Dodds, 2003).

The periphytic community is an intricate three-dimensional community where subsequent taxa overgrow earlier colonizers, acquiring nutrients and resources from the water column, unless capable of heterotrophy or nitrogen fixation (Stevenson & Glover, 1993). This community succession, similar to what happens in plant vegetation dynamics (Pickett et al., 2009), is due, in part, to the species' different growth rates, nutrient tolerances, morphological guilds, capability to acquire resources, allelopathy, among other factors (McCormick & Stevenson, 1991; Suikkanen, 2008; Passy & Larson, 2011).

This community is well represented in shallow ecosystems, considering that in these ecosystems there are several surfaces for its development, such as aquatic macrophytes, rocks, and sediments. Studies carried out during the last two decades (Wetzel, 1990, 1996) have demonstrated how these communities dominate in these ecosystems worldwide. These studies initiated an interest in the role of periphyton in aquatic ecosystem metabolism, principally consisting as the dominant source for synthesis of organic matter (Wetzel, 1990, 1996).

Several reasons have lead to the increasing use of periphyton in environmental studies, for example: a) its role as a chemical modulator, converting many inorganic forms into organic forms in the aquatic ecosystem (Stevenson, 1996); b) sessile mode of life, along with its short life cycle, which allows periphyton to respond quickly to changes in water quality, making it ideal for monitoring (Lowe & Pan, 1996; Stevenson, 1996); c) in relation to other groups of aquatic organisms, the community of periphytic algae is usually species-rich, providing a rich information system for environmental monitoring (Lowe & Pan, 1996); and d) it includes the quality of the water column, as well as the substrate to which it is associated, integrating both water and sediment quality, the latter where most substances that deteriorate environmental quality are accumulated (Lowe & Pan, 1996). Furthermore, periphyton is adequate for general hypotheses related to community colonization, succession, diversity, and stability, by having short generation times and constituting in a community that is spatially compressed, with well defined limits and considered a 'model ecosystem' (Stevenson, 1996).

Experimental studies with the periphytic community have been conducted evaluating the effects of enrichment on species diversity and/or characterization of algal species with disturbances (Carrick et al., 1988; Hillebrand & Sommer, 2000), phytoplankton and periphyton interactions (Havens et al., 1996), predicting the effects of eutrophication on productivity and water quality (Manny et al., 1994), simulating food web interactions and nutrient dynamics (Istvánovics et al. 1986), evaluating limiting nutrients in the environment (Francoeur et al., 1999; Huszar et al., 2005), among others. Considering that phosphorus (P) is often the key factor triggering eutrophication in freshwater environments, many experimental studies with periphyton have focused on the dynamics of this element in freshwater systems and to its effect on biodiversity. Such work has intensified since 1990.

The composite macrophyte with periphytic communities can substantially reduce inorganic nutrients in the pelagic region of aquatic systems. Various authors have reported the capacity of periphyton in removing nutrients from water (Havens et al., 1999a,b; Pizarro et al., 2006; Mulbry, 2008; Adey et al., 2011). Phosphorus, in particular, tends to be highly conserved in the macrophyte/periphyton/sediment associations (Wetzel, 1990). Within the periphytic 3D complex, this element is heavily recycled between autotrophic and heterotrophic components, largely assimilated by the periphyton, with little or nothing going to the open water (Wetzel, 1990, 2001).

Cronk & Mitsch (1994) evaluated periphytic productivity against different hydrological regimes and nutrient loads using artificial wetlands. They found that periphytic assemblages could serve as an indicator of nutrient availability in the water column, since the community responded to both concentration and nutrient loading in

these wetlands with higher productivity correlating with higher flow and higher nutrient availability. Also, using an experimental approach, Havens et al. (1999b) estimated that periphyton accumulated 40-70% of the phosphorus added to the water column over 28 days, introduced in wetland mesocosms. In a study comparing periphytic and phytoplanktonic communities, Havens et al. (2001) found that most of the phosphorus taken up in the littoral region was removed by the periphyton. This information reinforces the models by Sand-Jensen & Borum (1991), Goldsborough & Robinson (1996), and McCormick et al. (1998), which predict that attached algae dominate in terms of biomass and phosphorus content in relatively shallow systems with high irradiance.

Recent information on wetlands in Florida have reinforced the hypothesis of the role of periphyton in phosphorus removal, thus contributing to the maintenance of low concentrations of this element in water, soil, and macrophytes (McCormick et al., 2001; Havens et al., 2004), through the assimilation of excess phosphorus released by human activities in these systems. Besides this aspect, McCormick & Stevenson (1998) obtained promising results for establishing a threshold of P from which the balance of the system is changed by the characterization of oligotrophic periphyton assemblages, through a transitional community, to a final eutrophic assemblage. These authors emphasized that periphyton is sensitive to P enrichment, which can be used to detect early signs of eutrophication before other ecological changes are noted. Thus the use of the periphytic community in studies of anthropogenic impact assessment and to propose measures to restore impacted ecosystems is highly promising.

In summary, the studies point to the importance of periphyton not only for the diagnosis of environmental impact, but also to detect early signs of eutrophication and to establish recovery goals (McCormick & Stevenson, 1998; McCormick et al., 2001).

Longitudinal patterns in streams have been widely studied and are critical in the way these are viewed (Vannote et al., 1980; Fisher et al., 1982, 1983; Mulholland & Rosemond, 1992). For example, uptake of nitrogen in upstream reaches of streams can lead to longitudinal depletion, thus dominance of cyanobacteria in lower reaches (Fisher et al., 1982), since certain species of cyanobacteria are capable of fixing atmospheric nitrogen, under these conditions, and have a competitive advantage over the other algal species. In the river continuum concept, Vannote et al. (1980) comment how upstream communities are capable of influencing communities downstream through nutrient dynamics. Since the ATSTM is a continuous flow system, much like a lotic system, it is logical to assume that longitudinal patterns would occur in longer systems, due to self-organization of the periphytic community, nutrient depletion, maturity, and succession.

As described in Chapter 1, ATSTM is an ecologically engineered, flowway system for utilizing algal photosynthesis and growth to control a wide variety of water quality parameters. Developed in the early 1980's as a biomimic of coral reef primary productivity, ATSTM was initially used as a tool to manage an extensive series of living microcosm and mesocosm models of wild ecosystems (Adey & Loveland, 2007). During the 1990's and early 21st century, this ecological technology was successfully scaled-up for nutrient removal, from point-source and open waters, and ATSTM use ranged from aquaculture and tertiary treatment of sewage to agricultural canal amelioration of nutrients (Adey et al., 2011).

ATSTM was developed as a simple, flow-through, low cost means of utilizing algal photosynthetic and productivity potential using attached algae for remediating waters and growing a viable algal biomass that can be used for by-products. In the design of ATSTM, capital costs² are highest at the top and bottom of the ATSTM flowways, with low costs in the ‘trough’; where algae grow. Thus it is critical to understand maximum lengths in which these ATSTM flowways can be constructed, maximizing productivity and nutrient uptake, without losing biomass production, while understanding the species frequency on a longitudinal scale, relative to the functional role of species.

The aim of this chapter is to examine longitudinal patterns of the ATSTM units located at Muddy Run hydroelectric Power Plant. The Muddy Run system was chosen because it was longer than any other ATSTM included in this dissertation. Special attention is given to the top, middle, and bottom sections of these flowways, in order to examine longitudinal patterns. Each section is of 100 ft (30.5m) long. Several approaches at examining the longitudinal patterns are used: a specialization index, χ^2 test of deviation of a species’ distribution from an idealized distribution of equal, and a visual graphic of distribution frequency. Both patterns of nutrient uptake into biomass and species composition are investigated, while examining relationships between these two parameters.

² Capital costs refer to all the costs regarding the equipment and processes to pump water into the ATSTM flowway and from the ATSTM back into the main aquatic body to which it is ‘connected’.

Materials and Methods

Study Area

The ATSTM systems were located in SE Pennsylvania, near Lancaster, on the banks of the Susquehanna River. Incoming water came from the Muddy Run Reservoir, which is filled from and drains into the Susquehanna River daily during the operation of Exelon's pumped-storage hydroelectric facility. Thus the water input into the ATSTM is modified from ambient river conditions by retention time in this reservoir. Details of the ATSTM systems are given in Table 1.1.

Nutrients³

Water samples (0.1L) were collected at the inflow and outflow of the ATSTM before harvests in the late morning or early afternoon in order to quantify the maximum effect of metabolism of the algal community. These samples were acidified and stored at 4°C for analysis of total nitrogen (TN), total phosphorus (TP), nitrate (NO₃), and orthophosphate (PO₄). The samples were also analyzed for ammonium, but the resulting values were below detection limits or non-interpretable. Biomass samples (0.93m² sections for the aluminum flowway and 0.74m² sections for the wood flowway in replicates of 2) were analyzed for N and P after oven-drying. TN was determined using total Kjeldahl block digestion followed by flow injection analysis (Model 8000, Lachat Instruments, Milwaukee, WI) (APHA, 1995). Elemental analyses were verified using inductively coupled plasma analysis (APHA, 1995).

³ Data supplied by the thesis work of P.J. Klavon.

Algal Sampling

Periphytic samples from the screen were collected at the top, middle, and bottom sections on the aluminum ATS™ on 23/Jul/2008, 01/Aug/2008, 13/Aug/2008, 07/Mar/2009, 17/Jul/2009, and 09/Oct/2009 and wood ATS™ on 27/Oct/2008, 13/Aug/2008, 07/Mar/2009, 17/Jul/2009, and 09/Oct/2009, and samples were brought live for analysis at the National Museum of Natural History (NMNH). At NMNH samples were examined live and/or preserved in 4% formaldehyde or in acidic Lugol's. For each date, frequency data (presence/absence) was recorded for the samples at the top, middle, and bottom sections.

Qualitative analysis

Samples were examined between a slide and coverslip using an Olympus BX50 binocular light microscope (LM) in duplicate (n=2) for each sample site. For diatom identification, a sub-sample (20 ml) was boiled in 30% hydrogen peroxide in a 1:1 sample ratio, adding potassium dichromate concentration during the process to speed oxidization, until returning to the original volume with D1. The cleaned material was concentrated in a centrifuge, and rinsed several times with distilled water until reaching a neutral pH. This material was diluted into 3 different dilutions, air dried on coverslips, and processed for either LM or scanning electron microscopy (SEM).

For LM, coverslips were allowed to dry overnight, and mounted onto glass slides with the high refractive index (1.704) mounting medium Cargille Meltmount™ (Cargille-Sacher Laboratories, NJ). The samples were then analyzed under 400x or 1000x (oil

immersion) using an Olympus Bx50 compound microscope with phase contrast. Morphological characteristics were recorded for the taxa for specific delimitation, i.e., valve/cell diameter and length, diameter of central area, striae length, density, and number. For SEM, coverslips were mounted on specimen stubs and sputter-coated with a gold/palladium alloy (10 nm) analyzed using a Leica Stereoscan 440 SEM.

The following specific literature for identification was used for each group: Bacillariophyta (Krammer & Lange-Bertalot, 1986, 1988, 1991, 1991; Cox, 1996; Round et al., 1990); Cyanobacteria (Komárek & Anagnostidis, 1998, 2005); Chlorophyta (Prescott, 1982; Bicudo & Menezes, 2005; John & Williamson, 2009) in addition to using some regional floras (Prescott, 1982).

All samples and slides are maintained in the National Museum of Natural History, Smithsonian Institution.

Longitudinal patterns in algae: Specialists vs. generalists

To determine the presence of generalist or specialist species longitudinally, a specialization index was created, where a null hypothesis was proposed that the percent total frequency of each species would be equal between the top, middle, and bottom of the flowways. This is a frequency of 33% for a species for each section, since the total frequency that a species can occur on the flowway is 100%, and 33% is this total divided among the three sections. To categorize the deviation of the taxa from the null hypothesis (33%), the following formula was used: Specialization Index = $|(\% \text{ top} - 33\%)| + |(\% \text{ middle} - 33\%)| + |(\% \text{ bottom} - 33\%)|$ (Tables 3.6, 3.7). Thus the index ranges from 0 (complete mapping of null hypothesis: i.e., 33% top, middle and bottom) to

133 (for example, 100% at top and 0% at the middle and bottom). This index does not indicate where a species is found most frequently, but it is a quantitative index of how far a species' longitudinal distribution differs from being evenly distributed along the ATSTM flowway.

Statistical treatment

The results were initially evaluated using descriptive statistics, with graphs of means and histograms. Species frequency of algae among the systems on a longitudinal scale was calculated. To assess longitudinal patterns in nitrogen and phosphorus removal rates [gN or gP m² day⁻¹ calculated by biomass harvest (g m² day⁻¹) multiplied by the nutrient concentration in %] along the aluminum and wood ATSTM flowways, linear regressions between each of these parameters were computed for each sampling date and tested for significance of slopes (Tukey) with comparisons made between samples taken on three longitudinal sections: the top 100 ft (30.5m), the middle 100 ft (30.5 m), and the bottom 100 ft (30.5m). One-way analysis of variance (ANOVA) was also used to test the difference of each section. The linear regression was applied to test/determine if there was a significant linear component (i.e., if the slope of the line was different than 0), allowing either an ascending or descending pattern in each nutrient analyzed in the ATSTM relative to the length of the flowway. The statistical program SPSS (IBM, New York) was used to carry out these analyses.

To assess pattern in species longitudinal distributions, the deviation from the null hypothesis (33%) (i.e., expected value) was tested using the χ^2 test for the most dominant (>50% frequency) taxa (Tables 3.4, 3.5; Appendix 16, 17).

Results

Nutrients

Mean nutrient concentrations (n=17) of the incoming water for the sampling period from 2008 to 2009 were: 0.89 mg L⁻¹ (NO₃), 1.38 mg L⁻¹ (TN), 0.06 mg L⁻¹ (PO₄), and 0.12 mg L⁻¹ (TP). These nutrients decreased with algal growth as the water passed through the ATSTM flowway, where the turnover time of water in the systems was between 7 and 10 min. Midday removal percentages are presented in Table 3.1, which are point measurements during a diurnal cycle, remembering that ecosystem metabolism is highest at midday.

Table 3.1. Mean nutrient removal at midday during spring-fall 2009 (n=17). Data calculated by dividing outflow concentrations (bottom) by inflow concentrations (top) and multiplying by 100 (Kangas et al., 2010).

Nutrient	Aluminum ATSTM	Wood ATSTM
NO₃	18%	27%
PO₄	17%	50%
TN	28%	37%
TP	9%	17%

Nutrients in Biomass

The biomass production rate was found by the harvested mass by unit area divided by the number of days in which growth took place (time between harvests). Nutrient uptake by the ATSTM was found by multiplying the biomass production rate (g dry weight/m²/day) by the nutrient contents of the biomass (% of the biomass made up of N and P). Mean harvested biomass (production) is presented in Figure 3.1. Mean

percent nutrient (nitrogen and phosphorus) data for the longitudinal patterns (top-middle-bottom) during the study period for the both the aluminum and woods floway are demonstrated in Figure 3.2. Mean nutrient uptake (nitrogen and phosphorus) by both the aluminum and wood floway are demonstrated in Figure 3.3. Figure 3.4 illustrates for the aluminum and wood ATSTM percent of biomass as N and P in Figure 3.2. The ratio between nitrogen (N) and phosphorus (P) was approximately 8:1.

In the aluminum floway, as a whole, there was not a mean significant difference in N or P in the biomass across the floway; however, there were significant ($p < 0.05$, slope $\neq 0$) linear regressions on several dates (see Table 3.2). However there was a significant decrease in nutrient uptake ($p < 0.05$, Fig. 3.3). In the wood floway, longitudinal patterns in both N and P as a whole significantly increased from the top of the ATSTM floway to the bottom ($p < 0.01$, Fig. 3.2).

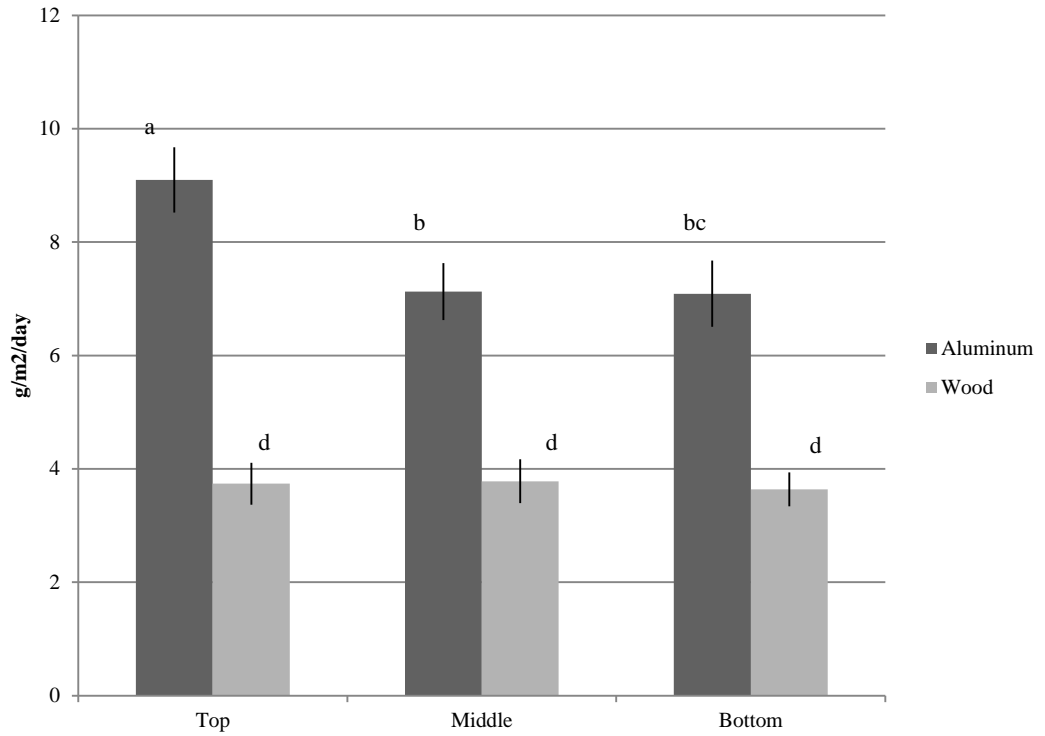


Figure 3.1. Mean ATSTM harvested biomass over the flowway (top-middle-bottom) during the study period (2008-2009) for the both the aluminum and wood systems. Error bars show standard error. Columns followed by the same letter do not differ by the pairwise t-test ($p < 0.05$).

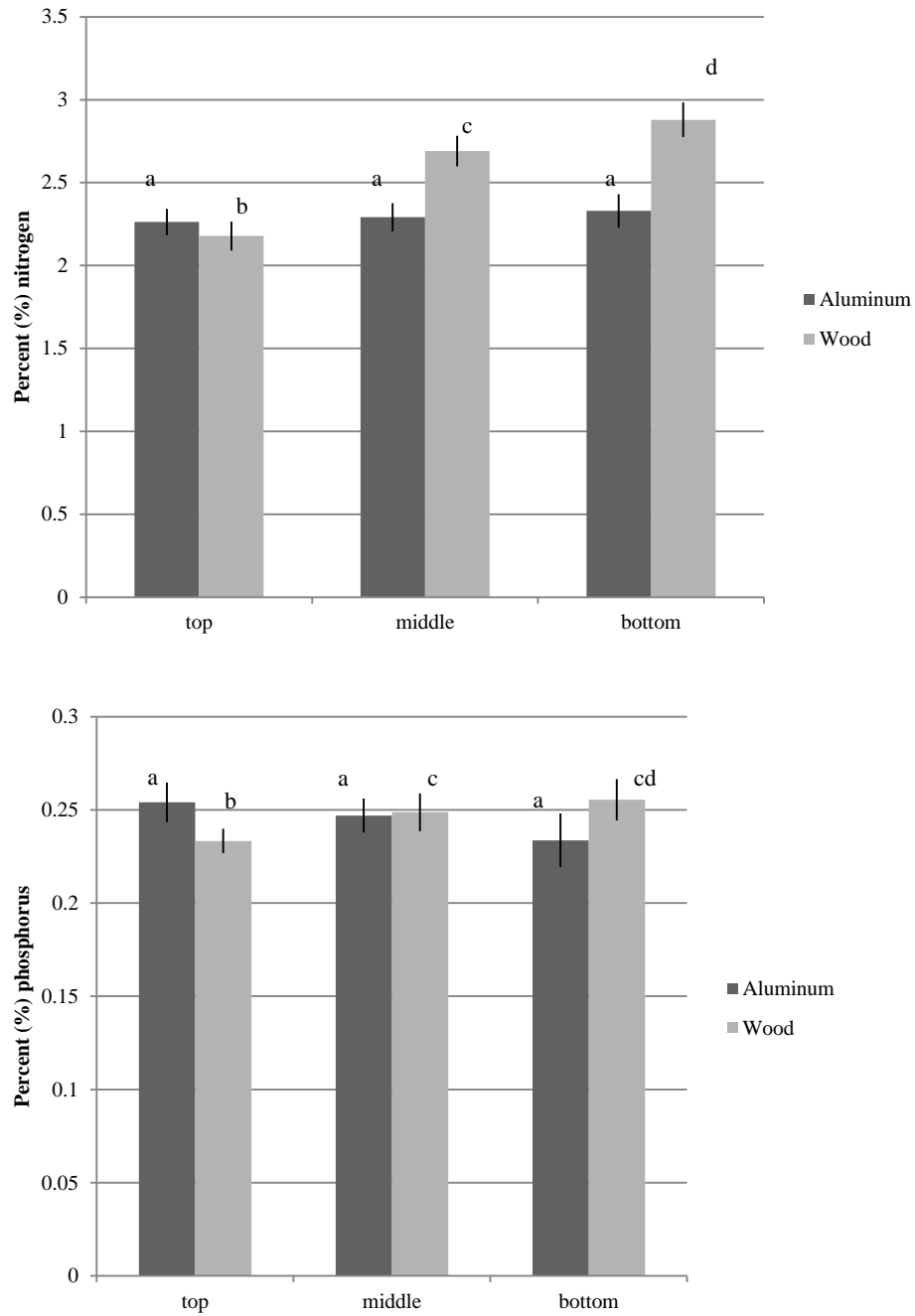


Figure 3.2. Mean percent nutrient content of scrubber biomass over the floway (top-middle-bottom) during the study period (2008-2009) for the both the aluminum and wood systems, (top) nitrogen and (bottom) phosphorus. Error bars show standard error. Columns followed by the same letter do not differ by the pairwise t-test ($p < 0.05$).

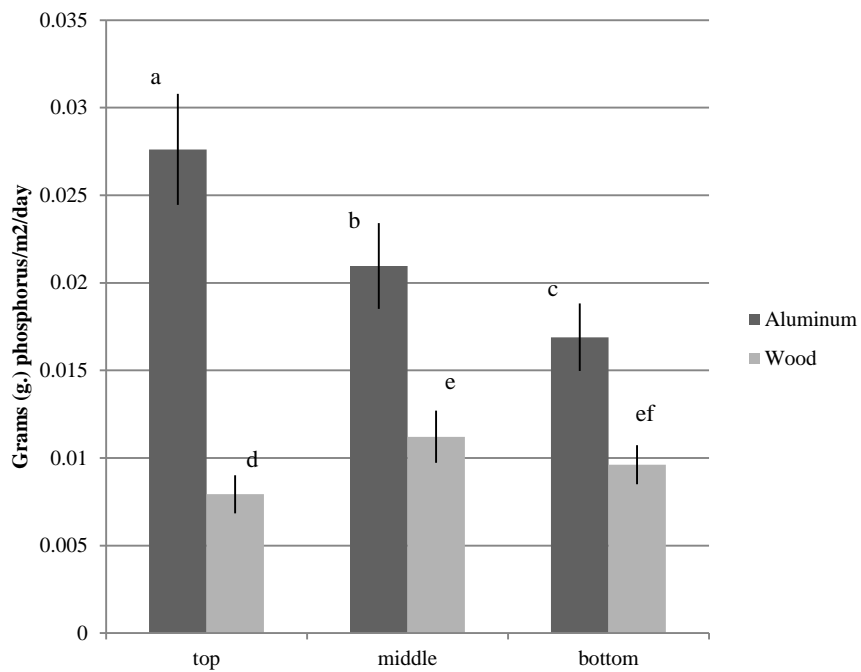
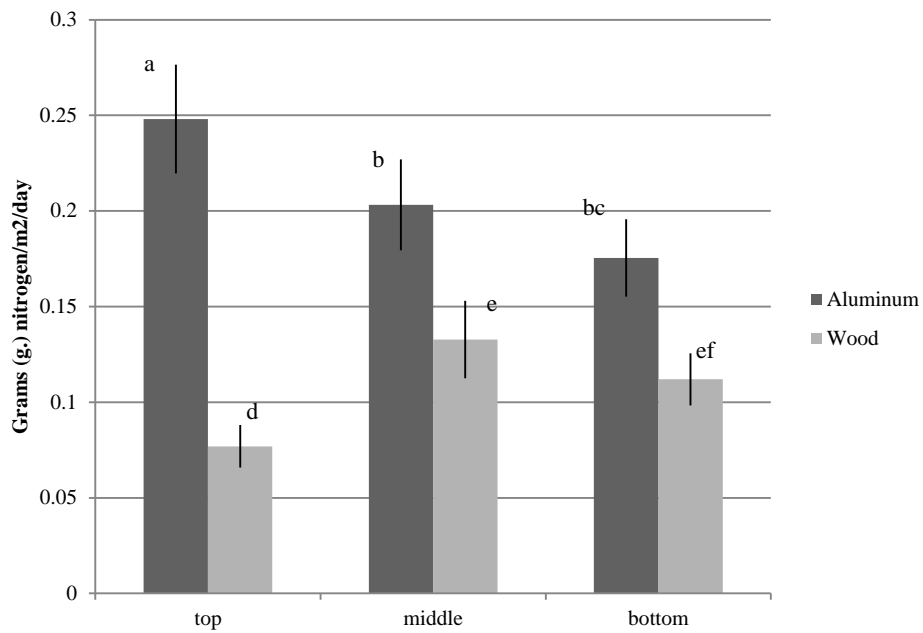


Figure 3.3. Mean nutrient uptake, (top) nitrogen and (bottom) phosphorus, by the aluminum and wood flowways. Error bars show standard error. Columns followed by the same letter do not differ by the pairwise t-test ($p < 0.05$).

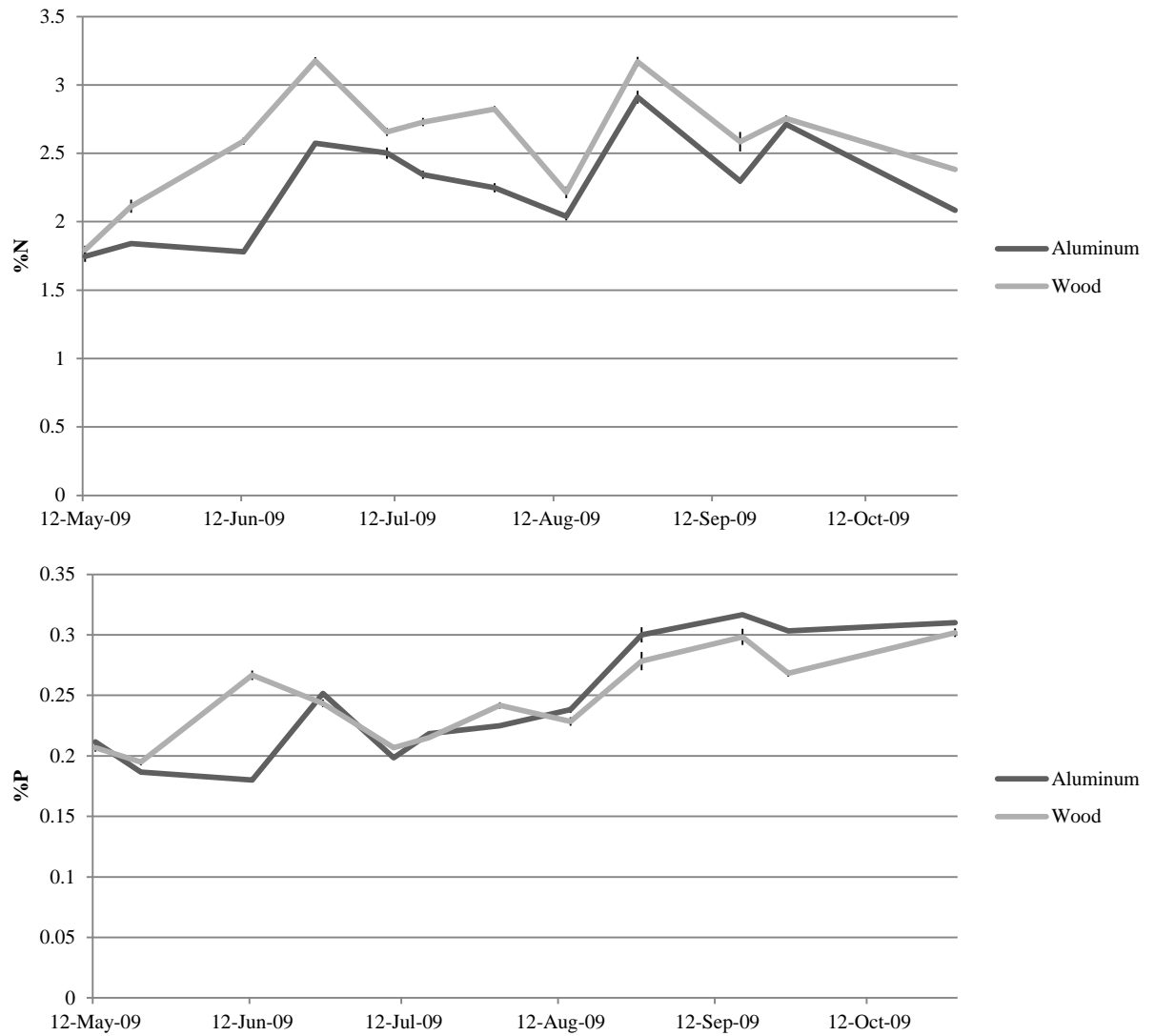


Figure 3.4. Percent nitrogen in the biomass (top) in the aluminum and wood ATSTM at Muddy Run during 2009. Percent phosphorus in the biomass (bottom) in the aluminum and wood ATSTM at Muddy Run during 2009. Error bars represent standard error.

Both ATSTM systems at Muddy Run received nutrients (nitrogen and phosphorus) through their input waters (see Materials & Methods; Table 3.1). However, input nutrients were higher than output nutrients, and Figs. 3.3 and 3.4 show biomass nutrient

concentrations (nitrogen and phosphorus) at the top, middle, and bottom sections of the screens for both raceways. Although the phosphorus and nitrogen, in the water, decreased from input to output; a slight mean increase in nitrogen content in biomass was verified and a decrease in phosphorus content in biomass was found (aluminum) ($p < 0.05$) (Figs. 3.2, 3.3). Overall, a negative linear regression slope was verified for both nitrogen and phosphorus (Table 3.2) on the aluminum floway until 14 Aug 09, in which slope then became positive. This change in slope for the linear regression analysis coincided with a change in the physical slope of the aluminum floway from 2% to 0.5%. Thus, it is possible that the system, as a whole, no longer had a difference in uptake rate along the floway as the physical slope changed. When compared to the wooden ATSTM (Table 3.3), where the slope of the floway was maintained at 1%, it was verified that this system demonstrated a positive linear regression slope, though not significant. It is important to note that these differences in slope seem to affect nutrient uptake, where 2% slope shows a negative linear regression and 1% slope, positive linear regression (Tables 3.2, 3.3). These results demonstrate the importance of the physical slope of the floway and its effect on nutrient uptake, and this is the first time this has been shown.

Table 3.2. Direction of the linear regression slopes for nutrient uptake (nitrogen-N and phosphorus-P) on the aluminum floway during the study period: (+) means slope increased from top to bottom, (-) means slope decreased from top to bottom. Regression was calculated on total nutrient uptake (g.), which is the g/m²/day. Both slope and significance are presented.

Date	Slope N (g.)	Significant	Slope P (g.)	Significant
28-Jul-08	-	no	-	yes
6-Aug-08	-	yes	-	yes
16-Aug-08	-	yes	-	yes
12-May-09	-	no	-	yes
21-May-09	-	no	-	no
12-Jun-09	-	yes	-	yes
26-Jun-09	-	yes	-	yes
10-Jul-09	-	yes	-	yes
17-Jul-09	-	yes	-	yes
31-Jul-09	-	yes	-	yes
14-Aug-09	+	yes	+	yes
28-Aug-09	+	no	+	no
17-Sep-09	+	no	+	yes
26-Sep-09	+	no	+	no
29-Oct-09	+	no	+	no

*dotted line indicates when there was a change in the physical slope of the floway.

Significance level (p<0.05)

Table 3.3. Direction of the linear regression slopes for nutrient uptake (nitrogen-N and phosphorus-P) on the wood floway during the study period: (+) means slope increased from top to bottom, (-) means slope decreased from top to bottom. Regression was calculated on total nutrient uptake (g.), which is the g/m²/day. Both slope and significance are presented.

Date	Slope N (g.)	Significant	Slope P (g.)	Significant
28-Jul-08				
6-Aug-08				
16-Aug-08				
12-May-09	+	no	+	no
21-May-09	+	no	+	no
12-Jun-09	+	no	+	no
26-Jun-09	+	no	-	no
10-Jul-09	+	no	+	no
17-Jul-09	+	no	+	no
31-Jul-09	+	no	+	no
14-Aug-09	+	no	+	no
28-Aug-09	+	no	+	no
17-Sep-09	-	no	-	no
26-Sep-09	+	no	-	no
29-Oct-09	+	no	+	no

Significance level (p<0.05)

Algal Community Structure

A total of 149 taxa were identified from six algal phyla on the wood ATSTM over the study period (*Appendix 14*) and a total of 136 taxa were identified from five algal phyla on the aluminum ATSTM (*Appendix 15*). Many of the species were rare based on frequency of occurrence: 53% of the total community was found only once (a frequency of 1/26 or 4%) on the aluminum ATSTM and 47% of the total community was found only once (a frequency of 1/22 or 5%) on the wooden ATSTM. Thus, as is typical of any ecological community, most of the species in the algal turf community were rare (McGill et al., 2007).

Fifteen species were found in at least half of the samples on the aluminum ATSTM, with 5 species showing different frequencies than the expected even longitudinal pattern (from the genera *Navicula*, *Stephanocyclus*, *Spirogyra*, *Ulnaria*, and *Melosira*) (Table 3.4). Twenty-seven species were found in at least half of the samples on the wooden ATSTM, with nine taxa demonstrating different frequencies than the expected (from the genera *Navicula*, *Diatoma*, *Ulnaria*, *Nitzschia*, *Stephanocyclus*, *Melosira*, *Spirogyra*, *Synedra*, and *Monoraphidium*) (Table 3.5).

Longitudinal patterns in algae: Specialization Index

The dominant taxa (Fig. 3.5) ranged from 0[%] (*Fragilaria capucina*, *Ulothrix zonata*, and *Navicula gregaria*) to 67% (*Oedogonium pluvioporum*) for the wood floway and from 5% (*Desmodesmus communis*) to 47% (*Phormidium retzii*) for the aluminum floway (Tables 3.6 and 3.7), calculated by the specialization formula provided in the Materials & Methods.

Table 3.4. Summarized χ^2 test table for the most dominant taxa on the aluminum floway demonstrating

(+) greater than expected frequency, (0) expected frequency, or (-) less than expected frequency.

	top	middle	bottom
<i>Cymbella</i> spp.	-	0	0
<i>Desmodesmus communis</i>	0	0	0
<i>Diadесmis contenta</i>	-	0	+
<i>Diatoma vulgare</i>	0	0	0
<i>Fragilaria capucina</i>	0	0	0
<i>Gomphonema truncatum</i>	0	0	0
<i>Melosira varians</i>	0	0	0
<i>Navicula</i> spp.	0	0	0
<i>Nitzschia</i> spp.	-	0	0
<i>Phormidium retzii</i>	0	0	0
<i>Rhoicosphenia abbreviata</i>	0	+	-
<i>Spirogyra</i> cf. <i>rivularis</i>	0	0	0
<i>Stephanocyclus meneghiana</i>	0	0	0
<i>Synedra</i> sp.	0	0	0
<i>Ulnaria ulna</i>	-	0	0

Table 3.5. Summarized χ^2 table for the most dominant taxa on the wood floway demonstrating (+) greater than expected frequency, (0) expected frequency, or (-) less than expected frequency.

	top	middle	bottom
<i>Cladophora glomerata</i>	0	0	0
<i>Closterium</i> sp.	0	0	0
<i>Cosmarium</i> sp.	-	0	0
<i>Cymbella</i> spp.	0	0	0
<i>Cymbella tumida</i>	0	0	0
<i>Desmodesmus communis</i>	0	0	-
<i>Diadsmis contenta</i>	-	0	+
<i>Diatoma vulgare</i>	0	0	0
<i>Fragilaria capucina</i>	0	0	0
<i>Gomphonema truncatum</i>	0	0	0
<i>Leptolyngbya</i> sp.	0	0	-
<i>Melosira varians</i>	0	0	0
<i>Monoraphidium arcuatum</i>	0	0	0
<i>Monoraphidium contortum</i>	0	0	0
<i>Navicula cryptocephala</i>	0	0	0
<i>Navicula gregaria</i>	0	0	0
<i>Navicula</i> spp.	0	0	0
<i>Nitzschia</i> spp.	0	0	0
<i>Oedogonium pluvioporum</i>	-	0	+
<i>Pediastrum boryanum</i>	0	0	0
<i>Pediastrum duplex</i>	0	0	0
<i>Phormidium retzii</i>	0	0	0
<i>Spirogyra rivularis</i>	0	0	0
<i>Stephanocyclus meneghiana</i>	0	0	0
<i>Synedra</i> sp.	0	0	0
<i>Ulnaria ulna</i>	0	0	0
<i>Ulothrix zonata</i>	0	0	0

Table 3.6. Specialization index values of the dominant taxa on the wood.

Species	Wood ATS TM floway
<i>Fragilaria capucina</i>	0
<i>Ulothrix zonata</i>	0
<i>Navicula gregaria</i>	0
<i>Melosira varians</i>	11
<i>Diatoma vulgare</i>	13
<i>Stephanocyclus meneghiana</i>	13
<i>Ulnaria ulna</i>	13
<i>Cymbella</i> spp.	17
<i>Phormidium retzii</i>	17
<i>Spirogyra</i> cf. <i>rivularis</i>	17
<i>Monoraphidium arcuatum</i>	17
<i>Navicula</i> spp.	19
<i>Nitzschia</i> spp.	19
<i>Synedra</i> sp.	21
<i>Gomphonema truncatum</i>	23
<i>Pediastrum duplex</i>	27
<i>Closterium</i> sp.	27
<i>Cladophora glomerata</i>	27
<i>Pediastrum boryanum</i>	27
<i>Monoraphidium contortum</i>	27
<i>Cymbella tumida</i>	27
<i>Navicula crytocephala</i>	27
<i>Diademis contenta</i>	33
<i>Cosmarium</i> sp.	37
<i>Desmodesmus communis</i>	37
<i>Leptolyngbya</i> sp.	37
<i>Oedogonium pluvioporum</i>	67

Table 3.7. Specialization index values of the dominant taxa on the aluminum floway.

Species	Aluminum ATS TM floway
<i>Desmodesmus communis</i>	5
<i>Spirogyra</i> cf. <i>rivularis</i>	12
<i>Stephanocyclus meneghiana</i>	13
<i>Gomphonema truncatum</i>	13
<i>Melosira varians</i>	13
<i>Fragilaria capucina</i>	17
<i>Synedra</i> sp.	19
<i>Diatoma vulgare</i>	21
<i>Navicula</i> spp.	21
<i>Ulnaria ulna</i>	39
<i>Cymbella</i> spp.	39
<i>Rhoicosphenia abbreviata</i>	41
<i>Diademis contenta</i>	43
<i>Nitzschia</i> spp.	45
<i>Phormidium retzii</i>	47

Discussion

Two ATSTM flowways, one wooden and one aluminum (Table 1.1), were analyzed for the effect of relative position (top-middle-bottom) on the species composition and putative effect of nutrients (nitrogen and phosphorus). Two hundred five species were found on the two scrubbers at Muddy Run, which together make-up around 60 m² of surface area. This high diversity can be attributed to the source communities for these systems. The species, which immigrated to colonize either system, originated from the lotic Susquehanna River or the lentic Muddy Run reservoir. Both lotic and lentic systems are distinct ecosystems, with different algal floras, thus allowing for a high diversity of potential colonizers on these applied ecosystems.

Among the various taxa of diatoms, *Diatoma vulgare*, *Fragilaria capucina*, *Gomphonema truncatum*, *Melosira varians*, *Stephanocyclus meneghiniana*, and *Ulnaria ulna* were the species of Bacillariophyceae most frequent (>75%) along the ATSTM. *Diatoma vulgare*, *F. capucina*, and *U. ulna* are araphid diatoms that form colonial rosettes adhered apically or as aggregated cells (Stevenson & Peterson, 1989; Biggs et al., 1998). *Melosira varians* and *S. meneghiniana* are both centric diatoms which form chains, and *G. truncatum* is a biraphid epiphytic species with a mucilaginous stalk. Araphid taxa are more active immigrants than monoraphid and biraphid taxa, since they form colonies that adhere apically to the substrate, thus capable of living vertically. However, some of the adhered monoraphid taxa persist on the substrate during disturbances (Stevenson & Peterson, 1989).

Passy & Larson (2011) comment that faster currents enhance nutrient uptake and stimulate growth of some species, which they consider tolerant high profile species, e.g.,

Synedra/Ulnaria species and *Gomphonema* species as well as filamentous chlorophytes, but tolerant unattached species can slough, e.g., *Fragilaria* and *Melosira* filaments. In the flowways, this was not readily seen since the faster current was at the top section (near the dump bucket) and *U. ulna* was significantly less frequent ($p < 0.05$), while more frequent towards the bottom, such as was seen with *G. truncatum*. However, both *Fragilaria* and *Melosira* showed patterns of higher frequency towards the bottom, though this pattern was not significant (Fig. 3.5, Tables 3.4, 3.5). It is possible that the abundance of the taxa changed, though this was not measured in this study.

Whitton et al. (2009) demonstrate the importance of the mucilaginous stalks in diatoms, showing that this is the site of most phosphatase activity in the organism. With this idea in mind, as the phosphorus (Fig. 3.3) content decreased on a longitudinal scale in both the wood and aluminum flowways, several mucilaginous stalk diatom species maintained abundance on both flowways (*Gomphonema truncatum*, *Cymbella* spp., *Cymbella tumida*, *U. ulna*, *Synedra* sp., *Rhoicosphenia abbreviata*) (Fig. 3.6; Tables 3.6, 3.7). Interestingly, the species with the shortest mucilage stalk (*R. abbreviata*) also had a significantly lower frequency ($p < 0.05$) at the bottom section, while *Diadesmis contenta*, which has practically no stalk, had a higher frequency ($p < 0.05$). Levels of phosphorus uptake at the bottom section of the flowway are significantly lower than the top sections (Fig. 3.3). This data shows that that the species frequency does not corroborate with the hypothesis by Whitton et al. (2009); however, cell abundance should be analyzed in the future to determine if the frequency and abundance agree, and if these species could function differently than those studied by Whitton et al. (2009).

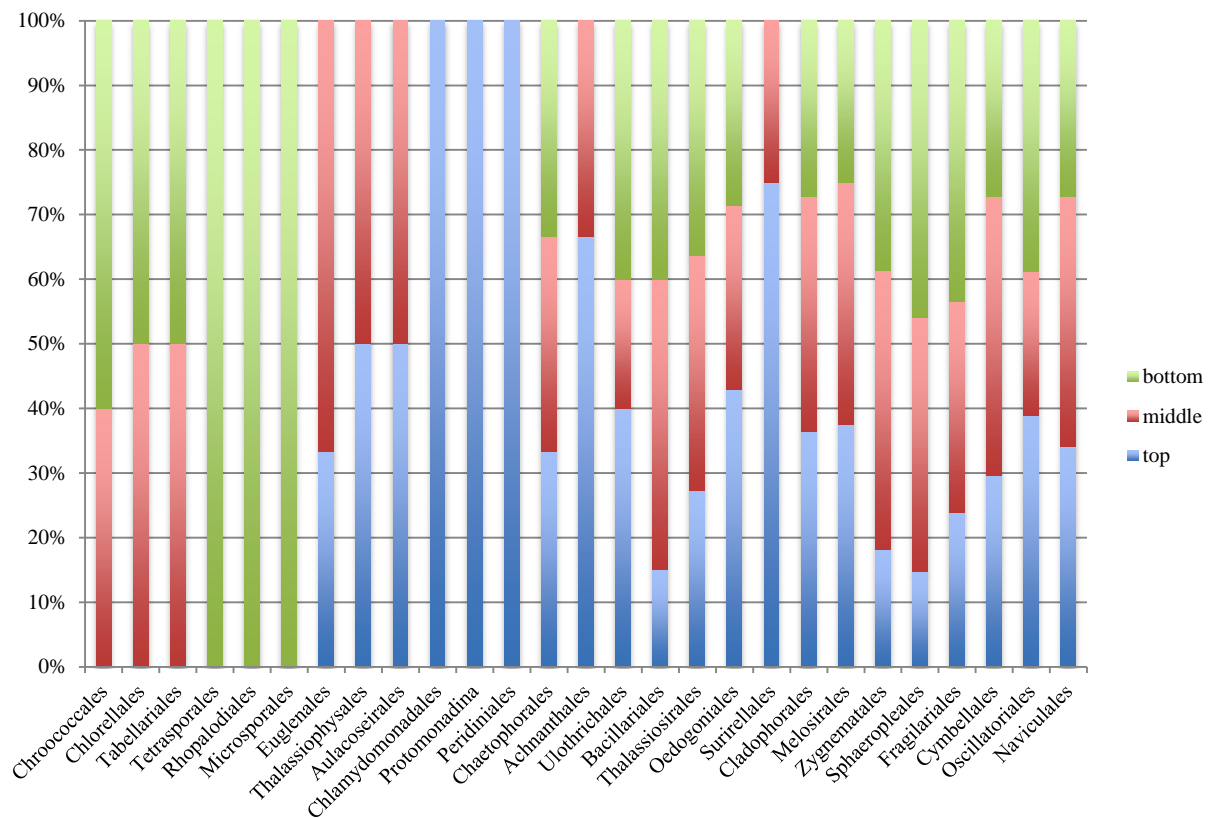
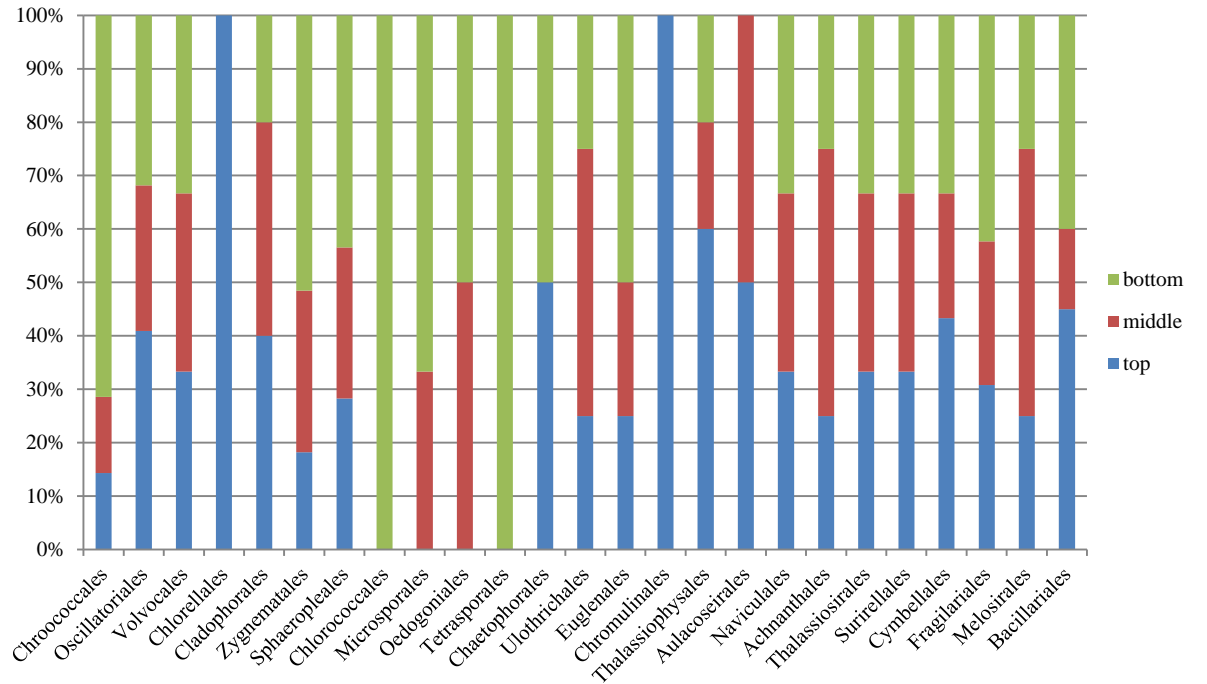


Figure 3.5. Longitudinal patterns of all taxa on the ATS™ flowways compiled into their respective Orders (top) wood ATS™ flowway; (bottom) aluminum ATS™ flowway.

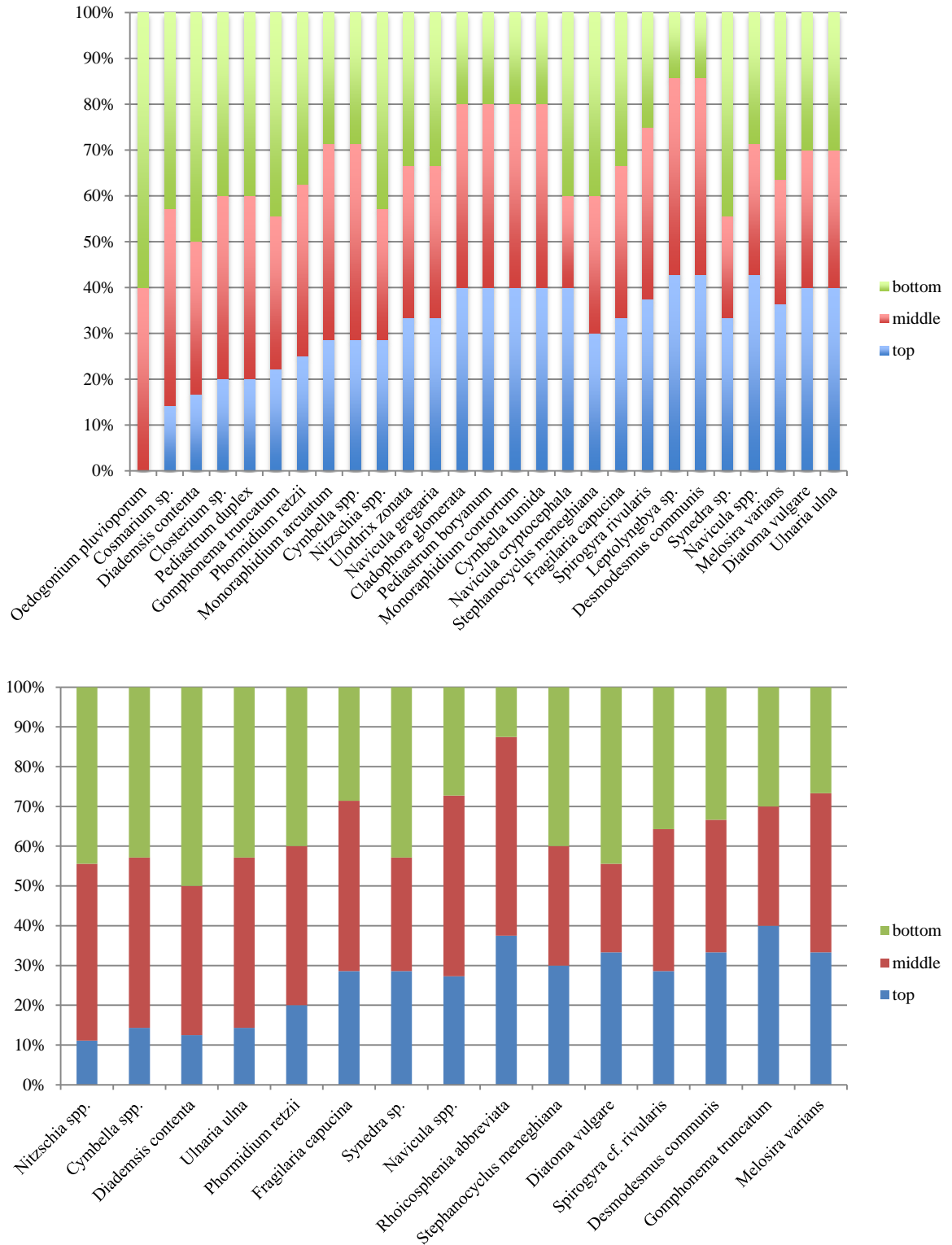


Figure 3.6. Longitudinal patterns of the dominant taxa on the wood flow (top) and aluminum flow (bottom).

Interspecific patterns in the characteristics of growth and emigration in diatoms indicate different ecological strategies. These strategies vary from opportunistic species that reproduce quickly and disperse when nutrient sources become limiting, to those competitive species with slower growth, which use resources in a more efficient manner (Stevenson et al., 1991). The ecological strategies vary by the ability to proliferate in spaces recently emptied (Peterson, 1996), by exploring sources of local or passing inorganic nutrients, and by the resistance of the species against disturbances (Biggs & Thomsen, 1995). The ability to proliferate and resist disturbances reveals a large plasticity in the species of the assemblages to establish and persist in different environmental conditions. Among these, *Encyonema minutum* and *Fragilaria capucina* are cited by Biggs et al. (1998) as species that rapidly grow and are found in disturbed environments.

The presence of cyanobacteria, desmids, and chlorophytes along the ATSTM, was related, in part, to the decrease in the abundance of diatoms, as well as succession of the community. The higher concentrations of phosphorus, at the top section of the ATSTM, in addition to the faster current, could have favored the cyanobacterial mat, which was readily present in both the wood and aluminum flowways during the whole study period, since studies show a positive correlation with phosphorus forms and the development of tolerant taxa, i.e., species of cyanobacteria (Douterelo et al., 2004; Perona & Mateo, 2006). In addition the higher turbulence in which the inflowing water enters favored this mucilaginous mat composed of species of the genera *Leptolyngbya*, *Phormidium*,

Pseudanabaena, and *Oscillatoria* (Appendix 14, 15), which may be more stable to the community.

Both systems had a significant increase in species number relative to position, with the trend being an increase from top to bottom of the system (Appendix 14, 15). Factors that could influence this trend are: change in nitrogen and/or phosphorus concentrations, pH, temperature, oxygen, and/or physical disturbance. Mostly, there was an increase in the number of species presence from the Orders Chroococcales (genera *Aphanocapsa*, *Aphanothece*, *Bacularia*, *Chroococcus*, *Eucapsis*, and *Merismopedia*); Zygnematales (genera *Closterium*, *Cosmarium*, *Pediastrum* 'lato sensu', and *Staurastrum*); Sphaerospleales (genera *Coelastrum*, *Desmodesmus*, *Gloeocystis*, *Hydrodictyon*, *Kirchneriella*, *Monoraphidium*, *Pseudocharacium*, *Scenedesmus*, *Schroederia*, and *Tetraëdron*); Microsporales (genus *Microspora*); and Fragilariales (genera *Meridion*, *Staurosirella*, and *Synedra*) towards the bottom of both systems. The Orders Zygnematales and Sphaerospleales are mostly represented by species, which are loosely fixed to the substrate. Species of these Orders grow in communities that are in intermediate stages of succession, and are related to a higher stability of the periphytic community, which was seen in the lower portions of both flowways, due to lower turbulence.

Dominant species on the flowway are either considered generalist species or specialist species, the latter demonstrating a greater affinity (frequency) to one or two sections of the flowway. Analyzing the deviations from the ideal frequency of the null hypothesis (i.e., expected frequency) (Tables 3.4, 3.5), it was noted that most species are generalist species. Five species on the aluminum and five species on the wood flowways

had a speciality for a particular section of the floway ($p < 0.05$). Overall, these species do specialize had a lower frequency at the top of the floway and higher frequency at the bottom of the floway. Only one species, *Rhoicosphenia abbreviata*, was found to have increased frequency at the middle section of the floway, when compared to the expected ($p < 0.05$). *Nitzschia* spp., *Cymbella* spp., *Diadismis contenta*, and *Ulnaria ulna* had a lower frequency than expected at the top ($p < 0.05$) on the aluminum floway and *Oedogonium pluvioporum*, *Cosmarium* sp., and *D. contenta* on the wood. At the bottom of the floway, six species had a significant difference in frequency, with *D. contenta* presenting an increased frequency at the bottom on the aluminum and the wood, while *O. pluvioporum* also demonstrated this trend on the wood floway. *Leptolyngbya* sp. and *Desmodesmus communis* decreased frequency on the wood floway, while *R. abbreviata* decreased frequency on the aluminum floway. It is generally recognized that most species whose ecological demands have been well studied are restricted to only a certain range of habits, due to their demands (Perona & Mateo, 2006). Thus these taxa are not ubiquitous and contain ecological niches, constrained by their ecological demands, which they have evolved over evolutionary time. Other species are broad-niched, which here, are those considered generalist species (Komárek, 1994). On these floways, most of the dominant taxa are broad-niched or, in other words, the null hypothesis (84.4% on the aluminum floway and 91.4% on the wood floway). There were more species that differed in frequency from the top to the bottom of the floways on the wood floway than on the aluminum floways, this could be due in part that the aluminum floway and the wood floways had different floway slopes. The aluminum floway had a physical gradient (slope) of 2% that was changed to 0.5% during the study period, while the wood floway

was maintained at 1% during the whole study period. At a 2% gradient of the flowway the slope of the linear regressions were significantly negative, but when this gradient was changed to 0.5%, the regressions became positive (aluminum flowway, Table 3.2). At a 1% gradient the linear regression slopes were almost always positive (though not significant) (wood flowway, Table 3.3). Furthermore, the percent phosphorus of the algal biomass was lower while at the 2% slope, and when this slope was changed to a 0.5%, the percent concentration became higher than the wood flowway at 1% slope (Fig. 3.4). This is the first time that it was shown that slope plays a role in nutrient dynamics in ATSTM, indicating that there may be a ‘threshold’ between the 0.5% and 1% physical slope for ATSTM flowways to obtain significant differences in nutrient data. These nutrient differentiations could be important for differing species frequency.

With the lower slopes one would expect that more planktonic species would be present on the wood flowway due to less turbulence. This is due to the possibility for a longer residence time of the water flowing over the flowway. Thus the natural history diagrams in Chapter 2 were verified and this pattern was not observed, at least for species number. Therefore the number of species present on both flowways, planktonic versus non-planktonic or not different. However, it could be that the abundance of these taxa is significantly different, though this was not studied.

Interestingly is that most dominant taxa found on these flowways did not present a significant difference in frequency from top to bottom (Table 3.4, 3.5) compared to the null hypothesis. However the specialization index (Table 3.6, 3.7) demonstrated that species did demonstrate patterns in distribution. These patterns are better visualized in Figure 3.6. Thus, the differences in nitrogen and phosphorus from top to bottom of the

floways did not affect most of the species frequencies in this study; however, overall, based on an ANOVA when all the taxa from each section were grouped, the frequencies significantly differed from top to bottom (*Appendix 22*), which coincides with nutrient uptake of both nutrients being significantly different from the top section to the bottom section ($p < 0.05$) (Fig. 3.3). Thus, taxa frequencies, as a community, differ between top and bottom sections; however, there still needs to be more studies undertaken to understand the influence of these nutrients on the frequency of each taxon. Moreover, other environmental factors which were not studied or considered, could be affecting the longitudinal patterns of these algae, such as pH.

Chapter 4: Systematic studies on periphytic Oscillatoriales (Cyanobacteria) from ATSTM floways along the Chesapeake Bay.

Cyanophyceae/Cyanobacteria

The Division Cyanobacteria (Domain Bacteria) contains only one class, Cyanobacteria. Cyanobacteria, also known as cyanophytes, cyanoprokaryotes, or blue-green algae, are primitive organisms, being one of the first to produce O₂ in the atmosphere. Many researchers admit that the evolutionary history of the group began in the Archezoic Era (3.5 billion years ago) (Whitton & Potts, 2000).

The success of cyanobacterial adaptation to a wide variety of habitats can be related to their long evolutionary history. This success is consequent of peculiar physiological characteristics, such as tolerance to extreme temperatures and solar irradiation, to desiccation, and to high concentrations of sulphuric gas. They also have the ability to use low concentrations of light and CO₂, in addition to the capability of fixing atmospheric nitrogen (Whitton, 1992; Whitton & Potts, 2000). They resist drastic environmental variations, occurring from the poles to tropics, oceans to ponds, and desert sands to tree trunks. There are also those with endophytic, epiphytic, and epilithic habitats (Hoek et al., 1995; Whitton, 1992; Whitton & Potts, 2000).

In continental waters, cyanobacteria can be responsible for sanitary problems due to their potential to produce toxins. Various cases of contamination, even human, caused by ingesting water containing toxic cyanobacteria and/or toxins liberated by these organisms, have been documented in various parts of the world. The most expressive case was documented in Brazil, with human death by hepatotoxins (microcystins) due to

the use of water contaminated by cyanobacteria in Caruaru, Pernambuco, in 1996, during routine dialysis treatment (Falconer & Fitzgerald, 1999).

Taxonomy/Systematics of Cyanobacteria

The Division Cyanophyta contains approximately 150 genera and around 2800 species (Hoek et al., 1995; Sant'Anna et al., 2006). They present numerous taxonomic and nomenclatural problems, mainly supported by review studies and floristic surveys undertaken by various authors. One of the biggest problems for cyanobacterial taxonomy is that many species present an array of different morphotypes, leading to difficulty in precise and specific identification (Werner & Laughinghouse, 2009).

The first classification systems of cyanobacteria were based exclusively on thallus morphology. In *Species Plantarum* (Linnaeus, 1753), the first classification of less complex forms of the group are found. During the 19th century, the classic works by Nägeli (1849), Rabenhorst (1865), and Thuret (1875) appeared where cyanobacteria were classified according to morphological characteristics. The review works carried out by Bornet & Flahault (1886-1888) and Gomont (1892) are the starting point of nostocaceans and oscillatoriaceans, respectively; thus, the beginning of filamentous cyanobacteria recognized under the *International Code of Nomenclature for algae, fungi, and plants* (ICN). In the 20th century other systems were proposed, the majority based on metric and morphological characters of preserved material. Among the most well known was Geitler (1932) who studied a large Central European flora. In addition, Frémy (1929-1933, 1930), Elenkin (1935, 1938-1949), Geitler (1942), Desikachary (1959), and Bourrelly (1970) contributed to describing the diversity of the group.

More recently, the systems by Komárek & Anagnostidis (1989, 1998, 2005) and Anagnostidis & Komárek (1990) were proposed, in which cyanobacteria were reorganized based on morphological, metric, ecological, physiological, and biochemical characteristics, where the following are important: cell division pattern, life cycle, thylakoid organization, ability of producing aerotopes and their respective location, cell wall structure, motility, trichome structure, and thallus type. Among the morphological characteristics, cell form, cell wall constriction, presence and type of sheath, granulation, and branching pattern are the diacritical characters used for the taxonomy of the group. According to this system, the class Cyanophyceae has four Orders: Chroococcales, Oscillatoriales, Nostocales, and Stigonematales.

In recent years, many researchers have incorporated molecular techniques answer questions related to taxonomy, population dynamics, and cyanobacterial evolution. According to Wilmotte (1994), molecular systematics is especially important in taxa where morphological variability is limited or the homology of these characteristics is not clear. Studies capable of incorporating both molecular and morphological data provide stronger descriptions and interpretations of biological diversity than those that study them in isolation (Wilmotte et al., 1994; Moffitt et al., 2001). Thus polyphasic taxonomy has been recommended for the classification of cyanobacteria and many studies are being published using this approach (Casamatta et al., 2005; Hoffmann et al., 2005; Taton et al., 2006; Johansen et al., 2011; Kling et al., 2012; Werner et al., 2012).

Molecular techniques involving the sequencing of the ribosomal RNA (rRNA) are commonly used to investigate evolutionary relations among different cyanobacterial genera. According to Wilmotte (1994) the genes that encode for rRNA present properties

which make them good candidates for broad use in evolutionary studies, such as: universality, functional constancy, and combination of conserved regions with variable regions.

Order Oscillatoriales Elenkin, 1934

Cyanobacteria of the Order Oscillatoriales are characterized as homocyte filamentous cyanobacteria (without heterocytes and akinetes), with a facultative mucilaginous sheath, and cell division in one plane (Castenholz, 2001). According to the review by Komárek & Anagnostidis (2005), the group differs from the other cyanobacteria mainly by presenting homocytic filaments; however, characters, such as presence or absence of sheath, filament aspect, false branching, and content or amount of cell pigment, are also relevant. For species, the main taxonomic criteria used are: cell size, cell shape (especially the terminal cells of trichomes), constriction at cross-walls, and cellular inclusions (granules and aerotopes), besides environmental characteristics.

The oscillatorian cyanobacteria generally have isopolar trichomes, which sometimes taper towards the ends. The terminal cell can differ morphologically to the adjacent cells and their characteristics are used for interspecific differentiation. Furthermore, an additional modification can develop around this cell, i.e., a thicker membrane or a calyptra (Castenholz, 2001; Whitton, 2002; Komárek & Anagnostidis, 2005). The trichomes can form hormogonia, reproductive structures with facultative motility, and some members produce false-branching (Anagnostidis & Komárek, 1988; Komárek & Anagnostidis, 2005). All genera and probably all species present facultative

motility. Many planktonic forms contain aerotopes, which are found in the entire protoplasm or only next to the walls (Komárek & Anagnostidis, 2005). Aerotopes are absent from benthic forms of the Order.

Cyanobacteria of the Order Oscillatoriales are found in a diverse number of habitats, from terrestrial to aquatic systems, planktonic or benthic, forming periphyton, soil crusts, or microbial mats (Sheath & Müller, 1997; Casamatta et al., 2005; Taton et al., 2006).

The monograph by Maurice Gomont, “Monographie des Oscillatoriées” (Gomont, 1892), is considered the first manual for taxonomic classification of Oscillatoriales, the starting-point of its validity under the ICN. The author recognized 15 genera within the Family Hormogonoeae, Subfamily Homocystae, which was divided into two tribes: Vaginariae and Lyngbyae, differing, by the type of mucilaginous sheath and by the number of trichomes per sheath.

In the 20th century, Geitler (1925, 1932) united all the oscillatorian cyanobacteria – classified by Gomont as Hormogoneae – into the Family Oscillatoriaceae, characterized mainly by the type of mucilaginous sheath, trichome type and its disposition within the sheath, cell dimensions, and habitat. In his two studies, 18 and 23 genera were separated, respectively. Following, studies by Frémy (1930), Elenkin (1936-1949), Desikachary (1959), Starmach (1966), and Kondratieva (1968) presented diverse taxonomic evaluations based on morphology, describing several more genera, in addition to revisions in the classification system.

Most recently, Anagnostidis & Komárek (1988) and Komárek & Anagnostidis (2005) undertook important revisions of the Order Oscillatoriales, introducing new

taxonomic criteria to obtain a natural classification system, such as cell proportions and patterns of cell division, presence or absence of aerotopes, and motility, besides environmental characteristics. The results transferred many species to new generic entities, distributed within the Families Pseudanabaenaceae, Schizotrichaceae, Borziaceae, Phormidiaceae, Gomontiellaceae, and Oscillatoriaceae. However, the systematics of the Order is still changing, with new information and novel techniques, facilitating understanding the evolution of these ancient organisms.

Based on the studies by the authors above, the Order Oscillatoriales is defined by presenting unisseriate trichomes, motile or not, with a transversal cell division along the width of the trichome; mucilaginous sheath present or absent; absence of true-branching; absence of heterocytes and akinetes; aerotopes present, absent or facultative; reproduction by hormogonia and hormocytes, rarely by planocytes.

Taxonomic studies of periphytic Oscillatoriales in the Chesapeake Bay region

There is no unique taxonomic survey of the periphytic Oscillatoriales in the Chesapeake Bay region. Taxonomy studies on cyanobacteria in North America initiated with J. Tilden (1910), though her study did not contain samples from the Bay area, with New Jersey being closest. Ott (1972) states in his review of Chesapeake Bay macroalgal flora that since periphytic microflora is not part of the phytoplankton and is not studied during benthic macroalgal surveys, there is no knowledge of these organisms in the Bay, thus not being able to attribute any kind of human impact on these organisms. Earlier studies carried out by Strickland (1940) and Zaneveld (1965) contain some oscillatorian taxa, though lack descriptions and/or illustrations; however, Strickland (1940) does cite

Herbarium vouchers. They also rely heavily on the assistance of F. Drouet for identifications, whose systematic view was never widely accepted by the cyanobacterial community, since he significantly reduced the number of genera and species without compelling arguments.

Francis Drouet (1939) carried out a study of cyanobacteria in Maryland reporting several oscillatoriales, although only one can be corroborated, *Phormidium weissii* Drouet, with both a description and illustrations. In a subsequent work, Drouet (1942) only described and illustrated *Spirulina weissii* Drouet, though he listed other species for North America. Thus, two species of the Order Oscillatorales, both novel when described, have been cited for the Chesapeake Bay and its tributaries in Somerset County, Maryland.

More recently, there is a review of phytoplankton for the Chesapeake Bay and its surroundings by Marshall et al (2005), containing a few species that could be found in the benthos (tychoplanktonic?). Since the authors do not present descriptions, illustrations, or voucher specimens, this report cannot be confirmed as a true taxonomic assessment. As a result, there has not been a thorough taxonomic survey carried out of this flora, thus demonstrating the need for a study of these important organisms, which play a crucial role in the aquatic environment.

This Chapter is divided into two Subchapters. Subchapter 1 aims to examine field populations of cyanobacteria from the Order Oscillatoriales in the Chesapeake Bay region by using morphological features that are easily recognizable under light microscopy. Phenotypic and ecological characterizations of natural (field) populations are necessary to increase the ecological and systematic knowledge of these important

organisms (Komárek et al., 2002; McGregor, 2007; Werner & Laughinghouse IV, 2009). The only current, widespread and practical method for recognizing the diversity of cyanobacteria is through phenotypic characterization, which is the first methodological step in a polyphasic characterization (McGregor, 2007). Subchapter 2 includes the elevation of the subgenus *Ilyonema* of the genus *Pseudanabaena* to generic status using a polyphasic approach, which is needed to correctly describe the periphytic organisms that are found in this project, as well as ascribe the correct phylogenetic placement of the organisms found in this (sub)genus. This level of detail is meant to compliment the more ecologically-focused previous algal community chapters, since this chapter has a more systematic and taxonomic focus.

Subchapter 1. *Periphytic Oscillatoriales (Cyanobacteria) from freshwater and brackish environments along the Chesapeake Bay, USA*

Introduction

Cyanobacteria are the largest group of photosynthetic prokaryotes with a wide occurrence, abundant frequency, and large morphological diversity. This group is vital due to their importance in primary productivity, role in biogeochemical cycles, and relevance in the trophic chain (Whitton & Potts, 2000). Due to the importance of the role that cyanobacteria play in different ecosystems, floristic studies of the group are necessary, aiming to increase our taxonomic knowledge of these organisms, as well as, support other studies of social-economical interest and public health.

Materials and Methods

Samples were taken from different algal turf scrubber systems (ATS™) of fresh- and brackish water environments from the Chesapeake Bay Region, USA (Figure 4.1). The ATS™ is an ecological engineered system, which uses naturally growing periphytic and benthic algae to remediate incoming waters while providing a useful algal biomass (Adey et al., 2011). In these systems periphytic algae are naturally selected to grow due to the different pressures of the system, thus a useful system for studying this community.

The morphometric analyses of natural and preserved samples were carried with an Olympus BX50 binocular light microscope with an attached Canon Rebel EOS Rebel T1i digital camera for photography. Thirty individuals and 20 to 30 measurements of each characteristic of taxonomic interest were analyzed for each specimen. Photographs and/or descriptions are presented for each species.

The classification system by Hoffmann et al. (2005) was used and species were classified according to Komárek & Anagnostidis (2005).

Results and Discussion

BORZIACEAE

Komvophoron minutum (Skuja) Anagnostidis et Komárek, 1988

Basionym: *Pseudanabaena minuta* Skuja

(Plate 1, A-D)

Trichomes solitary or forming mats, short, tangled, straight, deeply constricted; cells 1.9-2.5 μm wide, 0.9-1.9 μm long (length/width ratio 0.5-1), spherical to barrel-shaped; cell content blue-green; apical cells spherical, 2-2.9 μm wide, 1.9-2.5 μm long.

According to Skuja (1948), the diameter of cells varies from 2-2.5 μm wide, with cells 0.5-1.33 times longer than wide. Hašler & Poulíčková (2010) studying populations of *Komvophoron minutum* from the Czech Republic found that the diameter of cells can reach 4 μm . However, the Czech populations contained a wart-like protrusion on the apical cell, which was not seen in the studied specimens.

Komvophoron minutum resembles *K. constrictum* (Szafer) Anagnostidis & Komárek, but is smaller (about half the size), has shorter cells and its color is more pale. Furthermore, *K. minutum* lacks granules at the cross-walls, a character found in *K. constrictum*.

The type-specimen is cited as occurring occasionally in the plankton, being tychoplanktonic. This is in agreement with the benthic specimens found in this study in addition to the specimens found in the muddy sediments by Hašler & Poulíčková (2010).

Distribution: Muddy Run (PA)

PSEUDANABAENACEAE

Pseudanabaena galeata Böcher

(Plate 2, B)

Trichomes solitary or in fine, delicate mats, straight or flexuous, deeply constricted at the cross-walls; cells cylindrical, 0.9-2.2 μm wide, 1.4-7 μm long, usually 2-3x longer than

wide, slightly rounded, refractive aerotopes visible at the poles; cell content emerald-green; apical cell is conical or rounded, with 1 or more apical aerotopes.

The populations found in this study agree mostly with the morphometric description of *P. (=Ilyonema) galeata* presented in the review by Komárek & Anagnostidis (2005) [0.8-2.4(2.7) μm wide, (1.2)2-7(10-15) μm long]; however, specimens in this study were slightly smaller. McGregor (2007) found *P. galeata* [from Queensland (1-2.5 μm wide, 1.5-7.5 μm long)] more similar in size to the studied populations.

This species is regarded as a cosmopolitan species, common in the plankton of ponds, lakes, and reservoirs. Though found in the plankton, its life begins in the benthos, and is secondarily planktonic (Komárek & Anagnostidis, 2005). *Pseudanabaena galeata* is cited to produce the taste and odor compounds 2-methylisoborneol and geosmin, causing sanitary inconveniences for water impoundments (Izaguirre & Taylor, 2004).

Distribution: Muddy Run ATSTM.

Pseudanabaena lonchoides Anagnostidis

(Plate 7, A-C)

Trichomes solitary or in fine, delicate mats, straight or flexuous, deeply constricted at the cross-walls; cells cylindrical, 0.9-1.3 μm wide, 3.8-6 μm long usually (3.2)3.8-6x longer than wide, aerotopes absent; cell content blue-grey; apical cell rounded to conical, sometimes with refractive aerotope.

The morphological and metric characteristics of the studied specimens are within the limits cited for *Pseudanabaena* (= *Ilyonema*) *lonchoides* (0.6-1 µm wide) in the review by Komárek & Anagnostidis (2005)

This species was found to increase in abundance during the higher temperatures in the heated discharge canal at the Peach Bottom Atomic Power Station, demonstrating a putative preference for warmer waters. Komárek & Anagnostidis (2005) comment that this species can be found in thermal waters, indicating the preference that this species has for this habitat.

Distribution: Peach Bottom ATS™.

Pseudanabaena limnetica (Lemmermann) Komárek (1974)

Basionym: *Oscillatoria limnetica* Lemmermann (1900)

(Plate 2, C)

Trichomes solitary, straight or flexuous, motile, deeply constricted at the cross-walls; cells long-cylindrical, 1-2 µm wide, 3-9 µm long, bluntly rounded ends at the cross-walls, no aerotopes; cell content pale blue-green to olive-green, homogenous with a distinct chromatoplasm; apical cell rounded, without aerotopes.

Pseudanabaena limnetica is a common species in the plankton of lakes and reservoirs; however, begins in the benthos, then later becomes planktonic. It has a wide geographic distribution in temperate and tropical zones.

The morphometric characteristics of the studied specimens agree with the bibliography consulted for this species [Skuja, 1948 (as *Oscillatoria limnetica*); Komárek & Anagnostidis, 2005; McGregor, 2007; Whitton, 2011 (as *Oscillatoria limnetica*)].

Distribution: Muddy Run ATS™

Geitlerinema amphibium (Agardh ex Gomont) Anagnostidis, 1989

Basionym: *Oscillatoria amphibia* Agardh ex Gomont (1892)

(Plate 1, E-F)

Trichomes solitary or tangled, straight or bent, constricted at the ends; cells 2.2 µm wide, 3.5-6 µm long, 1.6-2.7x longer than wide; cell-content blue-green, homogenous; cross-wall granulated (1 granule), translucent; apical cells cylindrical to rounded, sometimes slightly attenuated, not thickened.

The specimens studied can be confused with *Geitlerinema unigranulatum* (R.N. Singh) Komárek et Azevedo. Besides the biogeographical and ecological differences of the studied material from those described by Komárek & Azevedo (2000) from populations in São Paulo, Brazil, it was verified that *G. unigranulatum* did not taper, and the cross-walls were indistinct. Slightly attenuate apical cells were found among the analyzed individuals, different from *G. unigranulatum*, which are always cylindrical and rounded, morphologically similar to the other vegetative cells (Komárek & Azevedo, 2000).

According to the authors above, *Geitlerinema amphibium* can present one or (rarely) two granules at the cross-walls, while *G. unigranulatum* has only one granule. In

the analyzed populations, only one granule was found at the cross-walls. The metric variations presented by Komárek & Azevedo (2000) for both species show an overlap in cell width and length; however, the width for *G. amphibium* is larger (1.2-4 µm) than *G. unigranulatum* [0.8-2(-2.4) µm].

The size limits of the specimens in this study are similar to those referred for *G. amphibium* by Romo et al. (1993) and Whitton (2011), ranging from 1.2-4 µm, from European waters. Diacritical characters in this species are also having distinct, thick, and translucent cross-walls, in addition to trichomes being slightly attenuated, sometimes inconspicuous.

The examined specimens can also be confused with *Jaaginema quadripunctatum* (Brühl et Biswas) Anagnostidis et Komárek. They differ from this species by movement. In live samples, motile individuals were observed. *Jaaginema* does not possess motility. In addition, the cross-walls in *J. quadripunctatum* can contain two or three (rarely) granules, and in the sampled individuals there was only one granule.

Distribution: Muddy Run ATS™

Leptolyngbya boryana (Gomont) Anagnostidis et Komárek (1988)

Basionym: *Plectonema boryanum* Gomont (1899)

Filaments curved, entangled, sometimes pseudobranched, up to 3 µm wide; pseudobranches thinner than main filament; mucilaginous sheath thin, colorless; trichomes not attenuated, constricted at cross-walls; trichomes 1-2 µm wide, cells

±isodiametric or slightly longer than wide; color blue-green, not granulated, apical cell rounded, without a calyptra.

The morphometric characteristics of the populations agree with those found by other authors (Gomont, 1892; Komárek & Anagnostidis, 2005; McGregor, 2007). A diacritical feature of *Leptolyngbya boryana* is its ability to form pseudobranches.

This species occurs in fresh water, metaphytic among other benthic algae and aquatic plants. It is widespread in slow-flowing waters worldwide (Komárek & Anagnostidis, 2005).

Distribution: Muddy Run ATSTM

Planktolyngbya limnetica (Lemmermann) Komárková-Legnerová et Cronberg, 1992

Basionym: *Lynngbya limnetica* Lemmermann (1898)

(Plate 2, A)

Filaments solitary, straight, or flexuous; mucilaginous sheath fine, homogenous, colorless, sometimes extending beyond the trichome at one or both sides; trichome 1-1.5 µm wide, not attenuated, not constricted; cells cylindrical, 2.5-5 µm long; cell content blue-green, homogenous; cross-walls vaguely evident to sometimes thick and evident, not granulose; apical cells rounded or conical, without thickened cap.

In a general manner, the studied specimens agree with the description of *Planktolyngbya limnetica* presented by Komárková-Legnerová & Cronberg (1992) for populations of southern Swedish lakes. According to these authors the cross-walls of the

trichomes can sometimes be inconspicuous, which was also seen in the analyses populations.

Populations in this study closely resemble those by McGregor (2007), except he noted that small refractive bodies were located on either side of the cross-walls. These bodies were not seen in the studied material from the Muddy Run ATS™.

This species is considered planktonic (Komárek & Anagnostidis, 2005), and in the ATS™ it was found in areas of slow moving water entangled with other algae. Komárek & Anagnostidis (2005) also comment of its occurrence in lakes and ponds among other algae, which is the case of the Muddy Run ATS™.

Distribution: Muddy Run ATS™

Spirulina subsalsa Oersted *ex* Gomont, (1892)

Trichomes sometimes solitary, densely and regularly spirally coiled, not constricted, 1-2 µm wide; spirals very tight, rarely with visible spaces between them, 3-5 µm wide; cell content blue-green, homogenous.

Spirulina subsala is recognizable since it is densely coiled and its spirals touch one another along the organism, different than the other species in the genus. Morphologically, the population studied agreed with the type description and descriptions presented in literature (Gomont, 1892; Geitler, 1932; Komárek & Anagnostidis, 2005; McGregor, 2007).

Most authors are unanimous in stating that the metric limits are 1-2 µm for the width of the trichomes and 3-5 µm for the width of the coils. However, wider limits for

the species were found by Sant'Anna et al. (1983) – 1.5-2.5 μm – in São Paulo, Brazil and by McGregor (2007) – up to 2.3 μm – in Queensland, Australia.

Distribution: Wicomico, VIMS

PHORMIDIACEAE

Leibleinia epiphytica (Hieronymus) Compère, (1985)

Lyngbya epiphytica Hieronymus in Kirchner (1898) *incl.*

Filaments solitary, straight, or flexuous, up to 2 μm wide; mucilaginous sheath thin, colorless; trichomes not attenuated, not constricted at cross-walls; cells 1-1.8 μm wide, 1-2.3 μm long, \pm isodiametric; color blue-green, not granular, apical cell rounded, without a calyptra.

Populations found in this study are within the metric limits known for this species. McGregor (2007) found narrower trichomes from NE Australia, however, the review by Komárek & Anagnostidis (2005) considers 1.5-2 μm the width of this species.

This species was common in flowing and stagnant waters, attached to other algae especially *Cladophora glomerata*. It is considered cosmopolitan (McGregor, 2007), although Komárek & Anagnostidis (2005) reinforce that the marine populations should be confirmed.

Distribution: Muddy Run ATSTM

Phormidium autumnale (Agardh) Trevisan *ex* Gomont (1892)

Basionym: *Oscillatoria autumnalis* Agardh (1812)

(Plate 2, E)

Thallus is thick, leathery; sheaths fine, hyaline, sometimes absent; trichomes mostly straight to slightly flexuous, 4.5-6.5 μm wide, not constricted at cross-walls; cells 3-5 μm long, mostly isodiametric; cell-content black-brown to dark blue-green, homogenous; cross-walls granulated; apical cells elongated to conical, ends abruptly attenuated, often capitate, with rounded or truncate calyptra; hormogonia common.

Phormidium autumnale is commonly encountered in periphytic, benthic habitats in slow-flowing waters of streams and rivers (Gomont, 1892; McGregor, 2007). This species is found in similar freshwater habitats worldwide.

The specimens observed in this study agree with the type reviewed by Gomont (1892) – trichomes 4-7 μm wide, cells 2-5 μm long. In addition, diacritical characters of this species are the abrupt attenuation of the trichome, the fast oscillatory movement of the filaments, and the presence of a calyptra.

Distribution: Muddy Run ATSTM, Peach Bottom ATSTM

Phormidium retzii (Agardh) Gomont *ex* Gomont (1892)

Basionym: *Oscillatoria retzii* Agardh (1812)

(Plate 3, A)

Thallus is thick, entwined, compact prostrate mat, mucilaginous; sheaths thin (0.5-1 μm wide) hyaline, usually diffluent, sometimes absent. Trichomes 5-11 μm wide tangled, usually straight, not constricted at cross-walls; cells 4-8 μm long, mostly isodiametric; cell-content dark blue-green, homogenous; cross-walls not granulated; apical cells

cylindrical-rounded to truncate, not attenuated, without thickened cell wall; hormogonia and necridia present.

The populations observed in this study agree with the morphometric characters for the type of *Phormidium retzii* presented by Gomont (1892) and later reviews. The difference with the populations in this study and those from Gomont (1892) is that the current populations are not as wide [Gomont (1892) – 4.5-12 µm wide, 4-9 µm long]. This species is probably the most common freshwater cyanobacterium of lotic environments, which leads to the broad range in its width and length reported in the literature possibly due to misidentifications by several authors. The range of habitats in which this species has been cited and the variability in its morphology suggests that this taxon is a complex of cryptic species (Casamatta et al., 2003).

Phormidium retzii is found on edges of streams, on rocks and wood. The original type was reported from cold, northern flowing or stagnant waters, springs, waterfalls, mountains; however it has been cited for tropical streams, warm waters, and thermal springs (Komárek & Anagnostidis, 2005). The species often forms entangled mats in fast currents, which was seen at the top of the ATSTM unit. Gomont (1892) noted this particular ecological characteristic of this species observing that *P. retzii* thrives in fast-moving currents, where it is capable of forming large clumps, attached to the substrate.

Distribution: Muddy Run ATSTM, Peach Bottom ATSTM

Phormidium simplicissimum (Gomont) Anagnostidis et Komárek, 1988

Basionym: *Oscillatoria simplicissima* Gomont (1892)

Thallus thin, sheaths absent. Trichomes straight or flexuous, long, 8-9.5 μm wide, not constricted at cross-walls; cells 2.5-4.5 μm long; cell-content dark blue-green, cross-walls slightly granulated; apical cells hemispherical to rounded.

The specimens in this study agree with the morphometric characters of the species *Oscillatoria simplicissima* (Gomont, 1892). However, the populations in this study had wider and longer cells than the type specimen. Other authors have found that this species can reach 9(10) μm wide and 4.5 (6) μm long (Komárek & Anagnostidis, 2005), resembling the populations in this study.

Phormidium simplicissimum was originally described from small stagnant waters near Paris and streams near Salzburg (Gomont, 1892). Komárek & Anagnostidis (2005) state that this species has been found in Europe, Asia, and Australia, periphytic in streams, stagnant waters, and occasionally in thermal springs.

Distribution: Muddy Run ATSTM

Phormidium stagninum Anagnostidis (2001)

Basionym: *Lyngbya stagnina* Kützing *ex* Gomont (1892)

Thallus thin, mucilaginous, sheaths (0.5-2 μm wide) distinct, firm, thick, slightly yellowish, lamellated. Trichomes tangled, usually straight, not constricted at cross-walls; cells 8-11 μm wide, 2.5-4.5 μm long; cell-content dark green or blue-green, homogenous; cross-walls granulated; apical cells cylindrical to rounded, not attenuated, without thickened cell wall.

Phormidium stagninum populations found in this study agree with the morphometric characters of the species presented in Komárek & Anagnostidis (2005). Moreover, these authors point out that this species is found in cold waters, which is interesting, since this species was found during the cold months of operating the ATS™ in southeastern Pennsylvania. The diacritical morphological features of this species are the tangled filaments, with yellowish, lamellated sheaths. These features were found in this species, and distinguish it from any other species similar in size.

Distribution: Muddy Run ATS™

Phormidium tergestinum (Kützing) Anagnostidis et Komárek, 1988

Basionym: *Oscillatoria tergestina* Kützing, (1836)

(Plate 4, A-B)

Thallus thin, mucilaginous, sheaths (0.5 µm wide) occur facultatively. Trichomes solitary or tangled, usually straight, sometimes irregularly bent, not constricted at cross-walls; cells 5-6 µm wide, 2.5-4.5 µm long, 1.2-2 times wider than long; cell-content grey-blue-green, homogenous; cross-walls (very) granulated, sometimes translucent; apical cells cylindrical to rounded, not attenuated, with or without thickened cell wall.

Phormidium tergestinum was originally described as *Oscillatoria tergestina* Kützing. The studied specimens agree with the description of *Oscillatoria tenuis* Agardh var. *tergestina* Rabenhorst presented by Gomont (1892) [4-6 µm wide], who described this species primarily as benthic, then later planktonic, since the populations were observed forming part of benthic/periphytic mats.

Distribution: Muddy Run ATS™

OSCILLATORIACEAE

Lyngbya giuseppeii F.E.Drouet, (1942)

(Plate 4, C-D)

Filaments usually straight, rarely flexuous; 14 µm; sheath thin, colorless, not lamellate; trichomes (8-)10.5-13 µm wide, not constricted at the cross-walls. Cells 2.5-3.5 long; cellular content finely granular, blue-green; cross-walls ungranulated; apical cell rounded with a thickened outer wall, capitate.

Drouet (1942) described *L. giuseppeii* from periphyton growing in New York and Minnesota, having trichomes from 5 to 10 µm wide. Although, specimens found in this study resemble the original description for *L. giuseppeii*, they have wider filaments. McGregor (2007) also found wider filaments [9-12.5 µm wide] of what he identified as *Lyngbya* cf. *giuseppeii* in Capalaba Wetlands, Queensland, Australia. Besides these studies, this species has not been readily found, demonstrating its rare occurrence, or that it has been overlooked in taxonomic surveys.

This cyanobacterium was found growing among other cyanobacteria (*Oscillatoria* and *Lyngbya* spp.) in dense periphytic mats in this study. It was difficult to find forming single-species strands, and separating it into unialgal cultures due to contamination of a finer *Lyngbya*. McGregor (2007) also observed this species among other algae, and noted that this species rarely formed large single-species mats.

Due to the morphometric similarity, specimens from this study lie within the length/width ratio of the type specimen, thus were identified as *Lyngbya giuseppeii*.

Distribution: Muddy Run ATSTM

Lyngbya major Meneghini *ex* Gomont, (1892)

(Plate 3, E)

Filaments solitary, in small clusters or mats, usually straight, 15-17 µm wide; sheath firm, thick (1-3 µm wide), colorless, sometimes lamellate; Trichomes (10-)12.5-13 µm wide, not constricted at cross-walls. Cells 2-2.6(-4) µm long, cellular content blue-green with finely granulated cross-walls; apical cell capitate, rounded, slightly attenuated, sometimes with a thickened outer wall, calyptra absent.

The population studied falls within the metric and morphological limits of the description presented by Gomont (1892). Moreover, the cell length:width ratio is similar to that presented by the author of the species, defending the identification of the species as *L. major*.

Gomont (1892), Geitler (1932), and Desikachary (1959) found this species to present blue-green coloration in its cells; however, Santa'Anna & Azevedo (1995) found that this species could be blue-green and/or brownish. In the present study, the cells were found to be blue-green.

Lyngbya major resembles *L. majuscula* Harvey *ex* Gomont, but they differ basically due to cell dimensions. *L. majuscula* has wider filaments and trichomes [16-60

µm, normally 20-40 µm (Gomont, 1892)] and a larger cell width:length ratio. Besides, the cross-walls in *L. major* are granulated, while in *L. majuscula* they are not.

Lyngbya major has been cited occurring in several different environments, such as stagnant waters, puddles, tanks, on mud, humid soils, and in thermal waters (Gomont, 1892; Geitler, 1932; Desikachary, 1959; Komárek & Anagnostidis, 2005).

Distribution: Muddy Run ATS™

Lyngbya martensiana Meneghini ex Gomont (1892)

(Plate 2, D; Plate 3, B-C)

Filaments solitary, straight or flexuous, or forming mats of entangled filaments, 10-12 µm wide; sheath firm, thick, sometimes lamellate, colorless, outside rough, 1.5-4 µm thick; trichomes not attenuated, not constricted, 8-10.5 µm thick; cells 2-3.5 µm long; cell content blue-green; cross-walls granulated; apical cells rounded, without thickened outer wall.

In the specimens from this study, the morphological characters, as well as the metric variations of the analyzed specimens, agree with those described by Gomont (1892) for *Lyngbya martensiana*. Interestingly, the original material found by Gomont (1892) was collected in thermal springs (Italy and Guadeloupe); the populations analyzed here were found in the heated water discharge canal at the Peach Bottom Nuclear Power Plant.

This species has been recorded for other ecosystems in temperate, tropical, and subtropical zones. According to Frémy (1930) and Geitler (1932), *Lyngbya martensiana*

can develop in lentic and lotic environments, though rarely in marine ecosystems; it has also been observed growing on moist soils. Geitler (1932) considered the species cosmopolitan, also shown by Komárek & Anagnostidis (2005) and McGregor (2007).

Distribution: Peach Bottom ATS™

Lyngbya nigra Agardh ex Gomont (1892)

(Plate 3, D)

Filaments in mats, straight, 14 µm wide; sheath thin, colorless, not lamellated; trichomes 9-12.5 µm wide, not constricted at cross-walls. Cells 2.5-3.5 µm long, cellular content blue-green to dark blue-green, finely granular, cross-walls not granulated. Apical cells rounded-conical, calyptra present.

Most of the studied specimens were within the metric limits of the original description of Gomont (1892). However, specimens from the Chesapeake Bay region were found to be a little wider.

The original description of *Lyngbya nigra* in Gomont (1892) presents trichomes from 8-11 µm wide, however populations in this study presented widths of up to 12.5 µm, similar to those found by McGregor (2007) whose northeastern Australian populations vary from 8-12(-14) µm. Due to the L:W ratio of the studied specimens here, as well as other diacritical characters, such as the apical cell presenting a calyptra, this specimen was identified as *L. nigra*.

This species resembles *Lyngbya hollerbachii* Elenkin, however, it differs in cell dimensions, where *L. hollerbachii* has larger filaments and trichomes (up to 20 µm wide),

as well as a larger width to length cell ratio (cells 1/3x as long as wide, 4-5 µm wide) (Komárek & Anagnostidis, 2005). In addition, the apical cell of *L. hollerbachii* is capitate, but has no calyptra.

Distribution: Muddy Run ATS™

Lyngbya salina Kützing ex Starmach (1966)

(Plate 5, C)

Filaments long, wavy, 12.5-14 µm wide; sheath compact, colorless, lamellate; trichomes 11-12 µm wide, not constricted at cross-walls. Cells 2-2.5(-3) µm long, cellular content bright blue-green. Apical cells rounded, sometimes with a thickened cell wall present, calyptra absent

This species was abundant at both the VIMS and Wicomico ATS™ flowways, and produced high biomass at certain times of the year. The metric limits of the morphological characters are in agreement to those reported in literature (eg. Komárek & Anagnostidis, 2005).

Distribution: Great Wicomico ATS™, VIMS ATS™

Oscillatoria curviceps Agardh ex Gomont (1892)

Trichomes solitary or in small clusters, ±straight with a hooked/bent end, not or slightly attenuated, 11-16 µm wide, not constricted at cross-walls; cells 3-5.5 µm long; cell content dark blue-green, homogenous, cross-walls sometimes with granules; apical cells flat-rounded, not capitate, sometimes with thickened cell wall.

Oscillatoria curviceps differs from other closely related species by its hooked or bent ends. This morphological feature clearly distinguishes it from other species of the genus. The metric limits agree with those presented other authors (Komárek & Anagnostidis, 2005; McGregor, 2007) from locations worldwide. In the Muddy Run ATSTM, it was found among other algae, in the periphyton, which is similar to shallow waters of its natural habitat reported in literature.

Peculiarly, *O. curviceps* is cited for stagnant waters, which is not a character of the algal turf system, however, there were occasions in which the system would form very slow moving currents due to dips in its construction and in these slow moving areas was where this organism was found.

Distribution: Muddy Run ATSTM

Oscillatoria froelichii Kützing ex Gomont (1892)

(Plate 5, A-B)

Trichomes solitary, straight, slightly attenuated, 7.5-8.5 µm wide, not constricted at cross-walls; cells 2-3 µm long; cell content blue-green, homogenous, cross-walls sometimes with granules; apical cells with distinct, hyaline, rounded to hemispherical calyptra.

The original type material of *Oscillatoria froelichii* ranges from (15-)18-21 µm, which is much wider than the studied populations of the project. However, Komárek & Anagnostidis (2005) state that specimens with trichomes only 8-9 µm wide have also been described for this species. Further, these authors suggest that the validity of these

narrower filaments with the type should be proven in the future. Since narrower filaments have been described for this species, and the diacritical character is the formation of a distinct, hyaline, rounded to hemispherical calyptra, the population studied is maintained as *Oscillatoria froelichii*, with the hope that future studies will be able to confirm if these wider and narrower filaments are in fact the same taxon.

Distribution: Muddy Run ATSTM

Oscillatoria limosa Agardh ex Gomont (1892)

(Plate 5, D-E)

Trichomes solitary, straight, sometimes quickly attenuated, slightly constricted, (7-)8.1-9 µm wide; cells 2.3-4.5 times shorter than long, 2-3.5 µm long; cell content blue-green, homogenous, cross-walls sometimes with granules; apical cells rounded, sometimes with a thickened outer wall.

According to Gomont (1892) the width of *Oscillatoria limosa* ranges from 11 to 20 µm (usually 13-16 µm). In the population studied, trichomes with a smaller width were found [(7-)8.1-9 µm].

Most other authors have found narrower trichome widths than originally described by Gomont (1892) (Tilden 1910; Frémy, 1930; Geitler, 1932; Desikachary, 1959; Franceschini, 1992; McGregor, 2007). The narrower trichomes are similar to the populations in this study. Despite the differences regarding cell width and cell length, the L:W ratio and morphological characteristics agree with the type presented in literature, justifying the present identification.

Oscillatoria limosa can develop in fresh and brackish water as well as on mud (Gomont, 1892; Settel & Gardner, 1903; Geitler, 1932), and is considered cosmopolitan (Fjerdingsstad, 1971).

Distribution: Muddy Run ATS™

Oscillatoria princeps Vaucher *ex* Gomont (1892)

Trichomes solitary, straight, or slightly curved at the ends, 30-45 µm wide, not constricted at cross-walls, not attenuated; cells 3.5-6 µm long; cell content blue green; cross-walls not granulated; apical cell widely rounded, sometimes slightly capitate and calyptrate.

The morphometric characteristics of the studied specimens agree with the traits for this species (Gomont, 1892; Geitler, 1932; Sant'Anna & Azevedo, 1995; Komárek & Anagnostidis, 2005, McGregor, 2007). *Oscillatoria princeps* is commonly found in periphyton, forming thick dark-green mats. According to Gomont (1892) the species is first found in the benthos, then capable of floating free in the plankton as it matures.

Distribution: Muddy Run ATS™

Oscillatoria sancta Kützing *ex* Gomont (1892)

(Plate 6, A-C)

Trichomes solitary, flexuous, straight, or sometimes slightly curved, constricted, 11-12 µm wide; cells discoid, 1.5-2.5 µm long; cell content blue-green or olive-green,

granulose; cross walls granulated; apical cells rounded to truncate-rounded, sometimes capitate, with a thickened outer cell wall.

The floway specimens agree with the description of *Oscillatoria sancta* presented by Gomont (1892). The only difference is the type of habitat. Gomont (1892) typified a species that occurred in tanks, on soil or moist rocks, while the material in this study was found in the hot water discharge from Peach Bottom Atomic Nuclear Power Plant.

Komárek & Anagnostidis (2005) report that the species can be found in thermal springs, especially in those of lower temperatures. According to Geitler (1932), the species can also be found in stagnant or flowing-waters, free-floating, or on soils or rocks.

Desikachary (1959) reports that *O. sancta* can develop in fresh- and brackish lakes, planktonic or epiphytic.

Distribution: Peach Bottom ATS™

Conclusions

The floristic study on periphytic Oscillatoriales demonstrated that our knowledge on this cyanobacterial flora in the Chesapeake Bay is truly scarce. Most of these species had not been previously found in the region, either overlooked or not inventoried.

Understanding the periphyton becomes pertinent in understanding further works of water quality and how potential climate change is affecting the Chesapeake Bay area. This study is seen as a baseline for further studies on periphytic cyanobacteria in the region using integrated morphological and molecular methods.

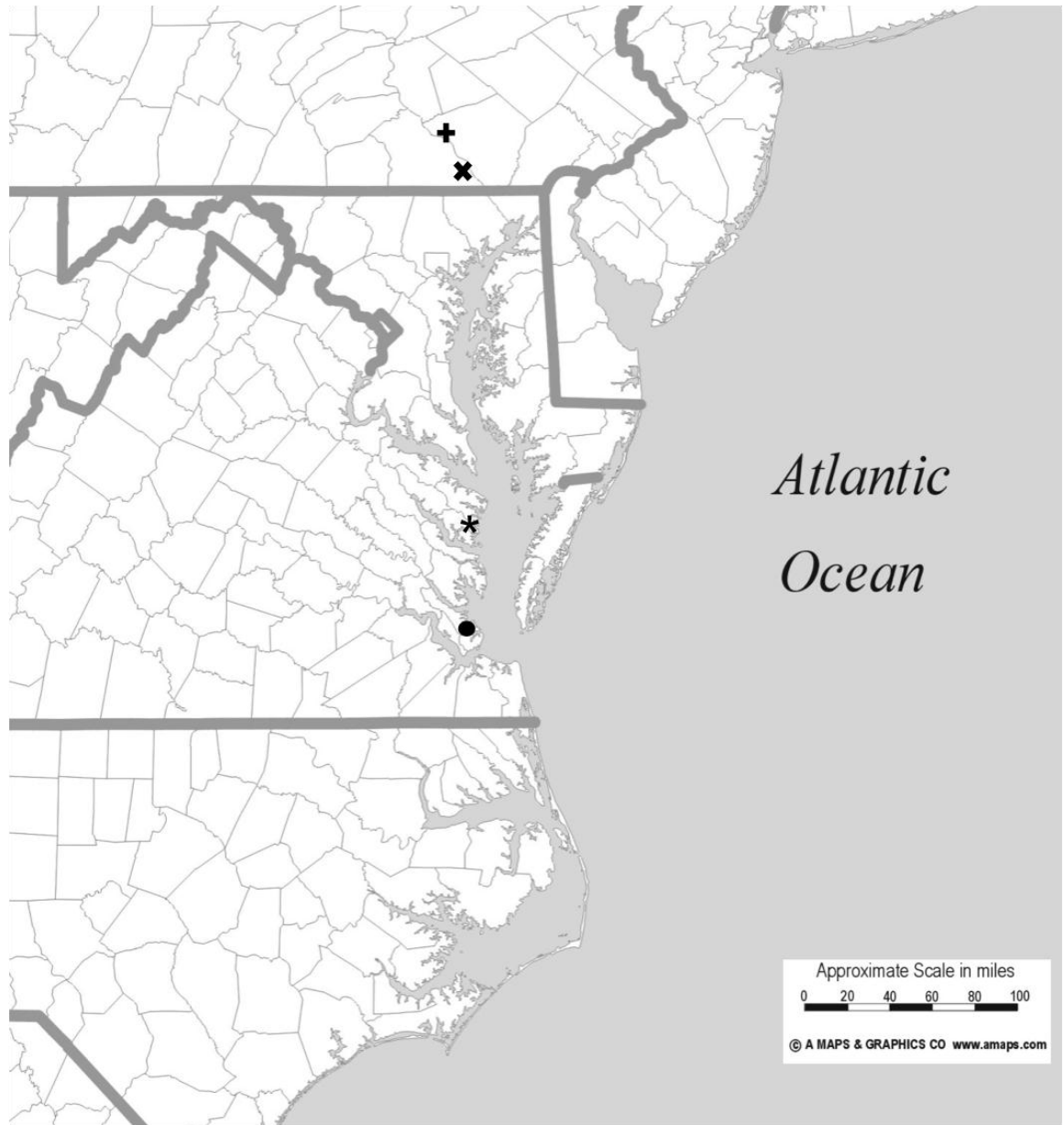


Figure 4.1. Map of the study area: (+) Muddy Run ATS™, (x) Peach Bottom ATS™, (*) Great Wicomico ATS™, and (•) VIMS ATS™.

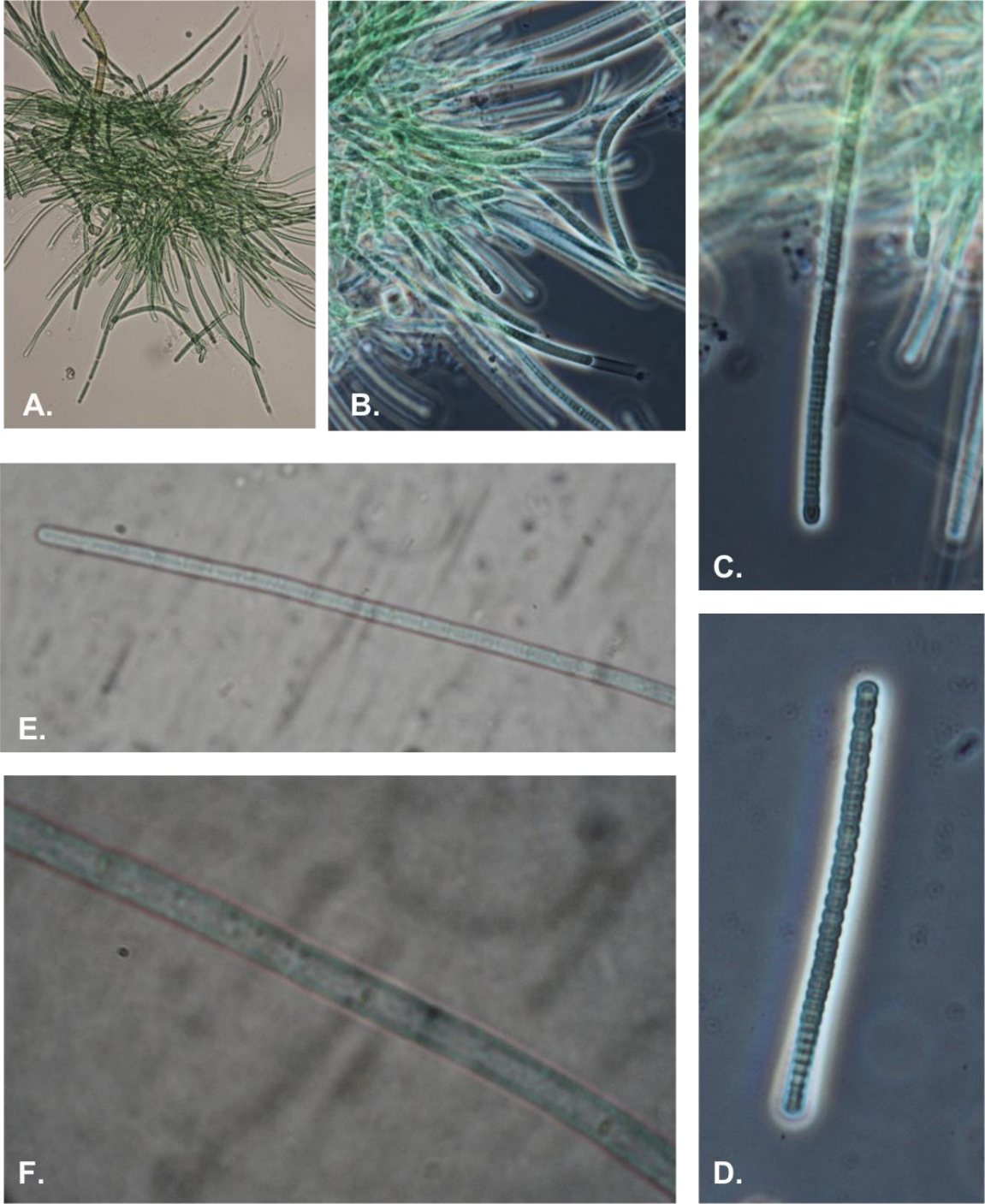


Plate 1. A-D. *Komvophoron minutum*, E-F. *Geitlerinema amphibium*.

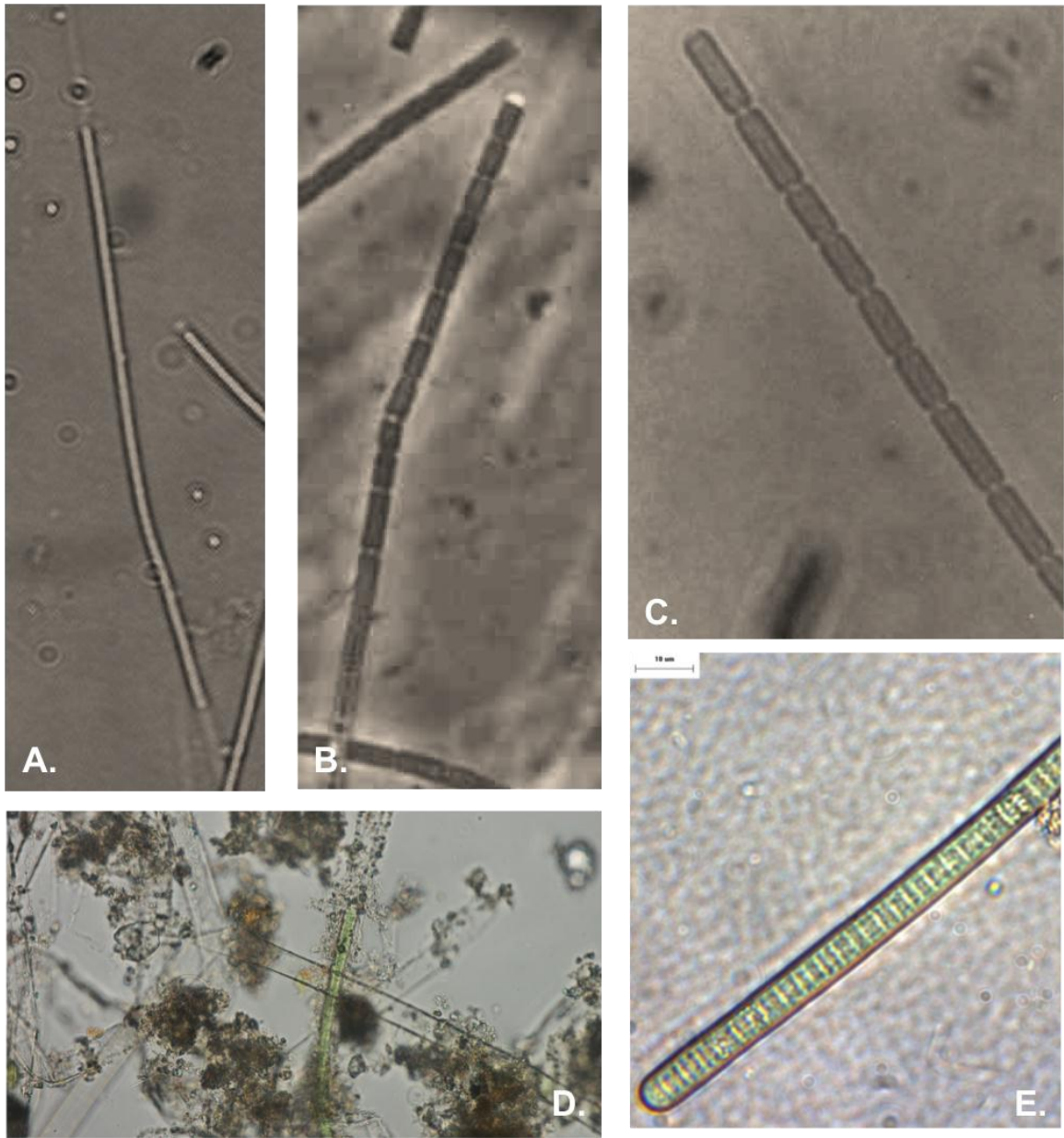


Plate 2. A. *Planktolyngbya limnetica*, B. *Pseudanabaena galeata*, C. *Pseudanabaena limnetica*, D. *Lyngbya martensiana*, E. *Phormidium autumnale*.

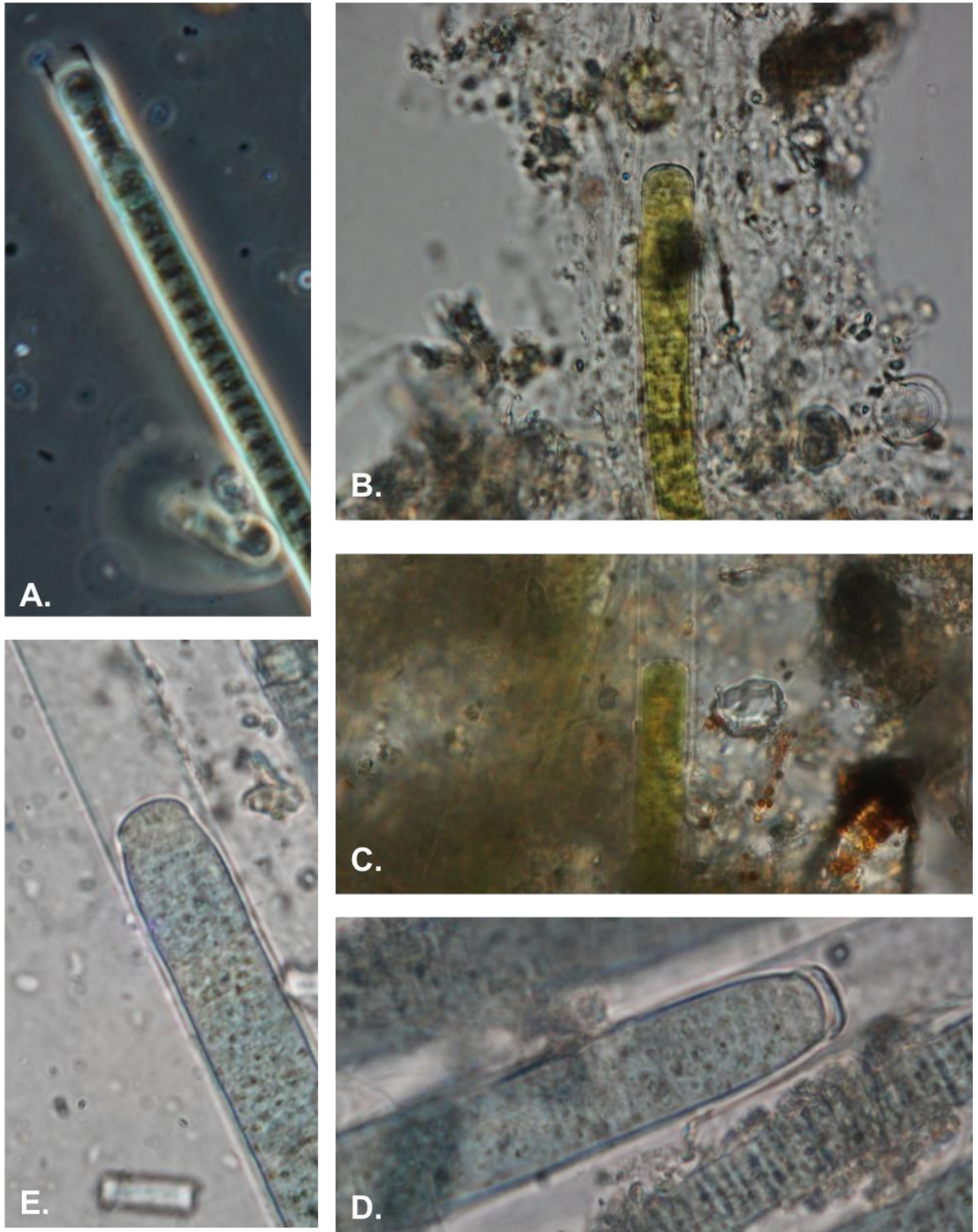


Plate 3. A. *Phormidium retzii*, B-C. *Lyngbya martensiana*, D. *Lyngbya nigra*, E. *Lyngbya major*.

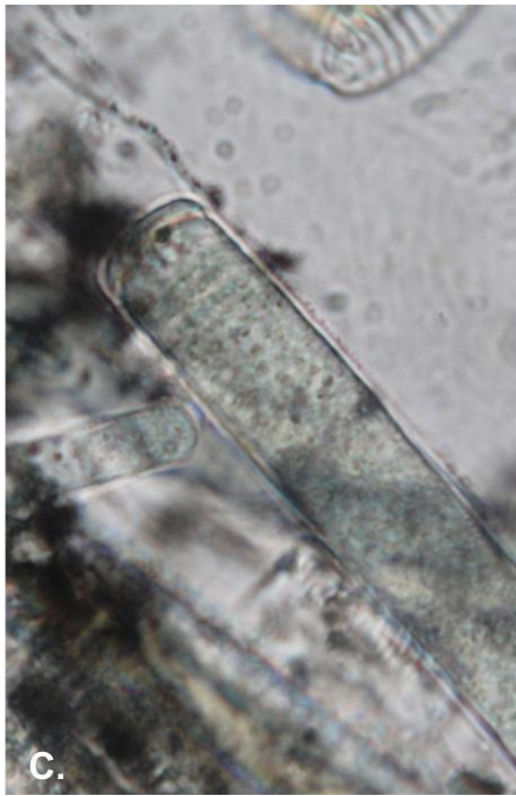
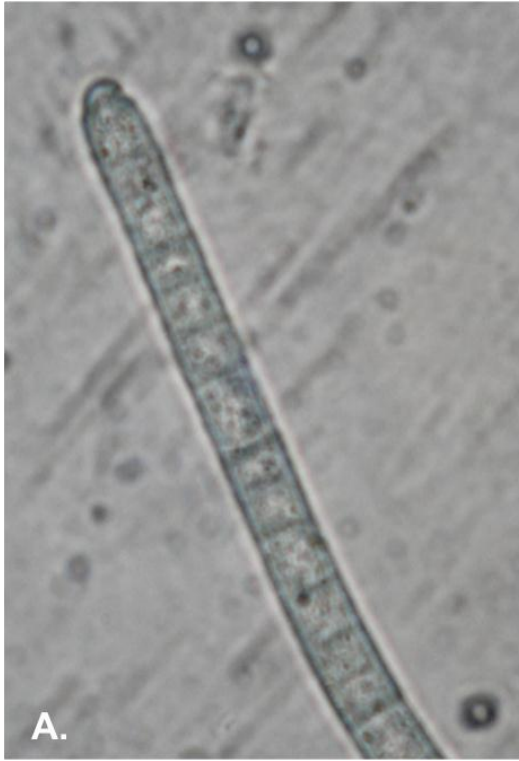


Plate 4. A-B. *Phormidium tergestinum*, C-D. *Lyngbya giuseppeii*.

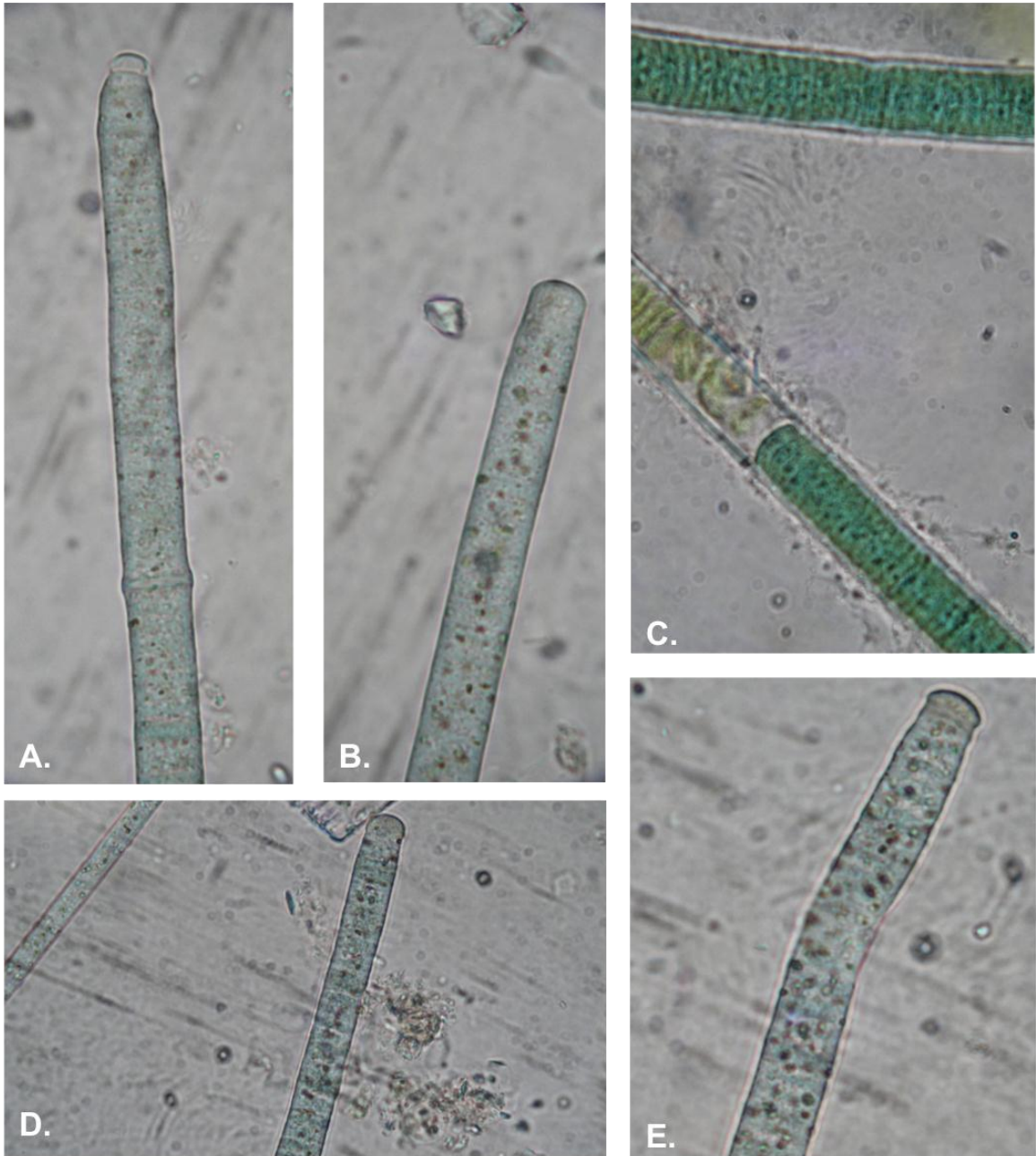


Plate 5. A-B. *Oscillatoria froelichii*, C. *Lyngbya salina*, D-E. *Oscillatoria limosa*.

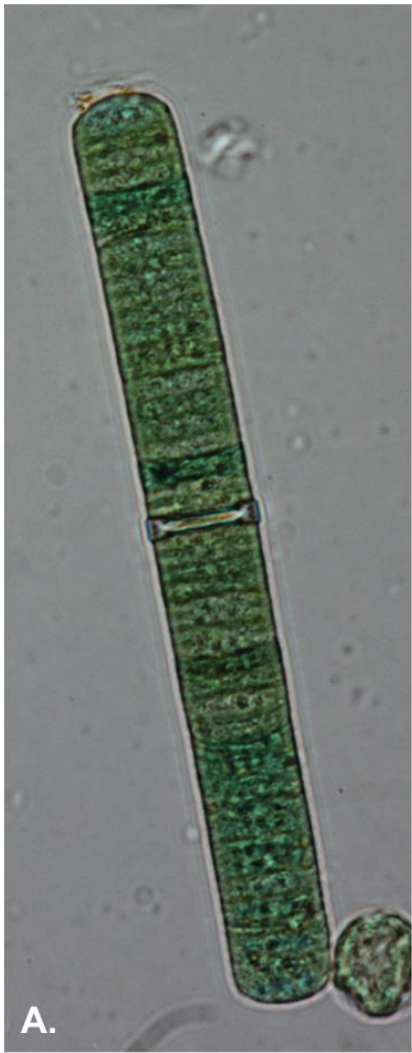


Plate 6. A-C. *Oscillatoria sancta*.

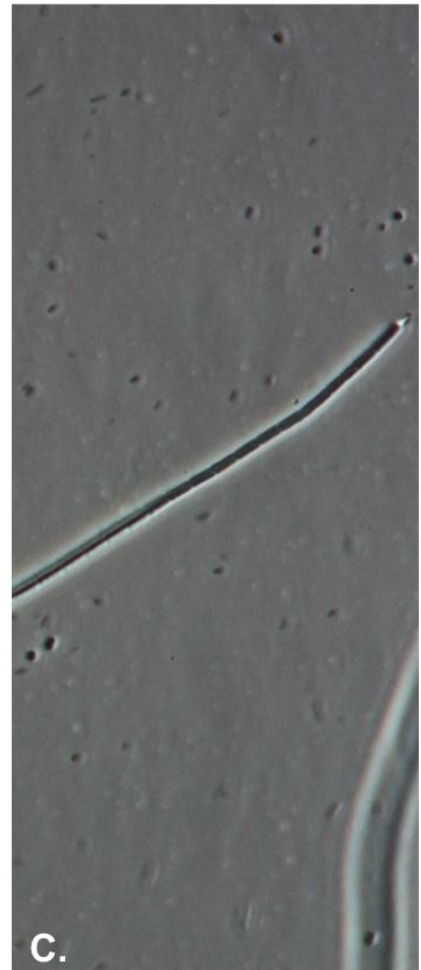
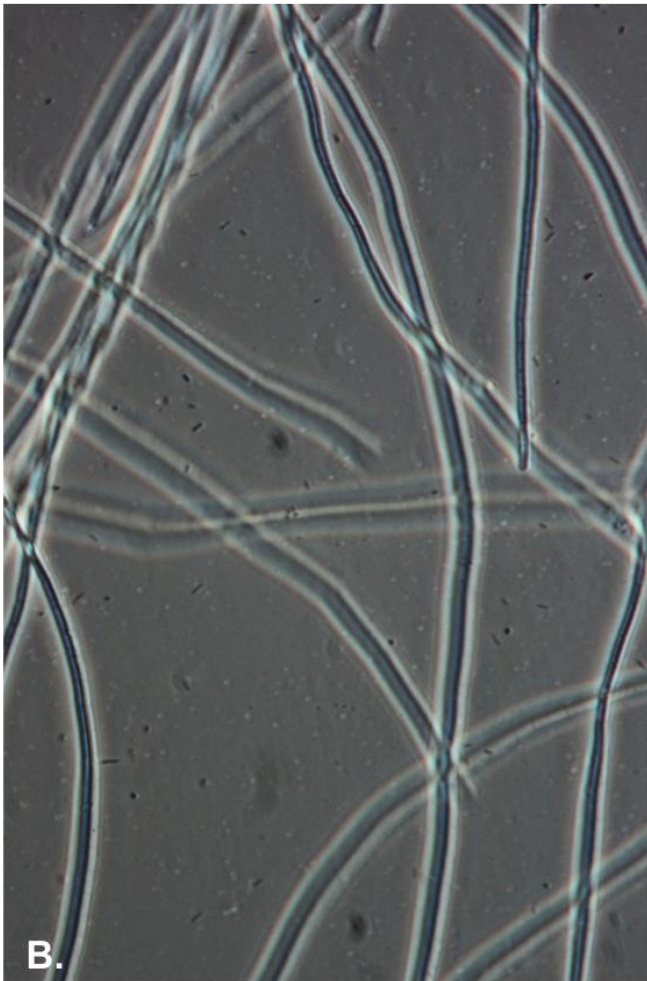


Plate 7. A-C. *Pseudanabaena lonchooides*.

Subchapter 2. Taxonomic revision of the freshwater periphytic ‘*Pseudanabaena*’ and its elevation to *Ilyonema* (*Anagnostidis et Komárek*) comb. nova

Introduction

Cyanobacteria are a dominant component of the plankton of several freshwater, brackish, and marine environments, and receive attention, especially when forming toxigenic blooms (Carvalho et al., 2008; Werner & Laughinghouse, 2009; Laughinghouse et al., 2012). However, the diversity of cyanobacteria surpasses the large bloom-forming species, and little attention is given to thin benthic and/or periphytic homocytic filamentous taxa. The potential existence of a larger biodiversity than currently described is well accepted in the cyanobacterial community, and especially demonstrated by the amount of novel taxa and systematic revisions currently being published (i.e. Zapomelová et al., 2009; Bohunická et al., 2011; Johansen et al., 2011; Perkerson et al., 2011; Strunecky et al., 2011; Kling et al., 2012; Werner et al., 2012). Understanding the true diversity of these organisms is vital for any downstream ecological work, especially when trying to interpret biogeographic patterns in these organisms and/or how they are affected with global climate change.

The genus *Pseudanabaena* Lauterborn, revised by Anagnostidis & Komárek (Anagnostidis & Komárek, 1988; Komárek, 2003), is morphologically variable (Romo & Miracle, 1994). To ascribe the morphological variability within this genus, Anagnostidis & Komárek (1988) erected three subgenera: *Pseudanabaena*, *Skujanema*, and *Ilyonema* within the genus, the latter (*Ilyonema*), containing benthic species, with cylindrical cells, rounded-conical terminal cell, and with the diacritical character of terminal gas vesicles.

These authors also foresaw that further revisions and transfers would be necessary to the genus, as systematic science progressed. The genus *Pseudanabaena* has been found closely related, both genetically and morphologically, to the genus *Limnothrix* Meffert, whose main diacritical marker separating it from the genus *Pseudanabaena* is the ability of forming gas vesicles and deep constrictions between the cells (Acinias et al., 2009). Furthermore, this similarity has been attributed between the planktonic subgenus *Pseudanabaena* (genus *Pseudanabaena*) and genus *Limnothrix* (Kling et al., 2012).

Acinias et al. (2009) noted that some planktonic morphotypes belonging to the genus *Pseudanabaena* form a monophyletic cluster, and this cluster in the phylogenetic tree (Figure 1) contains both members of *Pseudanabaena* and *Limnothrix*. Several authors have cited the genus *Pseudanabaena* as being heterogenous and/or polyphyletic (Anagnostidis & Komárek, 1988; Komárek & Anagnostidis, 2005; Kling et al., 2012), though no exhaustive attempts to resolve these systematic problems have been published up to date.

The aim of this study is to describe a novel cyanobacterial branch within the morphological and ecological limits of *Ilyonema* (= *Pseudanabaena*) *lonchoides* (Anagnostidis) comb. nova in the subgenus *Ilyonema* of the genus *Pseudanabaena*, while proposing to officially elevate *Ilyonema* to generic status due to (a) unique morphological character(s), ecology, phylogenetic placement, and evolutionary history.

Materials and Methods

Material. *Ilyonema* (= *Pseudanabaena*) *lonchoides* was found during routine analyses of periphytic samples from an algal turf scrubber system (ATSTM – see descriptions of ATSTM in Adey et al., 2011) receiving water from the discharge canal at the Peach Bottom Atomic Power Station situated on the banks of the Susquehanna River in Delta, Pennsylvania, USA (39.753129, -76.261082). The morphometric analyses of samples from nature, fixed material, and strains were undertaken using an Olympus BX50 binocular light microscope with an attached Canon Rebel EOS Rebel T1i digital camera for photography. Thirty individuals and 20 to 30 measurements of each were analyzed for each individual. Photographs and/or morphometric delimitations are presented.

Culture. Subsamples of natural material were isolated into BG-11 growth media. These are maintained in culture collection at the Molecular Microbial Ecology Laboratory of the Institute of Marine and Environmental Technology – University of Maryland Center for Environmental Sciences (IMET-UMCES), Baltimore, MD, USA, at ambient light and temperature.

Genomic DNA Extraction, PCR Amplification, and Sequencing. Total genomic DNA was isolated following a maceration/boiling technique described in Kling et al. (2012), using 2 ml of fresh culture.

Partial 16S rRNA was amplified using the oligonucleotide primers CYA106F (5'-CGG ACG GGT GAG TAA CGC GTG-3') and CYA781R (5'-GAC TAC AGG GGT

ATC TAA TCC-3') (Nübel et al. 1997). A 50 µl reaction for each sample was performed on a MJ Research PYC-200 Thermo Cycler, with the following conditions: 1) 94 °C for 5 min, 2) 94 °C for 60 sec, 3) 55 °C for 60 sec, 4) 72 °C for 60 sec, 5) repeat steps 2-4 for 35 cycles, 6) 72 °C for 10 min, then 7) 4 °C, indefinitely. A 1% agarose gel was used to verify amplified products. Direct sequencing of the PCR product was undertaken with the primer CYA106F.

The Basic Local Alignment Search Tool (BLAST) of the National Center for Biotechnology Information (NCBI) was used for locating OTUs similar to the sequences obtained. Sixty-four sequences were obtained from NCBI after performing BLAST.

After obtaining sequences from NCBI, they were aligned using MAFFT version 6 (Kato & Toh, 2008), then were manually refined considering conserved regions using SeaView version 4 (Gouy et al., 2010). For construction of the phylogenetic trees, substitution models for nucleotide evolution were determined using jModeltest (Guindon & Gascuel, 2003; Posada, 2008). Under the Bayesian Information Criterion (BIC), the TIM3+gamma model was used for the 16S rRNA. Two trees were constructed on this genetic marker. The software MrBayes v3.2 (Ronquist & Huelsenbeck, 2003) was used for determining Bayesian inference. A Dirichlet (1,1,1,1,1) prior was utilized for substitution rate parameters, in addition to a uniform prior (0,1) for the pinvar parameter. A uniform (0, 200) prior was set on the gamma shape parameters and for branch lengths, an unconstrained: Exponential (10) prior. Two runs of four chains (three heated and one cold) were run for 5×10^6 generations, sampling every 100 trees. In each run, the first 25% of samples were discarded as the burn-in phase. Maximum Likelihood (ML) was

determined using MEGA 5 (Tamura et al., 2011). Statistical analyses of tree topologies were carried out by performing bootstrap analysis with 1,000 pseudoreplicates.

Results and Discussion

Nuclear power plant discharge canals have been shown to increase chlorophyll *a* in rivers, partially due to high temperatures which increases bacterial activity and nutrient recycling, and partially due to selection for higher temperature species (Agha et al., 2012). Here, it was found that the high temperatures from the nuclear discharge canal at Peach Bottom Atomic Power Station also provide optimal conditions for the massive proliferation of benthic and periphytic cyanobacteria on the algal turf scrubbers (ATSTM). This two-unit nuclear generation facility located in SE Pennsylvania on the Susquehanna River is composed of boiling water reactors which use water from the Susquehanna River to cool the reactors.

Within this periphytic matrix a peculiar oscillatorian species was found, which had not been encountered previously in regional floristic studies. This was isolated and cultured. Morphologically, this species resembled taxa within the subgenus *Ilyonema* of the genus *Pseudanabaena* (Anagnostidis & Komárek, 1988), which are recognized as benthic or periphytic, with cylindrical intercalary cells, rounded-conical terminal cells, whose diacritical morphological character is the capability of forming terminal gas vesicles (Figure 2C). Komárek & Anagnostidis (2005) state that there are no clear limits between the genera *Limnothrix* and *Pseudanabaena*, and comment that this similarity is between the subgenus *Ilyonema* and the genus *Limnothrix*. Kling et al. (2012), while describing *Pseudanabaena rutilus-viridis* Kling, Laughinghouse IV & Komárek,

demonstrate that the phylogenetic similarity between these two groups are found between the subgenus *Pseudanabaena* and *Limnothrix*, which can also be interpreted by results presented in a study by Acinias et al. (2009) and the present study.

The two phylograms for the 16S rRNA undertaken in this study (Bayesian and maximum likelihood (ML) were similar in topology. *Ilyonema* (= *Pseudanabaena*) *lonchoides* does not fall within the clade of the genus *Pseudanabaena* (subgenus *Pseudanabaena*), but forms its own separate smaller clade with generic entities that have not been identified to the species-level. However, strain ANT.BFI.1 was re-examined morphologically and this material demonstrates similar morphology at the generic *Ilyonema*-level with that proposed in this study. It is known that caution should be used when obtaining data from GenBank (Kling et al., 2012), and several researchers believe that roughly 50% of the names of cyanobacterial taxa deposited in GenBank are incorrect (B. Whitton & J. Komárek, pers. commun.), and the present analysis demonstrates that there are both polyphyletic taxa with putative incorrect taxa names on strains.

Morphologically, the species found in this study could not be *Oscillatoria* since *Oscillatoria* is a well-defined genus with trichomes from 8-45 µm wide, with discoid cells, and no aerotopes. The genus *Leptolyngbya* is thin, similar to *Pseudanabaena* however, *Leptolyngbya* is characterized by the absence of gas vesicles and the presence of a thin- to thicker mucilaginous sheath. Also, genetically, the *Leptolyngbya boryana* clade demonstrates the phylogeny of true-*Leptolyngbya*, though recent studies have shown that some *Leptolyngbya*-like species actually belong to novel entities (Johansen et al., 2011; Perkerson et al., 2011), and our taxon does not cluster within this clade.

Pseudanabaena subgenus *Pseudanabaena* forms a larger *Limnothrix*/*Pseudanabaena* clade with the type-species of *Limnothrix*, *L. redekei* (van Goor) Meffert, which can be seen in the 16S rRNA phylogenetic trees (Figure 1), and with what is understood as the ‘true’ *Pseudanabaena* (Acinias et al., 2009; Kling et al., 2012). Interestingly, *Ilyonema* (= *Pseudanabaena*) *lonchoides* is a novel branch in a small clade with other taxa, named *Leptolyngbya* sp. and *Oscillatoria* sp., though ML support values are low. This analysis demonstrates that it is not the subgenus *Ilyonema* that is most closely related to *Limnothrix*, as stated by Komárek & Anagnostidis (2005), but in fact the subgenus *Pseudanabaena*.

Description

***Ilyonema* (Anagnostidis et Komárek) Laughinghouse, Kling et Kangas, comb. nova**

Basionym: *Pseudanabaena* Lauterborn (1915) subgenus *Ilyonema* Anagnostidis et Komárek (1988)

Description: Trichomes in benthos, periphytic, or metaphytic in fine mats, usually straight or slightly waved, constricted at the cross-walls; trichomes usually long (350-400 celled) sometimes short (15-celled). Cells cylindrical, thin (< 3.5 µm), with rounded ends, 2-6x longer than wide. Terminal cells conical to pointed, with the presence of terminal aerotopes (on the end not attached to the substrate).

Type species: *Pseudanabaena biceps* Böcher (1946)

Ilyonema lonchoides (Anagnostidis) Laughinghouse, Kling et Kangas, comb. nova

(Fig. 2A-C)

Trichomes solitary or in fine, delicate mats, straight or flexuous, deeply constricted at the cross-walls; cells cylindrical, 0.9-1.3 μm wide, 3.8-6 μm long usually (3.2)3.8-6x longer than wide, granules absent; cell content blue-grey; apical cell rounded to conical, sometimes with refractive granule (terminal gas vesicle?).

Occurrence: Heated discharge water canal (38 °C – 40 °C) at the Peach Bottom Atomic Power Station, York County, SE Pennsylvania on the Susquehanna River.

Nomenclatural revision of *Ilyonema* species:

With this study, we recommend that all previous *Pseudanabaena* species belonging to the subgenus *Ilyonema* be transferred to the newly elevated genus *Ilyonema*. The present work demonstrates that the genus *Pseudanabaena* is polyphyletic and that the subgenera *Pseudanabaena* and *Ilyonema* form distinct clades. Further work is still needed in the genus *Pseudanabaena* 'lato sensu', and future confusion will persist until the systematic placements of the taxa are completely understood, especially among the other subgenera.

- The genus *Ilyonema* has a unique phylogenetic placement (unique clade), in the 16S rRNA gene tree.
- Trichomes are isopolar, constrictions at cross-walls, without sheaths. Presence of gas vesicles in terminal cells and/or at cross-walls is a diactrical characteristic.
- Occurrence of this genus is in benthic, periphytic, and/or metaphytic environments, with trichomes up to 3 μm wide.

***Ilyonema amphigranulata* (van Goor) Laughinghouse et Kling, comb. nova –**

Basionym: *Oscillatoria amphigranulata* van Goor (1918)

***Ilyonema batrachospermorum* (Skuja) Laughinghouse et Kling, comb. nova –**

Basionym: *Oscillatoria batrachospermorum* Skuja (1961)

***Ilyonema biceps* (Böcher) Laughinghouse et Kling, comb. nova –** Basionym:

Pseudanabaena biceps Böcher (1946)

***Ilyonema galeata* (Böcher) Laughinghouse et Kling, comb. nova –** Basionym:

Pseudanabaena galeata Böcher (1949)

***Ilyonema lonchoides* (Anagnostidis) Laughinghouse, Kling et Kangas, comb. nova –**

Basionym: *Pseudanabaena lonchoides* Anagnostidis (1961)

***Ilyonema papillaterminata* (Kiselev) Laughinghouse et Kling, comb. nova –**

Basionym: *Phormidium papillaterminata* Kiselev (1927)

***Ilyonema thermalis* (Anagnostidis) Laughinghouse et Kling, comb. nova –** Basionym:

Pseudanabaena lonchoides Anagnostidis (1961)

***Ilyonema ulula* (Welsh) Laughinghouse et Kling, comb. nova –** Basionym:

Anabaenella ulula Welsh (1964)

Uncertain due to subaerophytic habitat

***Pseudanabaena skujae* Claus (1962)**

***Pseudanabaena spelaea* Anagnostidis (2001)**

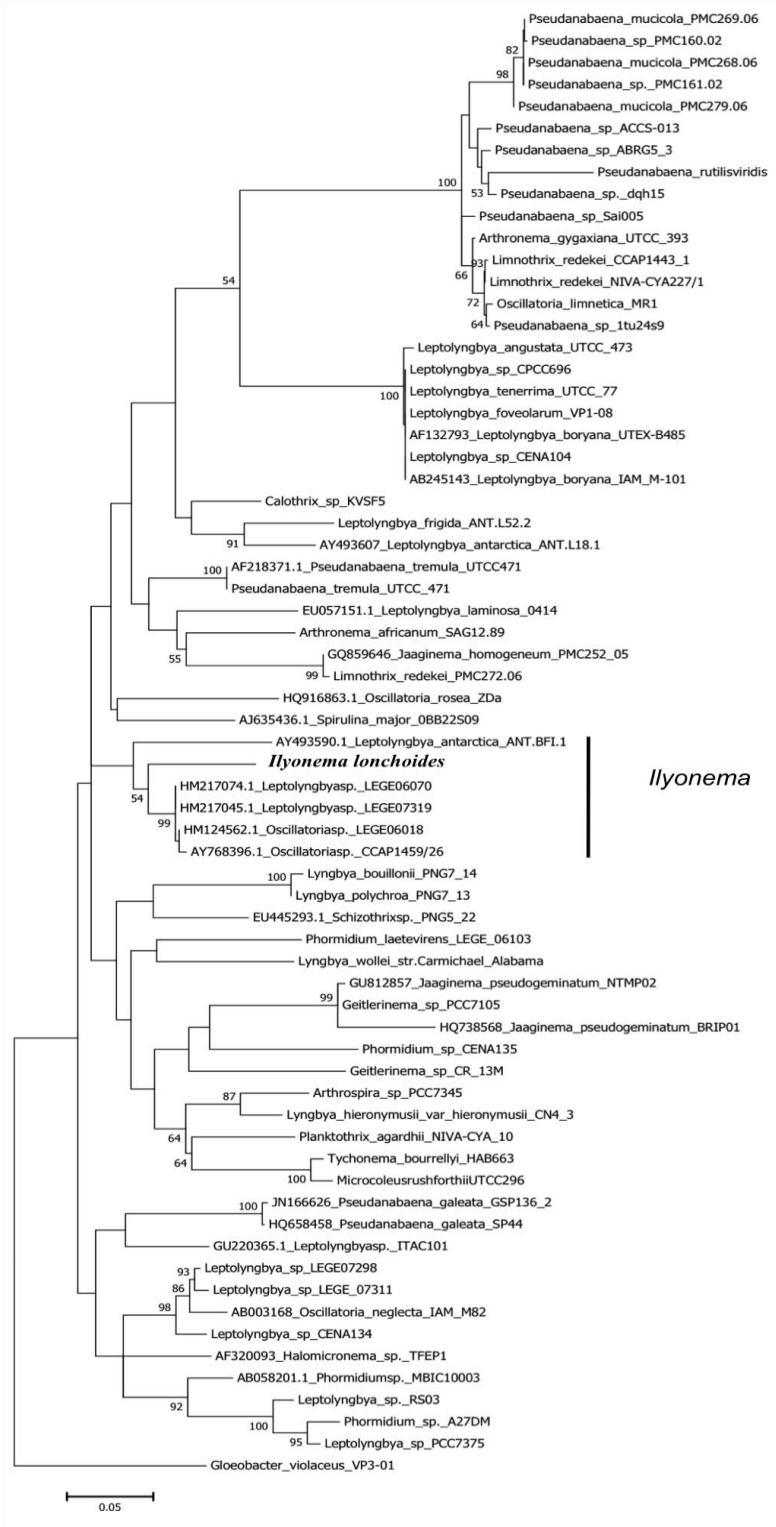


Figure 4.2. (16S rRNA) ML phylogram using the 16S rRNA gene marker. Node support is indicated with ML bootstrap support values.

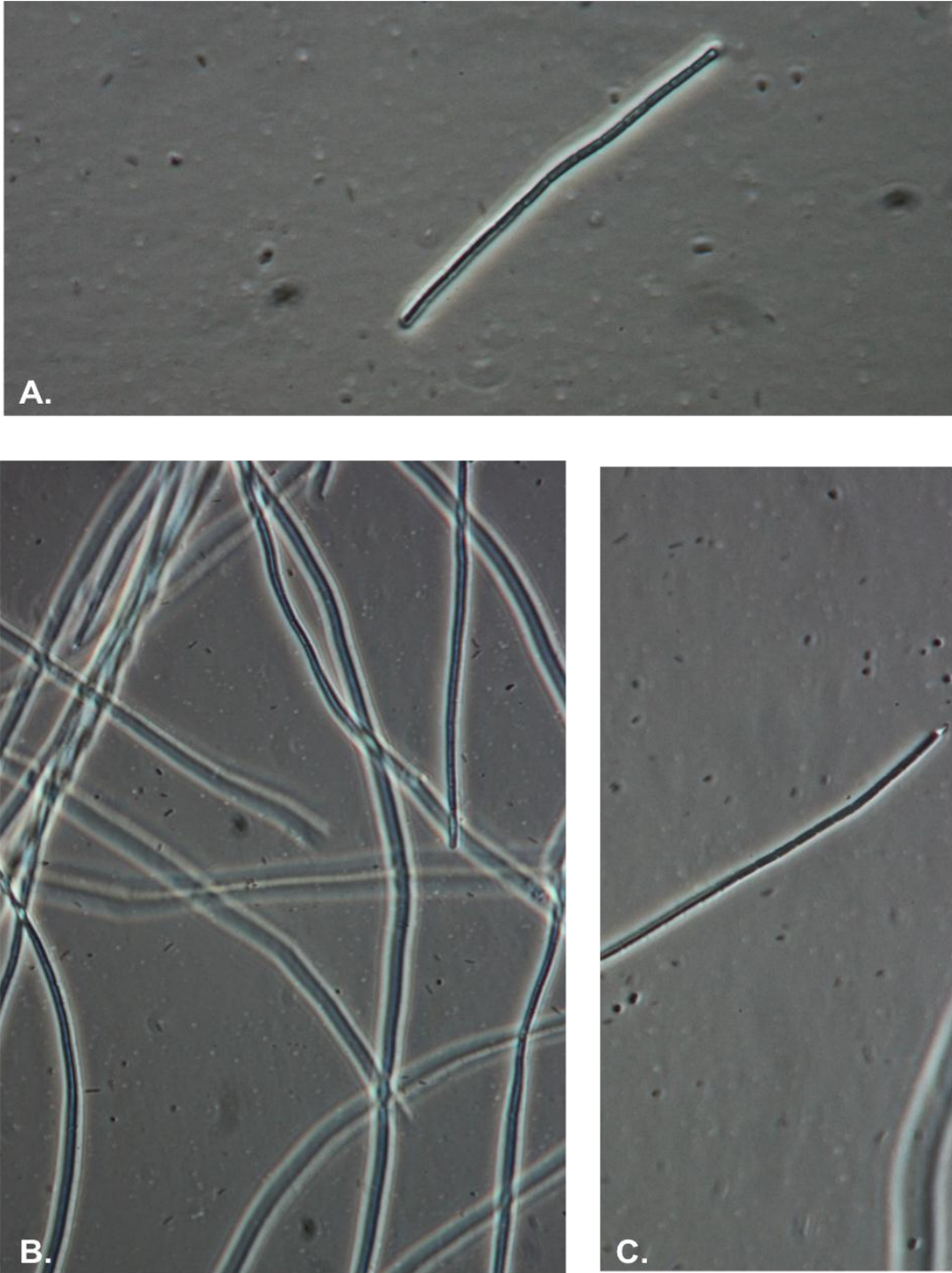


Figure 4.3. A-C. *Ilyonema lonchoides* comb. nova. A-C. LM images. C. Detail of terminal refractive granule.

Chapter 5: Final Conclusions

Algal Turf Communities

In Chapter 1, a model (Fig. 1.1) was introduced of the colonization process of an algal turf community on an ATSTM from a ‘species-pool’ through a filter (plastic screen), self-organizing into the ATSTM community studied throughout this project. With the data and knowledge acquired from this study, it was found that this model was too simplistic.

The updated diagram (Figure 5.1) depicts a more accurate conception of how source communities pass through filters and are found on the algal turf of the flowways. In this diagram, both the filamentous species and single-celled (a.k.a. solitary) species are separated as distinct source communities, since these have separate filter pressures acting on each. The filamentous species can physically attach to the system with a holdfast or mucilage; hence those found on ATSTM flowways are pre-adapted evolutionarily to attach to the ATSTM. Only select filamentous species colonize the ATSTM environment. The single-celled species have another filter pressure, where they can physically sediment into the turf environment of the ATSTM from the plankton, though being unattached. Furthermore, the filamentous complex, itself, facilitates this entrapment (depicted in Fig 5.1 by the returning arrow), where microzones and/or microhabitats can form specific niches with different microcurrents, nutrient regimes, pH, etc., favoring the growth of these unattached species. In addition, the mucopolysaccharide materials secreted by the algae (and associated heterotrophic bacteria) from this filamentous colonization can also segregate certain solitary species from the thin lamina of water, which flows through the turf community. An ultimate filter is the harvest, where the filamentous species have to maintain attached or solitary species have to re-colonize after each harvest.

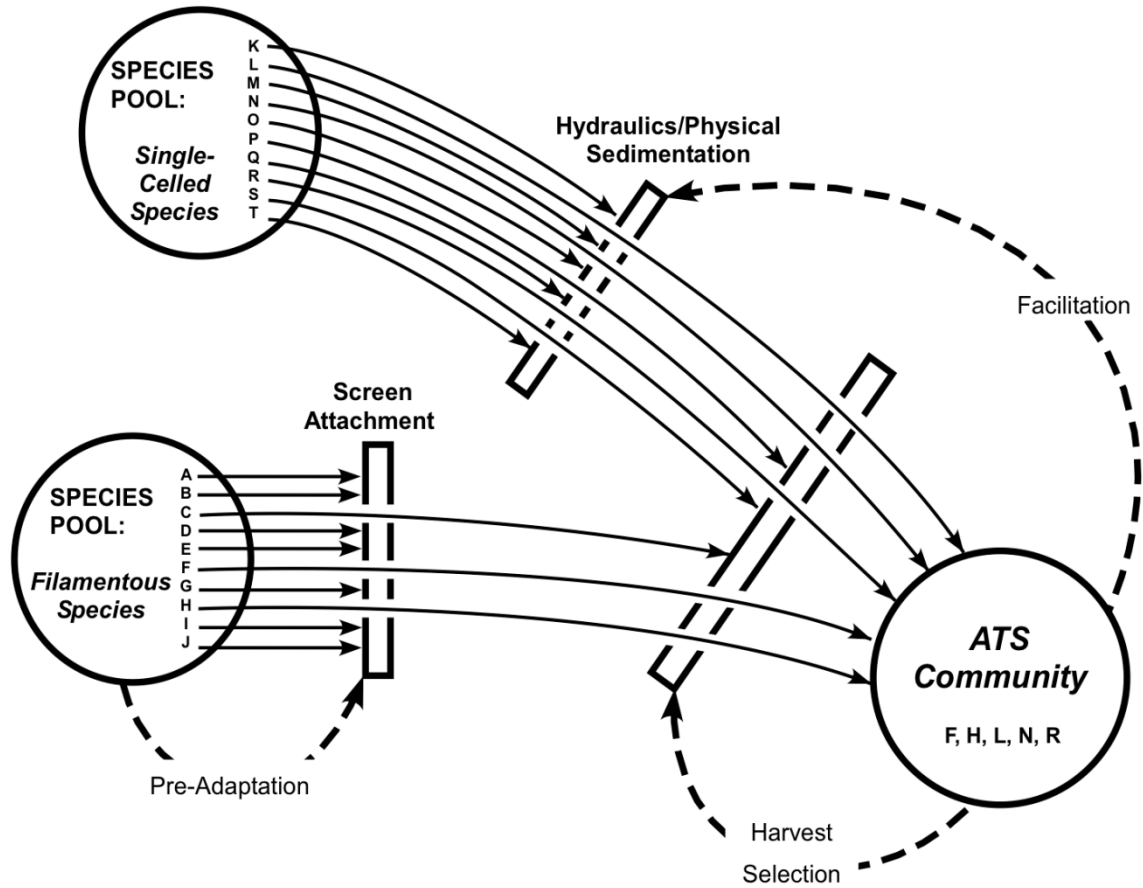


Figure 5.1. 'Updated' self-organization of a community from a species pool. Not all species are able to pass through the filters and become part of the ATSTM community.

The dissertation began in Chapter 1 with explaining how the ATSTM was composed of a periphytic community, defined as the 'complex community of microbiota composed of bacteria, fungi, algae, animals, and inorganic/organic detritus that live attached to live or dead submerged substrates' (Wetzel, 1983). However, the term periphyton itself, has a long history and is a little controversial, since authors working with the subject have slight variations/interpretations of what they consider periphyton, from just a few centimeters of biofilm to also including larger benthic algae in the overall matrix (Hoagland et al., 1982; Burgis & Morris, 1987; Steinman, 1996; Wetzel, 2001).

With the insights gained from the studies undertaken in Chapter 2, it was found that only 11% (± 6.8) of species diversity and 16% (± 11.53) of cell abundance were composed of those taxa known to be periphytic (or metaphytic). In fact, the ATSTM community is dominated by benthic and epiphytic (or epilithic/epipellic/episammic) taxa, in both species diversity and cell abundance. The high diversity of benthic taxa is due to most of the diatoms being single-celled benthic taxa, but, interestingly, only $\approx 52\%$ (± 4) of the algal abundance on the ATSTM is due to filamentous species; thus these solitary (or colonial and chain-forming) species are also a significant component of the relative abundance, thus overall biomass. This is critical to recognize for improving production materials during construction that can facilitate higher biomass yields for these applied systems.

The source-community study at VIMS (Chapter 2) also indicated that the ATSTM community algae are largely derived from the epiphytes of macroalgae, which they inhabit, since 40% of the taxa were shared between these habitats. Therefore, the algal turf scrubber could be referred to as an ‘epiphyte’ turf scrubber, with the idea that those algae which live as epiphytes in the surrounding areas are transported through the water column, colonizing the ATSTM. In this novel environment, they are able to rapidly grow and form the turf communities, common of the ATSTM. Research has demonstrated that epiphytes have higher organic productivity than other plant communities⁴, and Wetzel (2001) presented that this community can be up to 6 times more efficient than phytoplankton (see Wetzel, 2001, for more information). For flowway construction, this is extremely important since it acknowledges that knowing what is growing in the algal

⁴Plant communities is used here in a broad term considering forests, herbs/annuals, macrophytes, epiphytes, and phytoplankton.

communities around the ATSTM is vital for realizing what will potentially colonize the system. With this understanding, future locations to install ATSTM flowways can be chosen where there are more potential ‘colonizers’ from the source waters (i.e., which can potentially colonize the screen substrate) critical when investing private capital and/or public funds to potentially scale up this technology to thousands of acres to remediate large bodies of water.

Taxonomy/Systematics in applied studies

The manner in which people understand the functioning of machines, animals, plants, nature, atoms, etc., or anything unknown is by dividing them into their ‘building-blocks’ to then understand how everything functions together. Thus, to understand nature as a whole it can be divided into its ‘parts’, then pieced together to understand the functions.

A science that undertakes this task is Systematics where over time, and with novel information, it looks to find the exact positioning of organisms in a natural order. This science, when compared to other areas, is many times second due to budget constraints, thoughts of it being ‘out of style’, not containing spectacular findings which will bring large investments and funding, in addition to the idea that this science is only a question of ‘giving names’. However, Taxonomy (Systematics) is much more than a set of nomenclatural rules or possessive obsession to classify or identify an organism. Senna & Magrin (1999) claim that taxonomy is the base of all serious and organized scientific knowledge, arguing that without first knowing an organism exists, all subsequent studies

on that organism cannot be undertaken. If this importance were more emphasized, there would probably be more taxonomists and systematists and students dedicated to this area, with fewer threats on the ‘future of taxonomy’ (Wilson, 2000; Blackmore, 2002; Wheeler et al., 2004).

What exactly is taxonomy? Taxonomy is the science that deals with the identification, nomenclature, and classification of objects in biological nature (Lawrence, 1973). Identification consists in recognizing that a taxon is identical or similar to one already known, using specific literature, herbaria (nomenclatural types), photographs, and/or drawings. Nomenclature refers to the correct determination of a name according to the nomenclatural system, which is updated periodically. Finally, classification deals with placing the botanical entity or entities in categories according to the rules proposed in the *International Code of Nomenclature for algae, fungi, and plants* (Lawrence, 1973).

Taxonomy and systematics are vital for understanding biodiversity on Earth. However, is it important in applied systems such as the ATSTM? Returning to the previous comment, without knowing what exists in these systems, recommendations to improve the design of systems conforming to the specificities to the taxa that there grow are only speculative. Taxonomic variations of the algae which grow on these systems are capable of giving insights to differing physicochemical patterns on longitudinal scales. Furthermore, since different species have different physiologies, their biochemistries are different and are capable of producing different potential by-products (Adey et al., under review). During the study, utilizing taxonomical practices, source communities to these systems were able to be described as well as explain putative dynamics occurring on longitudinal scales.. Furthermore, taxonomy was key in helping with the design of a

three-dimensional screen system, since it was understood that chlorophytes did not contain high abundance, thus change had to be made to facilitate the attachment of the single-celled benthic and epiphytic diatoms which composed the majority of relative abundance and subsequent biomass (Adey et al., under review).

As seen in the taxonomic survey of Chapter 4, studying more thoroughly the diversity of Oscillatoriales demonstrated a hidden biodiversity that exists in the Chesapeake Bay area and on these applied systems. Putative novel taxa were found, and others that are in need of further investigation before describing their systematic position. Many species found had not yet been cited for the region, demonstrating a lack in understanding organisms found in the area, important in times of climate change when researchers are trying to understand what is happening to flora and fauna and predict what will happen in the future.

Future Directions

ATSTM systems have been studied for over 20 years (Adey & Steneck, 1985; Adey & Hackney, 1988; Adey et al., 1993; 1996; 2011; Craggs et al., 1996; Small & Adey, 2001; Pizarro et al., 2006; Adey & Loveland, 2007; Mulbry, 2008), and during this process improvements have been made with findings from research undertaken on flowways. While this dissertation gives an insight to the biodiversity of the microalgae growing on them, as is seen in many ecological studies, trying to understand the attribute and/or function of each species is difficult in holistic sense. Culture studies of the 'key-species' on these flowways could help in understanding; however, a predicament of culture

studies is that how the algal entity functions in culture may not necessarily replicate the diverse flowways.

To get a better insight on how the microalgae function and how metabolic routes can be optimized to obtain higher product yields, studies integrating metabolomics, genomics, transcriptomics, and/or proteomics should be carried out in the future, especially with the potential of using the ATSTM technology for remediating watersheds. Interestingly, ATSTM can be used as a model of lotic environments, thus integrating novel processes that can help in answering both basic science questions, while optimizing the engineering of the ATSTM. Since biodiversity can be high on these systems, it is important to characterize the biodiversity, and understand how this can change due to the various processes occurring on ATSTM. Characterizing and understanding ATSTM biodiversity allows for a fuller comprehension on the functioning of these applied systems, since each species has a role in the ATSTM algal community productivity.

Aspects of research, which also need to be expanded, are the diversity of heterotrophic bacteria and the processes they exert on the ATSTM. While analyzing samples, it is always seen that these bacteria exist and visually vary at different longitudinal scales and seasonally; however are there correlations in these processes? Since these bacteria are an integral part of the functioning of periphytic metabolism, research into characterizing these communities and the influence, which they exert on the flowways, is central for upscaling.

Summary

Chapter 2.

- 218 taxa were found at Muddy Run, 120 at Great Wicomico, and 68 at VIMS.
- This high diversity of species at Muddy Run ATSTM can be attributed to the source communities for these systems. The species, which immigrated to colonize either system, originated from the lotic Susquehanna River or the lentic Muddy Run reservoir.
- Most species encountered were rare, since they only occurred one time in the sampling efforts.
- In estuarine sites, the diatom genera *Berkeleya* and *Melosira* and the green alga *Ulva* are the dominant “canopy” species that structure most of the sampled algal communities, while at freshwater sites *Melosira* and *Ulothrix* fill this role.
- On the VIMS ATSTM, 27% of the taxa were shared with the plankton, 21% were shared with the sediment, and 40% with the macroalgal epiphytes.
- The ATS flowways in this study were dominated by diatom communities specialized to living on the benthos and by those organisms adapted to living attached to other substrata by mucilage (epiphytes), rather than periphyton and hard bottom algal turf communities.
- Of the studied sites, the most diverse was Muddy Run, followed by Wicomico then VIMS.
- In the freshwater systems, species of *Ulothrix* were dominant at the top of the flowway, while *Ulva intestinalis* was encountered at the top of estuarine systems.

Cyanobacteria were abundant in fall at Wicomico due to the large amount of two taxa (*Gloethece* sp. and *Lyngbya salina*).

- In freshwater systems, *Spirogyra* and *Melosira varians* are the most dominant taxa found during the summer, while *Diatoma vulgare*, *Fragilaria capucina* and *Tabellaria flocculosa* are most abundant during the winter months.

Chapter 3.

- At Muddy Run, the ratio between nitrogen (N) and phosphorus (P) was about 8:1.
- In the aluminum flowway, nitrogen and phosphorus uptake into biomass decreases longitudinally, while in the wood, there is an increase towards the middle, then subsequent decrease ($p < 0.05$).
- The nutrient data indicated that there is a 'threshold' between the 0.5% and 1% slope for ATSTM flowways to obtain significant differences in nutrient data.
- Higher concentrations of phosphorus, at the top section of the ATSTM, in addition to the faster current, could have favored the cyanobacterial mat at the this location.
- Most dominant species are generalist species, with only few taxa (nine) specialized to a determined section of the flowway.
- (Muddy Run ATSTM) Longitudinally, there is a trend of species number (biodiversity) increasing from the top to the bottom of the flowways.

Chapter 4.

- Periphytic Oscillatoriales is a group of Cyanobacteria that has been little studied in the Chesapeake Bay Region.

- Many of the taxa found in this study had, up to now, not been cited for the region.
- Studies utilizing gene markers on unique taxa, demonstrate that the degree of diversity is higher than solely based on phenotypic characters.
- Periphytic *Pseudanabaena* form a separate cluster than their planktonic counterparts, indicating the need to separate these two genera.

Appendices

A-I. Natural history classification information for taxa found on the Muddy Run ATS™ aluminum floway.

Species	Life Form	Habit	Attachment
Cyanobacteria			
<i>Aphanocapsa holsatica</i>	colony	planktonic	unattached
<i>Bacularia vermicularis</i>	colony	periphytic	mucilage
<i>Chroococcus minor</i>	colony	metaphytic	mucilage
<i>Chroococcus minutus</i>	colony	metaphytic	mucilage
<i>Eucapsis parralelepipedon</i>	colony	metaphytic	mucilage
<i>Geitlerinema amphibium</i>	filament	periphytic	mucilage
<i>Leibleinia epiphytica</i>	filament	epiphytic	mucilage
<i>Leptolyngbya</i> sp.	filament	periphytic	mucilage
<i>Merismopedia tenuissima</i>	colony	metaphytic	unattached
<i>Oscillatoria curviceps</i>	filament	periphytic	mucilage
<i>Oscillatoria princeps</i>	filament	benthic	mucilage
<i>Phormidium autumnale</i>	filament	periphytic	mucilage
<i>Phormidium interruptum</i>	filament	epilithic	mucilage
<i>Phormidium lividum</i>	filament	epilithic	mucilage
<i>Phormidium retzii</i>	filament	benthic/periphytic	mucilage
<i>Phormidium stagninum</i>	filament	benthic	mucilage
<i>Planktolyngbya brevicellularis</i>	filament	planktonic	unattached
<i>Pseudanabaena galeata</i>	filament	benthic/epiphytic	mucilage
<i>Pseudanabaena limnetica</i>	filament	benthic	mucilage
Dinophyta			
<i>Peridinium</i> sp.	solitary	planktonic	unattached
Chlorophyta			
<i>Bulbochaete</i>	filament	periphytic	holdfast
cf. <i>Pseudocharacium</i> sp.	solitary	epiphytic	holdfast
cf. <i>Schroederia</i> sp.	solitary	planktonic	unattached
<i>Cladophora glomerata</i>	filament	periphytic	holdfast
<i>Closteriopsis acicularis</i> var. <i>acicularis</i>	solitary	planktonic	unattached
<i>Chlorella</i> sp.	solitary	planktonic	unattached
<i>Coelastrum astroideum</i>	coenobia	planktonic	unattached
<i>Coelastrum</i> cf. <i>microporum</i>	coenobia	planktonic	unattached
<i>Cosmarium</i> cf. <i>subtumidum</i> var. <i>subtumidum</i> f. <i>minor</i>	solitary	metaphytic	unattached
<i>Cosmarium formosulum</i>	solitary	metaphytic	unattached
<i>Cosmarium monomazum</i> var. <i>polymazum</i>	solitary	metaphytic	unattached
<i>Cosmarium</i> sp.	solitary	metaphytic	unattached
<i>Cosmarium vexatum</i> var. <i>lacustre</i>	solitary	metaphytic	unattached
<i>Desmodesmus balatonicus</i>	coenobia	planktonic	unattached
<i>Desmodesmus communis</i>	coenobia	planktonic	unattached
<i>Desmodesmus gutwinskii</i>	coenobia	planktonic	unattached
<i>Desmodesmus intermedius</i>	coenobia	planktonic	unattached
<i>Desmodesmus polyspinosus</i>	coenobia	planktonic	unattached
<i>Desmodesmus</i> sp.	coenobia	planktonic	unattached
<i>Diacanthos belenophorus</i>	solitary	planktonic	unattached
<i>Kirchneriella lunaris</i>	colony	planktonic	unattached
<i>Microspora floccosa</i>	filament	periphytic	holdfast

<i>Microspora quadrata</i>	filament	periphytic	holdfast
<i>Monoraphidium arcuatum</i>	solitary	planktonic	unattached
<i>Monoraphidium contortum</i>	solitary	planktonic	unattached
<i>Monoraphidium griffithii</i>	solitary	planktonic	unattached
<i>Oedogonium</i> cf. <i>pluvioporum</i>	filament	epiphytic	holdfast
<i>Pediastrum biradiatum</i>	coenobia	metaphytic	unattached
<i>Pediastrum boryanum</i>	coenobia	metaphytic	unattached
<i>Pediastrum duplex</i>	coenobia	metaphytic	unattached
<i>Pediastrum tetras</i>	coenobia	metaphytic	unattached
<i>Rhizoclonium hieroglyphicum</i>	filament	periphytic	holdfast
<i>Scenedesmus acuminatus</i>	coenobia	planktonic	unattached
<i>Scenedesmus acutus</i>	coenobia	planktonic	unattached
<i>Scenedesmus alternans</i>	coenobia	planktonic	unattached
<i>Scenedesmus brevispina</i>	coenobia	planktonic	unattached
<i>Scenedesmus dimorphus</i>	coenobia	planktonic	unattached
<i>Scenedesmus linearis</i>	coenobia	planktonic	unattached
<i>Scenedesmus</i> sp.	coenobia	planktonic	unattached
<i>Sphaerocystis schroeteri</i>	colony	planktonic	unattached
<i>Spirogyra</i> cf. <i>rivularis</i>	filament	planktonic	unattached
<i>Staurastrum alternans</i>	colony	metaphytic	unattached
<i>Stigeoclonium tenue</i>	filament	periphytic	holdfast
<i>Tetraedron caudatum</i>	colony	planktonic	unattached
<i>Ulothrix</i> cf. <i>tenerrima</i>	filament	periphytic	holdfast
<i>Ulothrix</i> cf. <i>variabilis</i>	filament	periphytic	holdfast
<i>Ulothrix zonata</i>	filament	periphytic	holdfast
<i>Uronema elongatum</i>	filament	epiphytic	holdfast

Bacillariophyta

<i>Amphora libyca</i>	solitary	epilithic	mucilage
<i>Amphora</i> sp.	solitary	epilithic	mucilage
<i>Aulacoseira</i> cf. <i>granulata</i>	chain	planktonic	unattached
<i>Brachysira brebissonii</i>	solitary	epipellic/benthic	unattached
<i>Cocconeis</i> sp.	solitary	epiphytic	mucilage pad
<i>Stephanocyclus meneghiana</i>	solitary/chain	planktonic	unattached
<i>Cymbella</i> cf. <i>affine</i>	solitary	epiphytic	stalk
<i>Cymbella</i> cf. <i>parva</i>	solitary	epiphytic	stalk
<i>Cymbella cistula</i>	solitary	epiphytic	stalk
<i>Cymbella lanceolata</i>	solitary	epiphytic	stalk
<i>Cymbella</i> spp.	solitary	epiphytic	stalk
<i>Cymbella tumida</i>	solitary	epiphytic	stalk
<i>Cymbopleura</i>	solitary	epipellic/benthic moist soils/wet	unattached
<i>Diademsis</i> cf. <i>contenta</i>	solitary/colony	walls	unattached
<i>Diatoma ehrenbergii</i>	colony	benthic	mucilage pad
<i>Diatoma monoliformis</i>	colony	benthic	mucilage pad
<i>Diatoma tenue</i>	colony	benthic	mucilage pad
<i>Diatoma vulgare</i>	colony	benthic	mucilage pad
<i>Encyonema</i> cf. <i>caespitum</i>	colony	benthic	tubes
<i>Encyonema minutum</i>	colony	benthic	tubes
<i>Encyonema prostratum</i>	colony	benthic	tubes
<i>Encyonema</i> sp.	colony	benthic	tubes
<i>Fragilaria capucina</i>	colony	planktonic	unattached
<i>Fragilaria vaucheriae</i>	colony	planktonic	unattached
<i>Frustulia</i> sp.	solitary	benthic	tubes

Gomphonema cf. angustatum	solitary	epiphytic	stalk
Gomphonema cf. brasiliense	solitary	epiphytic	stalk
Gomphonema truncatum	solitary	epiphytic	stalk
Gyrosigma cf. attenuatum	solitary	epiphytic	stalk
Gyrosigma sp.	solitary	epipelic	unattached
Melosira cf. italica	chain	benthic	unattached?
Melosira varians	chain	benthic	unattached?
Meridion cf. circulare	colony	epiphytic	mucilage pad
Navicula capitata	solitary	benthic	unattached
Navicula cf. drouetiana	solitary	benthic	unattached
Navicula cf. hungarica	solitary	benthic	unattached
Navicula cryptocephala	solitary	benthic	unattached
Navicula gregaria	solitary	benthic	unattached
Navicula lanceolata	solitary	benthic	unattached
Navicula rhynccephala	solitary	benthic	unattached
Navicula spp.	solitary	benthic	unattached
Nitzschia angustatula	solitary	benthic	unattached
Nitzschia brevissima	solitary	benthic	unattached
Nitzschia paleacea	solitary	benthic/planktonic	mucilage pad
Nitzschia cf. radicula	solitary	benthic	unattached
Nitzschia sigmoidea	solitary	epipelic	unattached
Nitzschia vermicularis	solitary	epipelic	unattached
Nitzschia dissipata	solitary	benthic	unattached
Nitzschia linearis	solitary	epipelic	mucilage pad
Nitzschia spp.	solitary	benthic	unattached
Rhoicosphenia abbreviata	solitary	benthic	stalk
Rhopalodia sp.	solitary	benthic	mucilage pad
Sellaphora sp.	solitary	benthic	unattached
Surirella elgans f. elongata	solitary	benthic	unattached
Surirella minuta	solitary	benthic	unattached
Surirella sp.	solitary	benthic	unattached
Synedra formosa	solitary	epiphytic	mucilage pad
Synedra sp.	solitary	epiphytic	mucilage pad
Tabellaria cf. flocculosa	colony	epiphytic	mucilage pad
Tabellaria sp.	colony	epiphytic	mucilage pad
Thalassiosira sp.	solitary/chain	planktonic	unattached
Ulnaria ulna	solitary	epiphytic	mucilage pad
Chlamydomphyta			
Chlamydomonas sp.	solitary	planktonic	unattached
EUGLENOPHYCEAE			
Trachelomonas sp.	solitary	planktonic	unattached
RAPHIDOPHYCEAE			
Colponema sp.	solitary	planktonic	unattached

A-2. Natural history classification for the Muddy Run ATS™ wood floway

Species	Life Form	Habit	Attachment
Cyanobacteria			
<i>Aphanocapsa rivularis</i>	colony	epilithic	mucilage
<i>Aphanocapsa holsatica</i>	colony	planktonic	unattached
<i>Aphanothece</i> sp.	colony	periphytic	mucilage
<i>Asterocapsa</i>	colony	epilithic	mucilage
<i>Chroococcus minutus</i>	colony	metaphytic	mucilage
<i>Eucapsis carpatica</i>	colony	metaphytic	mucilage
<i>Leptolyngbya boryana</i>	filament	metaphytic	mucilage
<i>Leptolyngbya</i> sp.	filament	metaphytic	mucilage
<i>Leptolyngbya subtilis</i>	filament	metaphytic/benthic	mucilage
<i>Oscillatoria curviceps</i>	filament	periphytic	mucilage
<i>Oscillatoria princeps</i>	filament	benthic	mucilage
<i>Phormidium fonticulum</i>	filament	epilithic	mucilage
<i>Phormidium retzii</i>	filament	benthic/periphytic	mucilage
<i>Phormidium simplicissimum</i>	filament	periphytic	mucilage
<i>Planktolyngbya brevicellularis</i>	filament	planktonic	unattached
<i>Pseudanabaena galeata</i>	filament	benthic/epiphytic	mucilage
<i>Pseudanabaena limnetica</i>	filament	benthic	mucilage
CHLAMYDOPHYCEAE			
<i>Pandorina</i> sp.	colony	planktonic	unattached
Chlorophyta			
<i>Chlorella</i> sp.	solitary	planktonic	unattached
<i>Cladophora glomerata</i>	filament	periphytic	holdfast
<i>Closterium</i> cf. <i>sublaterale</i>	solitary	metaphytic	unattached
<i>Closterium</i> sp.	solitary	metaphytic	unattached
<i>Coelastrum astroideum</i>	coenobia	planktonic	unattached
<i>Coelastrum</i> cf. <i>cambricum</i>	coenobia	planktonic	unattached
<i>Coelastrum</i> cf. <i>microporum</i>	coenobia	planktonic	unattached
<i>Cosmarium</i> cf. <i>margaritatum</i>	solitary	metaphytic	unattached
<i>Cosmarium</i> cf. <i>pseudoconnatum</i>	solitary	metaphytic	unattached
<i>Cosmarium</i> cf. <i>pseudoexiguum</i>	solitary	metaphytic	unattached
<i>Cosmarium</i> cf. <i>sublobulatum</i>	solitary	metaphytic	unattached
<i>Cosmarium</i> cf. <i>trilobulatum</i>	solitary	metaphytic	unattached
<i>Cosmarium perforatum</i>	solitary	metaphytic	unattached
<i>Cosmarium</i> sp.	solitary	metaphytic	unattached
<i>Cylindrocapsa</i> sp.	filament	periphytic	holdfast
<i>Desmodesmus alternans</i>	coenobia	planktonic	unattached
<i>Desmodesmus balatonicus</i>	coenobia	planktonic	unattached
<i>Desmodesmus bicaudatus</i>	coenobia	planktonic	unattached
<i>Desmodesmus communis</i>	coenobia	planktonic	unattached
<i>Desmodesmus denticulatus</i>	coenobia	planktonic	unattached
<i>Desmodesmus intermedius</i>	coenobia	planktonic	unattached
<i>Desmodesmus opoliensis</i>	coenobia	planktonic	unattached
<i>Desmodesmus polyspinosus</i>	coenobia	planktonic	unattached
<i>Desmodesmus</i> sp.	coenobia	planktonic	unattached
<i>Gloeocystis</i> sp.	colony	planktonic	unattached
<i>Hydrodictyon reticulatum</i>	coenobia	planktonic	unattached
<i>Lagerheimia quadriseta</i>	solitary	planktonic	unattached
<i>Microspora floccosa</i>	filament	periphytic	holdfast

<i>Microspora quadrata</i>	filament	periphytic	holdfast
<i>Microspora wittrockii</i>	filament	periphytic	holdfast
<i>Monoraphidium arcuatum</i>	solitary	planktonic	unattached
<i>Monoraphidium contortum</i>	solitary	planktonic	unattached
<i>Monoraphidium griffithii</i>	solitary	planktonic	unattached
<i>Netrium interruptum</i>	solitary	metaphytic	unattached
<i>Netrium</i> sp.	solitary	metaphytic	unattached
<i>Oedogonium</i> cf. <i>pluvioporum</i>	filament	epiphytic	holdfast
<i>Pediastrum biradiatum</i>	coenobia	metaphytic	unattached
<i>Pediastrum boryanum</i>	coenobia	metaphytic	unattached
<i>Pediastrum duplex</i>	coenobia	metaphytic	unattached
<i>Pediastrum simplex</i>	coenobia	metaphytic	unattached
<i>Pediastrum tetras</i>	coenobia	metaphytic	unattached
<i>Quadricoccus</i> sp.	colony	planktonic	unattached
<i>Rhizoclonium hieroglyphicum</i>	filament	periphytic	holdfast
<i>Scenedesmus acutus</i>	coenobia	planktonic	unattached
<i>Scenedesmus alternans</i>	coenobia	planktonic	unattached
<i>Scenedesmus arcuatus</i>	coenobia	planktonic	unattached
<i>Scenedesmus</i> cf. <i>granulatus</i>	coenobia	planktonic	unattached
<i>Scenedesmus</i> cf. <i>ovalternus</i>	coenobia	planktonic	unattached
<i>Scenedesmus dimorphus</i>	coenobia	planktonic	unattached
<i>Scenedesmus</i> sp.	coenobia	planktonic	unattached
<i>Scenedesmus ecornis</i>	coenobia	planktonic	unattached
<i>Sphaerocystis schroeteri</i>	colony	planktonic	unattached
<i>Spirogyra</i> cf. <i>rivularis</i>	filament	planktonic	unattached
<i>Staurastrum alternans</i>	colony	metaphytic	unattached
<i>Stigeoclonium tenue</i>	filament	periphytic	holdfast
<i>Tetraedron caudatum</i>	colony	planktonic	unattached
<i>Ulothrix</i> cf. <i>variabilis</i>	filament	periphytic	holdfast
<i>Ulothrix zonata</i>	filament	periphytic	holdfast
<i>Uronema elongatum</i>	filament	epiphytic	holdfast
EUGLENOPHYCEAE			
<i>Lepocinclis</i> cf. <i>ovum</i>	solitary	planktonic	unattached
<i>Parmidium</i>	solitary	planktonic	unattached
<i>Trachelomonas</i> sp.	solitary	planktonic	unattached
CRYSOPHYCEAE			
<i>Ochromonas</i>	solitary	planktonic	unattached
Bacillariophyta			
<i>Amphora</i> cf. <i>pediculus</i>	solitary	epilithic	mucilage
<i>Amphora ovalis</i>	solitary	epilithic	mucilage
<i>Amphora</i> sp.	solitary	epilithic	mucilage
<i>Aulacoseira</i> cf. <i>granulata</i>	chain	planktonic	unattached
<i>Brachysira brebissonii</i>	solitary	epipellic/benthic	unattached
<i>Caloneis</i> sp.	solitary	benthic	unattached
<i>Cocconeis placentula</i>	solitary	epiphytic	mucilage pad
<i>Cocconeis</i> sp.	solitary	epiphytic	mucilage pad
<i>Stephanocyclus meneghiana</i>	solitary/chain	planktonic	unattached
<i>Cymatopleura solea</i>	solitary	epipellic	unattached
<i>Cymbella</i> cf. <i>parva</i>	solitary	epiphytic	stalk
<i>Cymbella cistula</i>	solitary	epiphytic	stalk

<i>Cymbella lanceolata</i>	solitary	epiphytic	stalk
<i>Cymbella leptoceras</i>	solitary	epiphytic	stalk
<i>Cymbella</i> spp.	solitary	epiphytic	stalk
<i>Cymbella tumida</i>	solitary	epiphytic	stalk
<i>Cymbopleura</i>	solitary	epipellic/benthic	unattached
<i>Diademsis</i> cf. <i>contenta</i>	solitary/colony	moist soils/wet walls	unattached
<i>Diatoma</i> cf. <i>mesodon</i>	colony	benthic	mucilage pad
<i>Diatoma ehrenbergii</i>	colony	benthic	mucilage pad
<i>Diatoma monoliformis</i>	colony	benthic	mucilage pad
<i>Diatoma tenuis</i>	colony	benthic	mucilage pad
<i>Diatoma vulgare</i>	colony	benthic	mucilage pad
<i>Encyonema</i> cf. <i>gracile</i>	colony	benthic	tubes
<i>Encyonema minutum</i>	colony	benthic	tubes
<i>Encyonema prostratum</i>	colony	benthic	tubes
<i>Encyonema</i> sp.	colony	benthic	tubes
<i>Fragilaria capucina</i>	colony	planktonic	unattached
<i>Fragilaria vaucheriae</i>	colony	planktonic	unattached
<i>Frustulia vulgaris</i>	solitary	benthic	tubes
<i>Frustulia rhomboidea</i>	solitary	benthic	tubes
<i>Frustulia</i> sp.	solitary	benthic	tubes
<i>Gomphoneis</i> cf. <i>minuta</i>	solitary	epiphytic	stalk
<i>Gomphonema capitatum</i>	solitary	epiphytic	stalk
<i>Gomphonema</i> cf. <i>hastatum</i>	solitary	epiphytic	stalk
<i>Gomphonema</i> cf. <i>olivaceum</i>	solitary	epiphytic	stalk
<i>Gomphonema truncatum</i>	solitary	epiphytic	stalk
<i>Melosira</i> cf. <i>italica</i>	chain	benthic	unattached?
<i>Melosira varians</i>	chain	benthic	unattached?
<i>Meridion</i> cf. <i>circulare</i>	colony	epiphytic	mucilage pad
<i>Navicula capitoradiata</i>	solitary	benthic	unattached
<i>Navicula</i> cf. <i>fonticola</i>	solitary	benthic	unattached
<i>Navicula</i> cf. <i>margalithi</i>	solitary	benthic	unattached
<i>Navicula cryptocephala</i>	solitary	benthic	unattached
<i>Navicula gregaria</i>	solitary	benthic	unattached
<i>Navicula lanceolata</i>	solitary	benthic	unattached
<i>Navicula rhynccephala</i>	solitary	benthic	unattached
<i>Navicula</i> spp.	solitary	benthic	unattached
<i>Neidium</i> sp.	solitary	benthic	unattached
<i>Nitzschia acicularis</i>	solitary	benthic/planktonic	unattached
<i>Nitzschia</i> cf. <i>agnita</i>	solitary	benthic	unattached
<i>Nitzschia amphibia</i>	solitary	benthic	unattached
<i>Nitzschia draveillensis</i>	solitary	benthic/planktonic	unattached
<i>Nitzschia filiformis</i>	solitary	benthic	tubes
<i>Nitzschia paleacea</i>	solitary	benthic/planktonic	mucilage pad
<i>Nitzschia</i> cf. <i>radicula</i>	solitary	benthic	unattached
<i>Nitzschia sigmoidea</i>	solitary	epipellic	unattached
<i>Nitzschia dissipata</i>	solitary	benthic	unattached
<i>Nitzschia obtusa</i>	solitary	benthic	unattached
<i>Nitzschia palea</i>	solitary	benthic	mucilage pad
<i>Nitzschia</i> spp.	solitary	benthic	unattached
<i>Pinnularia</i> sp.	solitary	benthic	unattached
<i>Rhoicosphenia abbreviata</i>	solitary	benthic	stalk
<i>Staurosirella leptostauron</i>	solitary/colony	epiphytic	mucilage pad
<i>Suirella</i> sp.	solitary	benthic	unattached
<i>Synedra acus</i>	solitary	epiphytic	mucilage pad

Synedra cf. affinis	solitary	epiphytic	mucilage pad
Synedra sp.	solitary	epiphytic	mucilage pad
Ulnaria ulna	solitary	epiphytic	mucilage pad

A-3. Natural history classification for the Boat Basin ATS™ floway at VIMS.

Species	Life Form	Habit	Attachment
CYANOPHYCEAE			
Calothrix sp.	filament	benthic	mucilage
Cyanosarcina sp.	colony	epipelic	mucilage
Leptolyngbya sp.	filament	metaphytic	mucilage
Lynghya sp.	filament	metaphytic/periphytic	mucilage
Nodularia sp.	filament	benthic/planktonic	mucilage
Oscillatoria sp.	filament	periphytic	mucilage
Pseudanabaena sp.	filament	benthic	mucilage
Spirulina sp.	filament	planktonic	unattached
CHLOROPHYCEAE			
Ulva intestinalis	filament	benthic	holdfast
Ulothrix sp.	filament	epiphytic	holdfast
BACILLARIOPHYTA			
Achnanthes brevipes	chains	periphytic	stalk
Achnanthes sp.	chains	periphytic	stalk
Achnantheidium sp.	solitary	epiphytic	stalk
Actinoptychus senarius	solitary	planktonic	unattached
Amphipleura sp.	solitary/filamentous	benthic	tubes
Amphora sp.	solitary	epilithic	mucilage
Anaulus sp.	solitary	epipelic	unattached
Bacillaria sp.	colonial	planktonic	unattached
Berkeleya fennica	filamentous	benthic/epiphytic	tubes
Berkeleya rutilans	filamentous	benthic/epiphytic	tubes
Caloneis sp.	solitary	benthic	unattached
Chaetoceros sp.	chains	planktonic	unattached
Cocconeis sp.	solitary	epiphytic	mucilage pad
Coscinodiscus sp.	solitary	planktonic	unattached
Ctenophora sp.	solitary	epiphytic	mucilage pad
Stephanocyclus meneghiana	solitary/chain	planktonic	unattached
Cymbella sp.	solitary	epiphytic	stalk
Cylindrotheca closterium	solitary	planktonic	unattached
Diatoma sp.	colony	benthic	mucilage pad
Diploneis sp.	solitary	epipelic/epilithic	unattached
Entomoneis sp.	solitary	epipelic	unattached
Eucampia sp.	chain	planktonic	unattached
Fragilaria sp.	chain	planktonic	unattached
Fragilariopsis sp.	chain	planktonic	unattached
Gomphonema sp.	solitary	epiphytic	stalk
Grammatophora sp.	colony	benthic	mucilage pad
Gyrosigma sp.	solitary	epipelic	unattached
Hantzschia sp.	solitary	benthic	unattached
Haslea sp.	solitary	epiphytic	mucilage pad
Licmorpha sp. complex	solitary/colony	epiphytic	stalk
Luticola sp.	solitary	epipelic	unattached

Lunella sp.	filamentous	planktonic/epipsammic	mucilage
Mastogloia sp.	solitary	epipellic	unattached
Melosira monoliformes	chain	benthic	mucilage
Melosira nummuloides	chain	benthic	mucilage
Minidiscus sp.	solitary	planktonic	unattached
Navicula sp. complex	solitary	benthic	unattached
Nitzschia sp. complex	solitary	benthic	unattached
Opephora sp.	colony	epipsammic	unattached
Parlibellus sp.	solitary	benthic	unattached
Pinnularia sp.	solitary	benthic	unattached
Plagiotropis sp.	solitary	epipellic	unattached
Pleurosigma cf. fasciola	solitary	benthic	unattached
Pseudonitzschia cf. multiseriis	chain	planktonic	unattached
Pseudonitzschia cf. pungens	chain	planktonic	unattached
Pseudonitzschia sp.	chain	planktonic	unattached
Rhopalodia sp.	solitary	benthic	mucilage pad
Sellaphora sp.	solitary	benthic	unattached
Skelatonema costatum	chain	planktonic	unattached
Stauroneis sp.	solitary	benthic	unattached
Stauronella sp.	solitary/chain	benthic/epiphytic	mucilage pad
Surirella sp.	solitary	benthic	unattached
Synedra sp.	solitary	benthic	unattached
Tabularia sp.	solitary	epiphytic	mucilage pad
Thalassiosira sp.	solitary/chain	planktonic	unattached
Unidentified diatom	solitary	benthic	unattached
DINOPHYTA			
Peridinium sp.	solitary	planktonic	unattached
RHODOPHYTA			
Ceramium sp.	filamentous	benthic	holdfast

A-4. Natural history classification for the combined ATS™ Floways 1 & 2 at the Great Wicomico River.

Species	Life form	Habit	Attachment
CYANOPHYCEAE			
Aphanocapsa	colonial	benthic	mucilage
Aphanothece	colonial	benthic	mucilage
Calothrix sp.	filament	benthic	mucilage
Chroococcus sp.	colonial	benthic/planktonic	unattached
Cyanobium sp.	solitary	planktonic	unattached
Cyanodictyon sp.	colonial	planktonic	unattached
Geitlerinema sp.	filament	benthic/epiphytic	mucilage
Gloeothece sp.	colonial	benthic	mucilage
Jaaginema sp.	filament	benthic	mucilage
Johannesbaptista pellucida	colonial	benthic	mucilage
Leptolyngbya sp.	filament	metaphytic	mucilage
Lynngbya sp.	filament	metaphytic/periphytic	mucilage
Oscillatoria sp.	filament	periphytic	mucilage
Phormidium sp.	filament	periphytic	mucilage
Pseudanabaena sp.	filament	benthic	mucilage
Spirulina sp.	filament	planktonic	unattached
CHLOROPHYCEAE			
Achrochaete sp.	filament	epiphytic	holdfast
Cladophora sp.	filament	benthic	holdfast
Ulva intestinalis	filament	benthic	holdfast
Ulothrix sp.	filament	epiphytic	holdfast
Pseudendozonium marinum	filament/pseudoparenchymatous	epiphytic	holdfast
Unknown green #2	filament	epiphytic	holdfast
Cocoid green	colonial	planktonic	unattached
DINOPHYTA			
Prorocentrum sp.	solitary	planktonic	unattached
Dino cysts	solitary	benthic	unattached
Alexandrium sp.	solitary	planktonic	unattached
Ceratium sp.	solitary	planktonic	unattached
cf. Katodinium sp.	solitary	planktonic	unattached
Dinophysis sp.	solitary	planktonic	unattached
Gyrodinium sp.	solitary	planktonic	unattached
BACILLARIOPHYTA			
Achnanthes brevippes	chains	periphytic	stalk
Achnanthes sp.	chains	periphytic	stalk
Achnantheidium sp.	solitary	epiphytic	stalk
Actinoptychus senarius	solitary	planktonic	unattached
Amphipleura sp.	solitary/filamentous	benthic	tubes
Amphora sp.	solitary	epilithic	mucilage
Bacillaria sp.	colonial	planktonic	unattached
Berkeleya fennica	filamentous	benthic/epiphytic	tubes
Berkeleya fragilis	filamentous	benthic/epiphytic	tubes
Berkeleya rutilans	filamentous	benthic/epiphytic	tubes
Caloneis sp.	solitary	benthic	unattached
cf. Diadesmis sp.	chain	benthic/epiphytic	mucilage
Chaetoceros sp.	chains	planktonic	unattached

<i>Camplyodiscus</i> sp.	solitary	epipelic	unattached
<i>Catenula</i> sp.	filamentous	planktonic/epipsammic	mucilage
<i>Cocconeis</i> sp.	solitary	epiphytic	mucilage pad
<i>Coscinodiscus</i> sp.	solitary	planktonic	unattached
<i>Cylindrotheca closterium</i>	solitary	planktonic	unattached
<i>Cymatosira</i> sp.	filamentous	benthic/epipsammic	mucilage
<i>Dactyliosolen</i> sp.	chain	planktonic	unattached
<i>Denticula</i> sp.	solitary/chain	periphytic/epiphytic	unattached
<i>Diploneis</i> sp.	solitary	epipelic/epilithic	unattached
<i>Ditylum brightwellii</i>	solitary/chain	planktonic	unattached
<i>Entomoneis</i> sp.	solitary	epipelic	unattached
<i>Epithemia</i> sp.	solitary	periphytic	mucilage
<i>Eunotia</i> sp.	solitary/chain	epiphytic	mucilage
<i>Eunotogramma laevis</i>	solitary	benthic	unattached
<i>Fogedia</i> sp.	solitary	epiphytic	mucilage
<i>Fragilaria martyii</i>	colony	planktonic	unattached
<i>Fragilaria</i> sp.	colony	planktonic	unattached
<i>Grammatophora</i> sp.	colony	benthic	mucilage pad
<i>Gyrosigma</i> sp.	solitary	benthic	unattached
<i>Hippodonta</i> sp.	solitary	benthic	unattached
<i>Leptocylindrus minimus</i>	chain	planktonic	unattached
<i>Licmophora</i> sp. (long)	solitary/colony	epiphytic	stalk
<i>Licmophora</i> sp. (short)	solitary/colony	epiphytic	stalk
<i>Lyrella</i> sp.	solitary	epipelic/epilithic	unattached
<i>Mastogloia</i> sp.	solitary	epipelic	unattached
<i>Melosira monoliformes</i>	chain	benthic	mucilage
<i>Melosira nummuloides</i>	chain	benthic	mucilage
<i>Meridion</i> cf. <i>circulare</i>	colony	epiphytic	mucilage pad
<i>Meuniera membranacea</i>	chain	planktonic	unattached
<i>Minidiscus</i> sp.	solitary	planktonic	unattached
<i>Navicula gregaria</i>	solitary	benthic	unattached
<i>Navicula smithii</i>	solitary	benthic	unattached
<i>Navicula</i> sp.	solitary	benthic	unattached
<i>Neodelphineis</i> sp.	colony	planktonic	unattached
<i>Nitzschia filiformis</i>	solitary/filamentous	benthic	tubes
<i>Nitzschia fusiformis</i>	solitary	benthic	unattached
<i>Nitzschia longissima</i>	solitary	epipelic	mucilage pad
<i>Nitzschia nana</i>	solitary	epipelic	unattached
<i>Nitzschia tryblionella</i>	solitary	benthic	unattached
<i>Nitzschia scalpelliformis</i>	solitary	epipelic	unattached
<i>Nitzschia sigma</i>	solitary	epipelic	unattached
<i>Nitzschia sigmaformis</i>	solitary	epipelic	unattached
<i>Nitzschia sigmoidea</i>	solitary	epipelic	unattached
<i>Nitzschia ventricosa</i>	solitary	benthic	unattached
<i>Nitzschia</i> sp.	solitary	benthic	unattached
<i>Opephora</i> sp.	colony	epipsammic	unattached
<i>Paralia sulcata</i>	chain	benthic	mucilage
<i>Parlibellus</i> sp.	solitary	benthic	unattached
<i>Pinnularia</i> sp.	solitary	benthic	unattached
<i>Plagiogramma</i> sp.	colony	planktonic	unattached
<i>Plagiotropis</i> sp.	solitary	epipelic	unattached
<i>Pleurosigma</i> cf. <i>fasciola</i>	solitary	benthic	unattached
<i>Podocystis</i> sp.	solitary	epipelic/epiphytic	mucilage pad
<i>Psammothidium</i> sp.	solitary	benthic	mucilage pad

Pseudostaurosira sp.	chains	epipsammic	mucilage
Rhaphoneis sp.	solitary	planktonic	unattached
Rhizosolenia sp.	chain/solitary	planktonic	unattached
Rhopaloidia sp.	solitary	benthic	mucilage pad
Sieminskia sp.	solitary	benthic	unattached
Skelatonema costatum	chain	planktonic	unattached
Stauronella sp.	solitary/chain	benthic/epiphytic	mucilage pad
Staurosirella sp.	solitary/colony	epiphytic	mucilage pad
Stephanocyclus meneghiana	solitary/chain	planktonic	unattached
Striatella sp.	solitary/chain	planktonic	unattached
Surirella sp.	solitary	benthic	unattached
Synedra sp.	solitary	epiphytic	mucilage pad
Synedropsis sp.	solitary/chain	benthic/epiphytic	mucilage
Tabularia sp.	solitary	epiphytic	mucilage pad
Thalassionema sp.	colony	benthic	mucilage pad
Thalassiosira sp.	solitary/chain	planktonic	unattached
Unidentified diatom	solitary	benthic	unattached
Centrales	solitary	planktonic	unattached
CHRYSOPHYTA			
Chromulina sp.	solitary	planktonic	unattached
EUGLENOPHYCEAE			
Phacus sp.	solitary	planktonic	unattached
Euglena sp.	solitary	planktonic	unattached
RHODOPHYTA			
Polysiphonia sp.	filamentous	benthic	holdfast

A-5. Algal community structure on the VIMS boat basin flowway for 5/18/09. Values are densities as numbers of individuals x 10³ per square centimeter of screen surface. Numbers in parentheses are percentages of the total average densities.

Species	Top	Middle	Bottom	Average
Diatoms				
<i>Berkeleya rutilans</i>	543	515	524	527 (45)
<i>Melosira nummuloides</i>	287	149	17	151 (13)
<i>Navicula</i> sp.	78	274	71	141 (12)
<i>Grammatophora</i> sp.	174	43	12	76 (7)
<i>Nitzschia nana</i>	0	50	17	22 (2)
<i>Achnanthes</i> sp.	9	47	4	20 (2)
<i>Nitzschia</i> sp.	6	34	13	18 (2)
<i>Skeletonema costatum</i>	0	19	33	17 (1)
<i>Stauroneis</i> sp.	6	9	17	11 (1)
<i>Cyclotella</i> sp.	0	13	4	6 (<1)
<i>Thalassiosira</i> sp.	0	0	17	6 (<1)
<i>Tabularia tabulata</i>	3	13	0	5 (<1)
<i>Chaetoceros</i> sp.	0	3	8	4 (<1)
<i>Coscinodiscus</i> sp.	0	3	8	4 (<1)
<i>Minidiscus</i> sp.	0	0	4	3 (<1)
<i>Cymbella</i> sp.	0	0	4	1 (<1)
<i>Diploneis</i> sp.	0	0	4	1 (<1)
<i>Entomoneis</i> sp.	0	0	4	1 (<1)
Unidentified pennate diatom	0	0	4	1 (<1)
<i>Amphora</i> sp.	3	0	0	1 (<1)
<i>Fragilaria</i> sp.	3	0	0	1 (<1)
Subtotal	1112	1172	769	1017 (87)
Non-Diatoms				
<i>Ceramium</i> sp.	0	206	0	69 (6)
<i>Pseudanabaena</i> sp.	0	0	125	42 (4)
<i>Ulva intestinalis</i>	0	0	96	32 (3)
Subtotal	0	206	221	143 (13)
Total	1112	1378	990	1160

A-6. Algal community structure on the VIMS boat basin flowway for 7/22/09. Values are densities as numbers of individuals x 10³ per square centimeter of screen surface. Numbers in parentheses are percentages of the total average densities.

Species	Top	Middle	Bottom	Average
Diatoms				
<i>Berkeleya rutilans</i>	2046	666	789	1167 (48)
<i>Melosira nummuloides</i>	433	1029	324	595 (24)
<i>Licmophora</i> sp. 1	415	62	22	166 (7)
<i>Fragilariopsis</i> sp.	41	98	122	87 (4)
<i>Pseudonitzschia</i> cf. <i>multiseries</i>	181	13	0	65 (3)
<i>Achnanthes</i> sp.	23	13	101	46 (2)
<i>Licmophora</i> sp. 2	58	27	22	37 (1)
<i>Tabularia tabulata</i>	12	36	53	34 (1)
<i>Navicula</i> sp.	6	36	31	24 (1)
<i>Amphora</i> sp.	6	45	18	23 (1)
<i>Bacillaria paxillifer</i>	0	4	35	13 (1)
<i>Nitzschia</i> sp.	0	36	0	12 (1)
<i>Minidiscus</i> sp.	12	13	0	8 (<1)
<i>Thalassosira</i> sp.	0	13	9	7 (<1)
<i>Cocconeis</i> sp.	0	13	4	6 (<1)
<i>Coscinodiscus</i> sp.	6	0	0	2 (<1)
<i>Entomoneis</i> sp.	6	0	0	2 (<1)
<i>Gyrosigma</i> sp.	0	4	0	1 (<1)
Subtotal	3245	2108	1530	2295 (94)
Non-Diatoms				
<i>Ulva intestinalis</i>	292	0	0	97 (4)
<i>Calothrix</i> sp.	0	98	0	33 (1)
<i>Nodularia</i> sp.	0	0	22	7 (<1)
<i>Oscillatoria</i> sp.	0	18	0	6 (<1)
<i>Peridinium</i> sp.	6	0	0	2 (<1)
Subtotal	298	116	22	145 (6)
Total	3543	2224	1552	2440

A-7. Algal community structure on the VIMS boat basin flowway for 10/28/09. Values are densities as numbers of individuals x 10³ per square centimeter of screen surface. Numbers in parentheses are percentages of the total average densities.

Species	Top	Middle	Bottom	Average
Diatoms				
<i>Berkeleya rutilans</i>	1563	277	3034	1291 (57)
<i>Nitzschia</i> sp.	44	216	26	95 (4)
<i>Actinoptychus</i> sp.	0	135	0	45 (2)
<i>Entomoneis</i> sp.	91	0	23	38 (2)
<i>Navicula</i> sp.	7	24	58	30 (1)
<i>Licmorpha</i> sp. 1	14	6	71	30 (1)
<i>Grammatophora</i> sp.	24	18	41	28 (1)
<i>Achnanthes</i> sp.	10	9	41	20 (1)
<i>Melosira nummuloides</i>	7	0	49	19 (1)
<i>Bacillaria</i> sp.	0	0	45	15 (1)
<i>Amphora</i> sp.	17	0	19	12 (1)
<i>Minidiscus</i> sp.	10	15	0	8 (<1)
<i>Licmorpha</i> sp. 2	0	0	15	5 (<1)
<i>Pseudonitzschia</i> sp.	0	0	15	5 (<1)
<i>Gyrosigma</i> sp.	0	0	11	4 (<1)
<i>Melosira monoliformes</i>	0	0	8	3 (<1)
<i>Coscinodiscus</i> sp.	0	0	8	3 (<1)
<i>Cocconeis</i> sp.	7	0	0	2 (<1)
<i>Cyclotella</i> sp.	0	0	4	1 (<1)
Subtotal	1794	700	2468	1654 (83)
Non-Diatoms				
<i>Ulva intestinalis</i>	0	0	1443	481 (21)
<i>Calothrix</i> sp.	405	0	0	135 (6)
Subtotal	405	0	1443	616 (17)
Total	2199	700	3911	2270

A-8. Algal community structure on the VIMS boat basin flowway for 11/03/09. Values are densities as numbers of individuals x 10³ per square centimeter of screen surface. Numbers in parentheses are percentages of the total average densities.

Species	Top	Middle	Bottom	Average
Diatoms				
<i>Berkeleya rutilans</i>	7886	943	1444	3424 (72)
<i>Melosira moniliformes</i>	763	16	22	267 (6)
<i>Achnanthes brevipes</i>	151	20	292	154 (3)
<i>Entomoneis</i> sp.	99	146	164	136 (3)
<i>Navicula</i> sp.	184	91	69	115 (2)
<i>Amphora</i> sp. 2	26	79	50	52 (1)
<i>Melosira nummuloides</i>	118	0	36	51 (1)
<i>Achnanthes</i> sp.	59	79	0	46 (1)
<i>Fragilariopsis</i> sp.	7	28	83	39 (<1)
<i>Pseudonitzschia</i> cf. <i>pungens</i>	0	107	0	36 (<1)
<i>Pseudonitzschia</i> sp.	20	0	83	34 (<1)
<i>Licmophora</i> sp. 1	59	8	31	33 (<1)
<i>Nitzschia</i> sp.	26	43	11	27 (<1)
<i>Tabularia tabulata</i>	26	8	0	11 (<1)
<i>Coscinodiscus</i> sp.	7	8	8	8 (<1)
<i>Cyclotella</i> sp.	7	16	0	8 (<1)
<i>Minidiscus</i> sp.	13	4	8	8 (<1)
<i>Bacillaria paxillifer</i>	0	0	22	7 (<1)
<i>Eucampia</i> sp.	0	20	0	7 (<1)
<i>Licmophora</i> sp. 2	13	0	6	6 (<1)
<i>Navicula</i> sp. (tube)	0	16	0	5 (<1)
<i>Melosira</i> sp.	13	0	0	4 (<1)
<i>Cylindrotheca closterium</i>	13	0	0	4 (<1)
<i>Cymbella</i> sp.	0	8	0	3 (<1)
<i>Tabularia</i> sp.	7	0	0	2 (<1)
<i>Thalassiosira</i> sp.	7	0	0	2 (<1)
<i>Sellaphora</i> sp.	0	0	6	2 (<1)
<i>Grammatophora</i> sp.	0	4	0	1 (<1)
<i>Pleurosigma</i> cf. <i>fasciola</i>	0	0	3	1 (<1)
Subtotal	9504	1644	2338	4493 (94)
Non-Diatoms				
<i>Ulva intestinalis</i>	539	0	0	180 (4)
<i>Calothrix</i> sp.	0	134	144	93 (2)
Subtotal	539	134	144	273 (6)
Total	10043	1778	2482	4766

A-9. Algal community structure on the VIMS boat basin floway for 12/08/09. Values are densities as numbers of individuals x 10³ per square centimeter of screen surface. Numbers in parentheses are percentages of the total average densities.

Species	Top	Middle	Bottom	Average
Diatoms				
<i>Nitzschia</i> sp. (long)	337	324	144	268 (30)
<i>Melosira nummuloides</i>	215	193	111	173 (19)
<i>Melosira monoliformes</i>	43	57	97	66 (7)
<i>Navicula smithii</i>	43	79	43	55 (6)
<i>Achnanthes brevipes</i>	97	26	22	48 (5)
<i>Navicula</i> sp. (small)	43	75	22	47 (5)
<i>Amphora</i> sp.	57	35	29	40 (4)
<i>Berkeleya rutilans</i>	36	39	36	37 (4)
<i>Nitzschia</i> sp. (small)	47	13	0	20 (2)
<i>Stauroneis</i> sp.	57	0	0	19 (2)
<i>Nitzschia</i> sp.	0	0	50	17 (2)
<i>Thalassiosira</i> sp.	22	0	14	12 (1)
<i>Nitzschia</i> sp. (mid)	26	0	4	10 (1)
<i>Achnanthes</i> sp.	0	13	14	9 (1)
<i>Cyclotella</i> sp.	18	9	0	9 (1)
<i>Pinnularia</i> sp. (small)	26	0	0	9 (1)
<i>Amphora</i> sp. (small)	18	0	0	6 (1)
<i>Pinnularia</i> sp.	18	0	0	6 (1)
<i>Navicula</i> sp. (mid)	14	0	0	5 (1)
<i>Fragilaria</i> sp.	0	0	14	5 (1)
<i>Navicula</i> sp.	0	13	0	4 (<1)
<i>Caloneis/Luticola</i> sp.	7	0	0	2 (<1)
<i>Skeletonema costatum</i>	7	0	0	2 (<1)
<i>Coscinodiscus</i> sp.	0	0	7	2 (<1)
<i>Hantzschia</i> sp.	0	0	7	2 (<1)
<i>Diploneis</i> sp.	4	0	0	1 (<1)
<i>Cymbella</i> sp.	0	4	0	1 (<1)
<i>Staurosira</i> sp.	0	4	0	1 (<1)
<i>Cocconeis</i> sp.	0	0	4	1 (<1)
<i>Gomphonema</i> sp.	0	0	4	1 (<1)
Subtotal	1135	884	622	878 (97)
Non-Diatoms				
<i>Ulothrix</i> sp.	39	0	0	13 (2)
<i>Oscillatoria</i> sp.	0	0	29	10 (1)
Subtotal	39	0	29	23 (3)
Total	1174	884	651	901

A-10. Algal community structure on the VIMS boat basin flowway for 03/29/10. Values are densities as numbers of individuals x 10³ per square centimeter of screen surface. Numbers in parentheses are percentages of the total average densities.

Species	Top	Middle	Bottom	Average
Diatoms				
<i>Berkeleya rutilans</i>	543	515	524	527 (45)
<i>Melosira nummuloides</i>	287	149	17	151 (13)
<i>Navicula</i> sp.	78	274	71	141 (12)
<i>Grammatophora</i> sp.	174	43	12	76 (7)
<i>Nitzschia nana</i>	0	50	17	22 (2)
<i>Achnanthes</i> sp.	9	47	4	20 (2)
<i>Nitzschia</i> sp.	6	34	13	18 (2)
<i>Skeletonema costatum</i>	0	19	33	17 (1)
<i>Stauroneis</i> sp.	6	9	17	11 (1)
<i>Cyclotella</i> sp.	0	13	4	6 (<1)
<i>Thalassiosira</i> sp.	0	0	17	6 (<1)
<i>Tabularia tabulata</i>	3	13	0	5 (<1)
<i>Chaetoceros</i> sp.	0	3	8	4 (<1)
<i>Coscinodiscus</i> sp.	0	3	8	4 (<1)
<i>Minidiscus</i> sp.	0	0	4	3 (<1)
<i>Cymbella</i> sp.	0	0	4	1 (<1)
<i>Diploneis</i> sp.	0	0	4	1 (<1)
<i>Entomoneis</i> sp.	0	0	4	1 (<1)
Unidentified pennate diatom	0	0	4	1 (<1)
<i>Amphora</i> sp.	3	0	0	1 (<1)
<i>Fragilaria</i> sp.	3	0	0	1 (<1)
Subtotal	1112	1172	769	1017 (87)
Non-Diatoms				
<i>Ceramium</i> sp.	0	206	0	69 (6)
<i>Pseudanabaena</i> sp.	0	0	125	42 (4)
<i>Ulva intestinalis</i>	0	0	96	32 (3)
Subtotal	0	206	221	143 (13)
Total	1112	1378	990	1160

A-11. Algal community structure on the VIMS boat basin flowway for 05/24/10. Values are densities as numbers of individuals x 10³ per square centimeter of screen surface. Numbers in parentheses are percentages of the total average densities.

Species	Top	Middle	Bottom	Average
Diatoms				
<i>Stauronella</i> sp.	211	202	1441	618 (41)
<i>Berkeleya rutilans</i>	173	326	85	195 (13)
<i>Navicula</i> sp.	61	52	136	83 (6)
<i>Nitzschia nana</i>	8	6	144	53 (4)
<i>Thalassiosira</i> sp.	34	20	85	46 (3)
<i>Plagiotropis</i> sp.	8	13	85	35 (2)
<i>Coscinodiscus</i> sp.	2	26	42	23 (2)
<i>Nitzschia</i> sp.	27	20	17	21 (1)
<i>Skeletonema costatum</i>	21	13	25	20 (1)
<i>Haslea</i> sp.	0	0	34	11 (1)
<i>Amphora</i> sp.	0	6	17	8 (<1)
<i>Cocconeis</i> sp.	0	0	25	8 (<1)
<i>Flagilariopsis</i> sp.	0	0	25	8 (<1)
<i>Melosira nummuloides</i> 2	2	13	0	5 (<1)
<i>Achnanthes</i> sp.	0	6	9	5 (<1)
<i>Licmophora</i> sp.	0	6	9	5 (<1)
<i>Achnantheidium minutissimum</i>	2	6	0	3 (<1)
<i>Actinoptychus senarius</i>	0	0	9	3 (<1)
<i>Cylindrotheca closterium</i>	0	0	9	3 (<1)
<i>Minidiscus</i> sp.	0	0	9	3 (<1)
<i>Unidentified diatom</i>	0	0	9	3 (<1)
<i>Cyclotella</i> sp.	4	0	0	1 (<1)
<i>Melosira monoliformes</i>	4	0	0	1 (<1)
<i>Opephora</i> sp.	2	0	0	1 (<1)
<i>Tabularia tabulata</i>	4	0	0	1 (<1)
Subtotal	563	715	2215	1163 (78)
Non-Diatoms				
<i>Ulva intestinalis</i>	749	0	0	250 (17)
<i>Oscillatoria</i> sp.	0	241	0	80 (5)
Subtotal	749	241	0	330 (22)
Total	1312	956	2215	1493

A-12. Algal community structure on the Great Wicomo Floway 1 from 1/July/2010 to 16/May/11. Values are densities as numbers of individuals per milliliter. .

Species	1-Jul-10	7-Jul-10	13-Jul-10	19-Jul-10	25-Jul-10	29-Aug-10	11-Sep-10	25-Sep-10	4-Dec-10	26-Mar-11	24-Apr-11	2-May-11	16-May-11
Cyanophyceae													
<i>Aphanocapsa</i>	0	292321	0	0	0	0	0	0	122775	0	0	0	0
<i>Cyanobium</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	150336
<i>Cyanodictyon</i> sp.	0	0	0	0	0	0	1157590	0	0	0	0	0	0
<i>Gloeothece</i> sp.	0	0	0	0	0	0	35043410	0	0	0	0	0	0
<i>Johannesbaptista pellucida</i>	0	0	0	0	0	155904	0	0	0	0	0	0	0
<i>Leptolyngbya</i> sp.	0	0	25056	0	25056	0	0	0	0	289398	164430	0	0
<i>Lyngbya</i> sp.	0	1753924	0	0	0	0	0	16925371	0	26309	0	0	0
<i>Oscillatoria</i> sp.	0	0	0	0	0	0	0	0	0	0	32886	21924	0
<i>Phormidium</i> sp.	0	0	0	0	0	0	0	0	0	0	32886	0	0
<i>Pseudanabaena</i> sp.	50112	0	0	0	0	0	0	292321	0	0	295975	197316	0
<i>Spirulina</i> sp.	0	0	25056	0	42387	0	0	0	0	0	263089	482329	0
Chlorophyceae													
<i>Achrochaete</i> sp.	0	0	0	3507849	15346839	38976	0	0	0	0	0	0	0
<i>Cladophora</i> sp.	100224	0	0	0	25056	0	0	0	87696	1210208	98658	504253	139061
<i>Pseudoclonium marinum</i>	100224	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ulva intestinalis</i>	3983914	116928	7090866	8681926	1474689	0	0	3946330	0	3314917	0	0	496110
<i>Ulothrix</i> sp.	0	0	0	0	0	0	0	0	0	0	16114180	21924	9971060
Dinophyta													
<i>Prorocentrum</i> sp.	0	0	0	0	0	19488	0	0	0	131544	230203	43848	0
<i>Dino cysts</i>	0	0	25056	0	112752	0	0	0	0	26309	0	0	18792
Bacillariophyta													
<i>Achnanthes brevippes</i>	0	0	0	0	0	0	0	0	0	0	0	43848	26309
<i>Achnanthes</i> sp.	350785	175392	1027299	570025	407519	38976	140314	175392	648952	920810	131544	21924	22550
<i>Achnantheidium</i> sp.	0	0	0	0	0	0	0	0	3262299	105235	0	21924	45101
<i>Actinoptychus senarius</i>	25056	0	25056	0	0	0	0	0	0	0	0	0	0
<i>Amphora</i> sp.	451009	146160	375841	1446988	271142	331297	1683767	584641	543717	447251	197316	241165	246176
<i>Bacillaria</i> sp.	0	58464	0	0	25056	0	35078	0	0	0	0	0	0
<i>Berkeleya fennica</i>	0	0	0	0	0	0	0	0	4647900	0	0	0	0
<i>Berkeleya fragilis</i>	0	0	0	0	0	0	2174866	175392	0	0	0	0	0
<i>Berkeleya rutilans</i>	150336	233857	325729	9032711	2973081	837986	7401561	1461604	5437166	13285977	2334912	833114	2989815

<i>Camplyodiscus</i> sp.	0	0	0	0	0	0	0	0	0	0	32886	0	0
<i>Caloneis</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	18792
<i>Catenula</i> sp.	0	0	0	0	51156	0	0	0	0	0	0	0	131544
<i>Cocconeis</i> sp.	50112	29232	0	0	29232	0	0	0	52618	0	32886	43848	242417
<i>Coscinodiscus</i> sp.	0	0	50112	0	50112	0	0	0	35078	26309	32886	21924	52618
<i>Cyclotella</i> sp.	0	0	0	0	27840	0	0	0	17539	0	32886	0	0
<i>Cylindrotheca closterium</i>	0	0	50112	0	14616	194880	0	87696	0	0	0	0	18792
<i>Cymatosira</i> sp.	0	0	0	0	175392	0	0	0	0	0	0	0	0
<i>Denticula</i> sp.	0	0	0	0	0	0	0	0	0	0	32886	0	26309
<i>Diploneis</i> sp.	0	0	0	0	14616	0	0	0	0	26309	0	0	35705
<i>Ditylum</i> sp.	0	0	0	0	0	0	0	0	0	26309	0	0	0
<i>Entomoneis</i> sp.	0	58464	0	0	0	0	0	0	0	0	0	0	0
<i>Epithemia</i> sp.	0	0	0	0	0	0	0	0	35078	78927	0	21924	0
<i>Eunotogramma laevis</i>	0	0	0	0	0	19488	0	0	0	0	0	0	0
<i>Fogedia</i> sp.	0	0	0	0	0	0	0	0	0	0	131544	0	52618
<i>Fragilaria martyii</i>	0	0	0	0	0	38976	0	0	0	0	0	0	0
<i>Fragilaria</i> sp.	0	0	0	0	86861	0	70157	0	0	0	164430	0	315706
<i>Grammatophora</i> sp.	0	58464	125280	87696	225672	0	35078	730802	719109	605104	65772	21924	18792
<i>Gyrosigma</i> sp.	25056	0	0	0	23942	0	0	0	17539	0	0	0	0
<i>Licmophora</i> sp. (long)	0	0	0	0	418436	19488	2034552	29232	175392	0	1019469	0	537453
<i>Licmophora</i> sp. (short)	0	0	0	0	112752	1675972	841884	0	70157	52618	460405	263089	3076258
<i>Lyrella</i> sp.	0	0	0	0	87696	0	0	0	0	26309	0	0	0
<i>Mastogloia</i> sp.	25056	233857	50112	43848	303894	19488	70157	175392	52618	26309	131544	21924	45101
<i>Melosira monoliformes</i>	300673	584641	0	3858634	1931474	0	1438218	3858634	228010	0	0	0	0
<i>Melosira nummuloides</i>	300673	1812389	3282344	6708761	810086	97440	1122512	760034	17539	184162	32886	0	26309
<i>Minidiscus</i> sp.	0	0	0	0	25056	0	0	0	0	0	0	0	0
<i>Navicula smithii</i>	0	0	0	0	0	0	0	0	0	0	98658	109620	78927
<i>Navicula</i> sp.	400897	58464	200449	43848	241493	0	140314	58464	87696	289398	0	43848	169128
<i>Neodelphineis</i> sp.	0	0	0	0	0	38976	140314	0	0	0	0	0	0
<i>Nitzschia filiformis</i>	0	0	0	0	0	0	0	0	0	184162	0	0	0
<i>Nitzschia fusiliformis</i>	0	0	0	263089	0	0	0	0	0	0	0	0	0
<i>Nitzschia longissima</i>	0	0	0	0	0	0	0	0	105235	0	0	0	0
<i>Nitzschia nana</i>	0	0	0	0	129957	0	0	0	0	289398	32886	109620	310069
<i>Nitzschia scalpelliformis</i>	0	0	0	0	0	0	0	0	140314	0	0	0	0
<i>Nitzschia sigma</i>	4109194	0	1302915	0	175392	0	0	0	0	0	0	0	0
<i>Nitzschia sigmaformis</i>	0	0	0	350785	0	214369	105235	0	0	0	0	0	0
<i>Nitzschia sigmoidea</i>	0	2250870	651458	0	43848	0	0	58464	0	0	0	0	0
<i>Nitzschia</i> sp.	50112	116928	225505	350785	349711	233857	35078	0	0	52618	0	21924	674634

<i>Opephora</i> sp.	0	0	0	0	25056	0	0	0	0	0	32886	43848	0
<i>Parlibellus</i> sp.	0	0	0	0	0	97440	0	0	0	0	0	0	0
<i>Pinnularia</i> sp.	0	0	25056	0	0	19488	0	0	0	0	0	21924	18792
<i>Podocystis</i> sp.	0	0	0	0	43848	0	0	0	0	0	0	0	18792
<i>Psammothidium</i> sp.	0	0	0	0	105235	0	0	0	0	0	0	0	0
<i>Rhaphoneis</i> sp.	25056	0	0	0	0	0	0	0	0	0	0	0	0
<i>Rhizosolenia</i> sp.	0	0	0	0	75168	0	0	0	0	0	0	0	0
<i>Rhopaloidia</i> sp.	0	0	50112	0	0	0	70157	175392	0	0	0	0	0
<i>Skelatonema</i> sp.	0	0	0	0	0	0	0	0	0	78927	0	0	0
<i>Sieminskia</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	18792
<i>Stauronella</i> sp.	751682	175392	100224	43848	203073	136416	701570	292321	1017276	1052355	32886	65772	107115
<i>Staurosirella</i> sp.	0	0	0	0	14616	0	0	0	0	26309	0	0	0
<i>Synedra</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	78927
<i>Tabularia</i> sp.	0	760034	50112	175392	1321588	272833	350785	233857	0	420942	0	0	48859
<i>Thalassionema</i> sp.	0	0	0	0	0	0	0	0	0	289398	0	21924	1698801
<i>Thalassiosira</i> sp.	0	0	100224	0	56376	0	0	0	35078	342015	559063	87696	304431
<i>Unidentified diatom</i>	0	0	25056	0	0	0	0	0	0	0	0	0	0
<i>Centrales</i>	0	0	0	0	0	0	0	0	0	0	0	504253	0
Chrysophyta													
<i>Chromulina</i> sp.	0	29232	0	657722	131544	0	0	0	0	0	0	0	0
Euglenophyceae													
<i>Phacus</i> sp.	0	29232	0	0	0	0	0	0	0	26309	0	0	0
Rhodophyta													
<i>Polysiphonia</i> sp.	0	0	0	0	140314	0	0	0	0	0	0	0	0

A-13. Algal community structure on the Great Wicomo Floway 1 from 3/July/2010 to 26/May/11. Values are densities as numbers of individuals per milliliter. .

Species	3-Jul-10	11-Jul-10	18-Jul-10	1-Aug-10	24-Aug-10	6-Sep-10	26-Sep-10	13-Nov-10	27-Nov-10	8-Jan-11	23-Jan-11	6-Feb-11	29-Mar-11	26-May-11
Cyanophyceae														
<i>Aphanocapsa</i>	0	3273992	0	0	0	0	0	0	0	0	0	605104	0	0
<i>Aphanothece</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	482329
<i>Calothrix</i> sp.	0	0	0	974402	0	0	0	0	0	0	0	276243	0	0
<i>Chroococcus</i> sp.	0	58464	140314	0	0	0	0	0	0	0	0	0	0	0
<i>Cyanodictyon</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Geitlerinema</i> sp.	0	0	0	0	0	0	0	0	0	745418	0	0	0	0
<i>Gloeothece</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Jaaginema</i> sp.	0	0	0	0	0	0	0	0	0	0	323380	263089	0	0
<i>Johannesbaptista pellucida</i>	0	0	0	0	0	0	545665	0	0	0	0	0	0	0
<i>Leptolyngbya</i> sp.	0	0	0	38976	0	0	0	0	0	0	0	434096	372709	184162
<i>Lyngbya</i> sp.	0	0	420942	0	31658336	206713	6684401	9339647	21924	43848	3540735	670876	0	0
<i>Pseudanabaena</i> sp.	0	0	0	0	0	0	662594	0	0	0	87696	5682715	0	201701
<i>Spirulina</i> sp.	0	0	0	0	0	0	0	0	0	43848	0	0	0	87696
Chorophyceae														
<i>Achrochaete</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Cladophora</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	394633	46041
<i>Pseudoclonium marinum</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ulva intestinalis</i>	1227747	0	35078	1890341	0	0	1071843	0	0	0	0	26309	0	13285977
Unknown green #2	0	0	0	0	0	0	0	131544	0	0	0	0	0	0
<i>Ulothrix</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	306937	903271
Cocoid green	0	0	0	0	0	0	0	0	0	0	0	0	0	460405
Dinophyta														
<i>Alexandrium</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	21924	0
<i>Ceratium</i> sp.	0	0	0	0	0	0	0	0	21924	0	0	0	0	0
cf. <i>Katodinium</i> sp.	0	0	0	0	0	0	0	0	43848	0	0	0	0	0
Dino cysts	0	0	0	0	0	0	0	0	0	0	0	105235	0	0
<i>Dinophysis</i> sp.	0	0	0	0	0	0	0	0	21924	0	0	0	0	0
<i>Gyrodinium</i> sp.	0	0	0	0	0	0	0	0	43848	0	0	0	0	0
<i>Prorocentrum</i> sp.	29232	0	0	0	0	0	0	0	0	0	158949	171008	65772	26309
Bacillariophyta														
<i>Achnanthes brevipes</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	131544
<i>Achnanthes</i> sp.	380017	58464	596334	1071843	482329	25056	77952	131544	76734	142506	641279	289398	131544	24116
<i>Achnantheidium</i> sp.	0	0	0	58464	0	0	0	0	876962	0	0	447251	0	116197
<i>Actinoptychus senarius</i>	0	0	0	0	0	0	0	0	0	0	21924	0	0	0
<i>Amphipleura</i> sp.	0	0	0	0	0	0	0	0	0	54810	0	0	0	65772
<i>Amphora</i> sp.	292321	263089	631413	331297	1140051	137808	545665	1907393	219241	449443	372709	381479	87696	425327

<i>Bacillaria</i> sp.	29232	29232	0	0	0	12528	0	0	0	0	0	52618	0	0
<i>Berkeleya fennica</i>	0	0	0	0	0	0	0	953696	1337367	487810	0	263089	0	0
<i>Berkeleya fragilis</i>	0	0	0	0	0	0	311809	0	0	0	0	0	0	0
<i>Berkeleya rutilans</i>	3537081	1110819	1403140	311809	2587038	952130	389761	5360431	975620	3668625	4686267	4590897	5174077	15134175
<i>Caloneis</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	21924
<i>Catenula</i> sp.	0	0	0	0	87696	0	0	0	0	0	0	0	0	0
cf. <i>Diadesmis</i> sp.	0	175392	0	0	0	0	0	0	0	0	306937	0	0	0
<i>Chaetoceros</i> sp.	0	29232	0	38976	0	0	0	0	43848	0	65772	0	0	0
<i>Cocconeis</i> sp.	496945	175392	0	77952	0	12528	19488	0	0	76734	0	0	131544	399018
<i>Coscinodiscus</i> sp.	0	0	0	19488	0	0	0	65772	21924	0	43848	26309	0	0
<i>Cyclotella</i> sp.	0	0	0	0	0	0	0	0	54810	43848	71253	0	65772	0
<i>Cylindrotheca closterium</i>	0	0	0	38976	131544	0	19488	65772	87696	0	0	0	0	0
<i>Dactyliosolen</i> sp.	0	0	0	0	0	0	0	0	0	43848	0	0	0	0
<i>Denticula</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	52618
<i>Diploneis</i> sp.	0	29232	0	0	0	12528	0	0	0	0	0	0	21924	0
<i>Ditylum brightwellii</i>	0	0	0	0	0	0	0	0	21924	0	0	26309	0	0
<i>Entomoneis</i> sp.	0	0	0	0	0	0	0	65772	0	0	0	0	0	0
<i>Epithemia</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	21924	0
<i>Eumotia</i> sp.	0	0	0	0	0	0	0	65772	131544	0	0	0	0	0
<i>Eumotogramma laevis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Fogedia</i> sp.	0	0	0	0	0	0	0	0	0	43848	0	0	0	26309
<i>Fragilaria martyii</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Fragilaria</i> sp.	0	0	0	38976	0	12528	0	0	0	0	0	0	0	184162
<i>Fragilariopsis</i> sp.	0	0	35078	0	0	50112	0	0	0	0	137025	210471	219241	0
<i>Frustulia</i> sp.	0	0	0	0	175392	0	0	0	0	0	0	0	0	0
<i>Grammatophora</i> sp.	204625	175392	596334	311809	306937	187920	233857	361747	504253	847730	1008507	1591686	219241	96466
<i>Gyrosigma</i> sp.	116928	29232	35078	0	0	0	0	0	21924	0	0	0	0	26309
<i>Hippodonta</i> sp.	29232	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Leptocylindrus minimus</i>	0	0	0	0	0	0	0	0	131544	274051	0	0	0	0
<i>Licmophora</i> sp. (long)	0	0	140314	0	131544	225505	19488	263089	32886	0	65772	26309	21924	21924
<i>Licmophora</i> sp. (short)	0	0	0	19488	2060861	212977	0	32886	87696	82215	21924	157853	21924	146891
<i>Mastogloia</i> sp.	29232	643106	175392	38976	613874	50112	194880	98658	21924	0	60291	0	109620	122775
<i>Melosira monoliformes</i>	0	0	0	58464	0	0	194880	295975	0	32886	0	52618	21924	0
<i>Melosira nummuloides</i>	6314128	993890	3086907	3936586	1973165	125280	1344675	1479874	109620	215587	71253	78927	153468	133737
<i>Meridion</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	21924	0
<i>Meuniera</i> sp.	0	0	0	0	0	0	0	0	65772	0	0	0	0	0
<i>Navicula gregaria</i>	0	29232	0	0	0	0	0	0	0	0	0	0	76734	0
<i>Navicula</i> sp.	58464	175392	140314	214369	87696	75168	214369	98658	43848	115101	65772	197316	87696	613874
<i>Navicula smithii</i>	0	0	0	0	0	62640	0	0	0	350785	131544	0	0	109620
<i>Neodelphineis</i> sp.	0	0	0	0	0	0	38976	0	0	0	0	0	0	0
<i>Nitzschia</i> cf. <i>longissima</i>	0	0	3016750	38976	0	0	0	0	0	0	0	0	0	0
<i>Nitzschia filiformis</i>	0	0	0	0	219241	0	19488	0	0	0	0	0	230203	0
<i>Nitzschia nana</i>	0	3800170	0	623618	0	37584	0	0	0	350785	153468	26309	43848	475752
<i>Nitzschia scalpelliformis</i>	0	0	0	0	0	0	0	0	0	0	43848	52618	0	0
<i>Nitzschia sigma</i>	0	0	0	253345	0	162864	0	0	0	0	0	0	0	0
<i>Nitzschia sigmaformis</i>	0	0	0	0	789266	0	19488	98658	208279	0	0	0	0	0
<i>Nitzschia sigmoidea</i>	3040136	0	0	0	0	62640	0	0	0	0	0	0	0	0
<i>Nitzschia tryblionella</i>	0	0	0	0	0	0	0	0	0	0	21924	0	0	0

<i>Nitzschia</i> sp.	0	204625	0	58464	219241	0	253345	263089	208279	0	49329	26309	0	131544
<i>Nitzschia</i> sp. (tube)	0	0	0	0	0	0	0	0	0	953696	65772	0	0	0
<i>Nitzschia ventricosa</i>	0	0	0	0	0	0	0	0	0	43848	0	0	0	0
<i>Opephora</i> sp.	0	0	0	0	43848	12528	0	0	0	0	0	0	0	26309
<i>Paralia</i> sp.	0	0	0	0	0	0	0	0	0	131544	0	0	0	0
<i>Parlibellus</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pinnularia</i> sp.	0	29232	0	0	0	0	0	0	0	0	0	0	0	26309
<i>Plagiogramma</i> sp.	0	58464	0	0	0	0	0	0	0	0	0	0	0	0
<i>Plagiotropis</i> sp.	0	0	0	0	43848	0	0	0	0	0	0	0	0	0
<i>Pleurosigma</i> sp.	0	0	0	19488	0	0	0	0	0	0	0	0	0	0
<i>Pseudostaurosira</i> sp.	0	0	0	0	0	0	0	0	21924	0	0	0	0	0
<i>Rhaphoneis</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Rhopaloidia</i> sp.	29232	58464	0	0	789266	0	0	65772	0	43848	0	0	0	0
<i>Skelatonema costatum</i>	0	0	0	0	0	0	0	0	0	756380	1600456	3499079	0	0
<i>Stauronella</i> sp.	467713	438481	70157	155904	438481	0	136416	0	0	400114	65772	39463	986582	868193
<i>Staurosirella</i> sp.	0	0	35078	0	0	0	0	0	0	0	0	52618	21924	898886
<i>Striatella</i> sp.	0	0	0	0	0	0	0	0	0	0	21924	0	0	0
<i>Surirella</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	21924	0
<i>Synedropsis</i> sp.	0	0	0	0	0	12528	0	0	0	0	0	0	0	0
<i>Tabularia</i> sp.	964658	175392	771727	370273	1534684	37584	0	197316	208279	69426	126063	92081	109620	109620
<i>Thalassionema</i> sp.	0	0	0	19488	0	0	0	394633	6237394	11999766	12102078	5156538	1512760	0
<i>Thalassiosira</i> sp.	0	0	0	58464	0	0	38976	0	0	0	0	3801631	65772	24116
Unidentified diatom	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrysophyta														
<i>Chromulina</i> sp.	0	526177	0	233857	1753924	87696	0	0	175392	0	0	0	0	0
Euglenophyceae														
<i>Euglena</i> sp.	0	0	0	0	0	0	0	0	0	32886	0	0	0	0
Rhodophyta														
<i>Polysiphonia</i> sp.	0	0	0	954914	0	0	0	0	0	0	285013	460405	0	0

A-14. Algal species on the wood ATSTM floway during the study period (2008-2009) at Muddy Run, PA.

Wood	Top				Middle				Bottom			
	28-Oct-08	8-Mar-09	18-Jul-09	10-Oct-09	28-Oct-08	8-Mar-09	18-Jul-09	10-Oct-09	28-Oct-08	8-Mar-09	18-Jul-09	10-Oct-09
	Wood_1	Wood_1	Wood_1	Wood_1	Wood_2	Wood_2	Wood_2	Wood_2	Wood_3	Wood_3	Wood_3	Wood_3
Chroococcales												
<i>Aphanocapsa rivularis</i>									1		1	
<i>Aphanocapsa</i> sp.												1
<i>Aphanothece</i> sp.								1				1
<i>Asterocapsa</i> sp.	1											
<i>Chroococcus minutus</i>									1			
<i>Eucapsis carpatica</i>									1			
Oscillatoriales												
<i>Leptolyngbya boryana</i>	1				1							
<i>Leptolyngbya</i> sp.	1	1		1	1	1		1	1			
<i>Leptolyngbya subtilis</i>												1
<i>Oscillatoria curviceps</i>				1								
<i>Oscillatoria princeps</i>												1
<i>Phormidium coutinhoi</i>			1									
<i>Phormidium fonticulum</i>	1				1							
<i>Phormidium retzii</i>	1			1	1	1		1	1	1		1
<i>Phormidium simplicissima</i>		1										
<i>Planktolyngbya brevicellularis</i>									1			
<i>Pseudanabaena galeata</i>		1			1					1		
<i>Pseudanabaena limnetica</i>	1				1				1			
Volvocales												
<i>Pandorina</i> sp.	1				1				1			
Chlorellales												
<i>Chlorella</i> sp.		1										
<i>Lagerheimia quadriseta</i>		1										
<i>Quadricoccus</i> sp.				1								
Cladophorales												

<i>Cladophora glomerata</i>		1		1		1		1
<i>Rhizoclonium hieroglyphicum</i>	1			1				
Zygnmentales								
<i>Closterium cf. sublaterale</i>								1
<i>Closterium sp.</i>		1		1	1			1
<i>Cosmarium cf. margaritatum</i>								1
<i>Cosmarium cf. pseudoconnatum</i>				1				1
<i>Cosmarium cf. pseudoexiguum</i>								1
<i>Cosmarium cf. sublobulatum</i>				1				1
<i>Cosmarium cf. trilobulatum</i>								1
<i>Cosmarium perforatum</i>								1
<i>Cosmarium sp.</i>		1		1	1	1		1
<i>Netrium interruptum</i>								1
<i>Netrium sp.</i>							1	
<i>Pediastrum biradiatum</i>								1
<i>Pediastrum boryanum</i>		1	1			1	1	
<i>Pediastrum duplex</i>	1			1	1			1
<i>Pediastrum simplex</i>				1				1
<i>Pediastrum tetras</i>	1			1				1
<i>Spirogyra cf. rivularis</i>	1	1	1	1		1	1	1
<i>Staurastrum alternans</i>					1			1
Sphaeropleales								
<i>Coelastrum astroideum</i>	1	1		1				1
<i>Coelastrum cf. cambricum</i>		1						
<i>Coelastrum cf. microporum</i>						1		
<i>Desmodesmus alternans</i>								1
<i>Desmodesmus balatonicus</i>							1	
<i>Desmodesmus bicaudatus</i>							1	
<i>Desmodesmus communis</i>	1	1	1	1		1	1	
<i>Desmodesmus denticulatus</i>	1							
<i>Desmodesmus intermedius</i>	1			1				
<i>Desmodesmus opoliensis</i>							1	
<i>Desmodesmus polyspinosus</i>	1							1
<i>Desmodesmus sp.</i>								1

<i>Fragilaria capucina</i>	1	1	1		1		1	1		1	1	1
<i>Fragilaria</i> sp.	1				1					1		
<i>Meridion circulare</i>										1		
<i>Staurosirella leptostauron</i>										1		
<i>Synedra acus</i>												1
<i>Synedra affinis</i>							1					
<i>Synedra</i> sp.	1			1	1			1		1	1	1
<i>Ulnaria ulna</i>	1	1		1	1	1		1		1		1
Melosirales												
<i>Melosira varians</i>	1	1		1	1	1		1		1	1	1
Bacillariales												
<i>Nitzschia acicularis</i>												1
<i>Nitzschia</i> cf. <i>agnita</i>												1
<i>Nitzschia amphibia</i>	1									1		
<i>Nitzschia</i> cf. <i>draveillensis</i>												1
<i>Nitzschia</i> cf. <i>filiformis</i>												1
<i>Nitzschia</i> cf. <i>paleacea</i>												1
<i>Nitzschia</i> cf. <i>radicula</i>												1
<i>Nitzschia sigmoidea</i>												1
<i>Nitzschia dissipata</i>												1
<i>Nitzschia obtusa</i>												1
<i>Nitzschia palea</i>						1				1	1	
<i>Nitzschia</i> spp.	1				1		1		1	1	1	1

A 1 indicates presence; a 'blank' indicates absence.

A-15. Algal species on the aluminum ATS™ floway during the study period (2008-2009) at Muddy Run, PA.

Aluminum	Top						Middle						Bottom					
	23-Jul-08	1-Aug-08	13-Aug-08	7-Mar-09	17-Jul-09	9-Oct-09	23-Jul-08	1-Aug-08	13-Aug-08	7-Mar-09	17-Jul-09	9-Oct-09	23-Jul-08	1-Aug-08	13-Aug-08	7-Mar-09	17-Jul-09	9-Oct-09
	Alum_1	Alum_1	Alum_1	Alum_1	Alum_1	Alum_1	Alum_2	Alum_2	Alum_2	Alum_2	Alum_2	Alum_2	Alum_3	Alum_3	Alum_3	Alum_3	Alum_3	Alum_3
Chroococcales																		
<i>Aphanocapsa</i> sp.											1							1
<i>Bacularia vermicularis</i>														1	1			
<i>Chroococcus minor</i>														1				
<i>Chroococcus minutus</i>																		1
<i>Merismopedia tenuissima</i>							1	1										1
<i>Eucapsis parralelepipeton</i>								1										
Oscillatoriales																		
<i>Geitlerinema amphibium</i>		1																
<i>Leibleinia epiphytica</i>		1	1						1					1	1			
<i>Leptolyngbya</i> sp.					1													1
<i>Oscillatoria curviceps</i>						1												1
<i>Oscillatoria princeps</i>				1	1						1		1				1	
<i>Phormidium autumnale</i>		1																
<i>Phormidium interruptum</i>								1										
<i>Phormidium lividum</i>		1												1				
<i>Phormidium retzii</i>				1		1			1	1	1	1	1			1	1	1
<i>Phormidium stagninum</i>					1													
<i>Planktolyngbya brevicellularis</i>														1				
<i>Pseudanabaena galeata</i>	1			1						1				1		1		
<i>Pseudanabaena limnetica</i>																		
Chlorellales																		
<i>Chlorella</i> sp.											1							1
<i>Closteriopsis acicularis</i> var. <i>acicularis</i>																		1
<i>Diacanthos belenophorus</i>											1							
Cladophorales																		
<i>Cladophora glomerata</i>	1	1	1			1					1							

<i>Rhizoclonium hieroglyphicum</i>					1	1	1			1	1	1		
Zygnematales														
<i>Closterium</i> sp.					1									
<i>Cosmarium subtumidum</i> var. <i>subtumidum</i> f. <i>minor</i>												1		
<i>Cosmarium formosulum</i>														1
<i>Cosmarium monomazum</i> var. <i>polymazum</i>														1
<i>Cosmarium</i> sp.		1								1	1			1
<i>Cosmarium vexatum</i> var. <i>lacustre</i>														1
<i>Pediastrum biradiatum</i>														1
<i>Pediastrum boryanum</i>			1	1										1
<i>Pediastrum duplex</i>				1	1	1								1
<i>Pediastrum tetras</i>														1
<i>Spirogyra</i> cf. <i>rivularis</i>	1	1		1	1	1	1	1	1	1	1	1	1	1
<i>Staurastrum alternans</i>														1
Sphaeropleales														
<i>Coelastrum astroideum</i>														1
<i>Coelastrum microporum</i>				1										1
<i>Desmodesmus balatonicus</i>														1
<i>Desmodesmus communis</i>		1		1	1	1	1	1	1	1	1	1	1	1
<i>Desmodesmus gutwinskii</i>							1							
<i>Desmodesmus intermedius</i>														1
<i>Desmodesmus polyspinosus</i>														1
<i>Desmodesmus</i> sp.														1
<i>Gloeocystis</i> sp.														1
<i>Kirchneriella lunaris</i>														1
<i>Monoraphidium arcuatum</i>				1	1									1
<i>Monoraphidium contortum</i>		1												1
<i>Monoraphidium griffithii</i>														1
<i>Pseudocharacium</i> sp.														1
<i>Scenedesmus acuminatus</i>														1
<i>Scenedesmus acutus</i>														1
<i>Scenedesmus alternans</i>														1

<i>Scenedesmus brevispina</i>				1					
<i>Scenedesmus dimorphus</i>					1			1	
<i>Scenedesmus linearis</i>									1
<i>Scenedesmus</i> sp.	1							1	
<i>Schroederia</i> sp.									1
<i>Tetraedron caudatum</i>									
Microsporales									
<i>Microspora floccosa</i>									1
<i>Microspora quadrata</i>								1	1
Oedogoniales									
<i>Bulbochaete</i> sp.								1	
<i>Oedogonium pluvioporum</i>			1	1				1	1
Tetrasporales									
<i>Sphaerocystis schroeteri</i>									1
Chaetophorales									
<i>Stigeoclonium tenue</i>									1
<i>Uronema elongatum</i>	1		1						1
Ulothrichales									
<i>Ulothrix tenerrima</i>									1
<i>Ulothrix variabilis</i>									1
<i>Ulothrix zonata</i>								1	
Euglenales									
<i>Trachelomonas volvocina</i>	1								1
<i>Phacus</i> sp.									1
Thalassiophysales									
<i>Amphora libyca</i>									1
<i>Amphora</i> sp.									1

Aulacoseirales*Aulacoseira granulata*

1

1

Aulacoseira italica

1

Naviculales*Brachysira* sp.

1

Diademsis contenta

1

1

1

1

1

1

1

1

Frustulia sp.

1

1

1

Gyrosigma attenuatum

1

Gyrosigma sp.

1

1

Navicula capitata

1

Navicula drouetiana

1

Navicula hungarica

1

Navicula cryptocephala

1

1

1

1

Navicula gregaria

1

1

1

1

1

1

Navicula lanceolata

1

1

Navicula rhynccephala

1

1

Navicula spp.

1

1

1

1

1

1

1

1

1

1

1

Sellaphora sp.

1

Achnanthes*Cocconeis* sp.

1

1

1

Thalassiosirales*Stephanocyclus meneghiana*

1

1

1

1

1

1

1

1

1

1

Thalassiosira sp.

1

Surirellales*Surirella elegans* f. *elongata*

1

Surirella minuta

1

Surirella sp.

1

1

Cymbellales*Cymbella affine*

1

1

Cymbella cistula

1

A-16. Chi-square tables for dominant taxa at the aluminum flowway at Muddy Run ATS™

Nitzschia spp.	Observed	Expected	(O-E)	Chi-square
Top	11	33	-22	14.67
Middle	44	33	11	3.67
Bottom	44	33	11	3.67
				22.00

Cymbella spp.	Observed	Expected	(O-E)	Chi-square
Top	14	33	-19	10.94
Middle	43	33	10	3.03
Bottom	43	33	10	3.03
				17.00

Diademsis contenta	Observed	Expected	(O-E)	Chi-square
Top	13	33	-20	12.12
Middle	38	33	5	0.76
Bottom	50	33	17	8.76
				21.64

Ulnaria ulna	Observed	Expected	(O-E)	Chi-square
Top	14	33	-19	10.94
Middle	43	33	10	3.03
Bottom	43	33	10	3.03
				17.00

Phormidium retzii	Observed	Expected	(O-E)	Chi-square
Top	20	33	-13	5.12
Middle	40	33	7	1.48
Bottom	40	33	7	1.48
				8.09

Fragilaria capucina	Observed	Expected	(O-E)	Chi-square
Top	29	33	-4	0.48
Middle	43	33	10	3.03
Bottom	29	33	-4	0.48
				4.00

Synedra sp.	Observed	Expected	(O-E)	Chi-square
Top	29	33	-4	0.48
Middle	29	33	-4	0.48
Bottom	43	33	10	3.03
				4.00

<i>Navicula</i> spp.	Observed	Expected	(O-E)	Chi-square
Top	27	33	-6	1.09
Middle	45	33	12	4.36
Bottom	27	33	-6	1.09
				6.55

<i>Rhoicosphenia abbreviata</i>	Observed	Expected	(O-E)	Chi-square
Top	38	33	5	0.76
Middle	50	33	17	8.76
Bottom	13	33	-20	12.12
				21.64

<i>Stephanocyclus meneghiana</i>	Observed	Expected	(O-E)	Chi-square
Top	30	33	-3	0.27
Middle	30	33	-3	0.27
Bottom	40	33	7	1.48
				2.03

<i>Diatoma vulgare</i>	Observed	Expected	(O-E)	Chi-square
Top	33	33	0	0.00
Middle	22	33	-11	3.67
Bottom	44	33	11	3.67
				7.33

<i>Spirogyra</i> cf. <i>rivularis</i>	Observed	Expected	(O-E)	Chi-square
Top	29	33	-4	0.48
Middle	36	33	3	0.27
Bottom	36	33	3	0.27
				1.03

<i>Desmodesmus communis</i>	Observed	Expected	(O-E)	Chi-square
Top	33	33	0	0.00
Middle	33	33	0	0.00
Bottom	33	33	0	0.00
				0.00

<i>Gomphonema truncatum</i>	Observed	Expected	(O-E)	Chi-square
Top	40	33	7	1.48
Middle	30	33	-3	0.27
Bottom	30	33	-3	0.27
				2.03

Melosira varians	Observed	Expected	(O-E)	Chi-square
Top	33	33	0	0.00
Middle	40	33	7	1.48
Bottom	27	33	-6	1.09
				2.58

A-17. Chi-square tables for dominant taxa at the wood floway at Muddy Run ATS™

<i>Oedogonium pluvioporum</i>	Observed	Expected	(O-E)	Chi-square
Top	0	33	-33	33.00
Middle	40	33	7	1.48
Bottom	60	33	27	22.09
				56.58

<i>Cosmarium sp.</i>	Observed	Expected	(O-E)	Chi-square
Top	14	33	-19	10.94
Middle	43	33	10	3.03
Bottom	43	33	10	3.03
				17.00

<i>Diademsis contenta</i>	Observed	Expected	(O-E)	Chi-square
Top	17	33	-16	7.76
Middle	33	33	0	0.00
Bottom	50	33	17	8.76
				16.52

<i>Closterium sp.</i>	Observed	Expected	(O-E)	Chi-square
Top	20	33	-13	5.12
Middle	40	33	7	1.48
Bottom	40	33	7	1.48
				8.09

<i>Pediastrum duplex</i>	Observed	Expected	(O-E)	Chi-square
Top	20	33	-13	5.12
Middle	40	33	7	1.48
Bottom	40	33	7	1.48
				8.09

<i>Gomphonema truncatum</i>	Observed	Expected	(O-E)	Chi-square
Top	22	33	-11	3.67
Middle	33	33	0	0.00
Bottom	44	33	11	3.67
				7.33

<i>Phormidium retzii</i>	Observed	Expected	(O-E)	Chi-square
Top	25	33	-8	1.94
Middle	38	33	5	0.76
Bottom	38	33	5	0.76
				3.45

Monoraphidium arcuatum	Observed	Expected	(O-E)	Chi-square
Top	29	33	-4	0.48
Middle	43	33	10	3.03
Bottom	29	33	-4	0.48
				4.00

Cymbella spp.	Observed	Expected	(O-E)	Chi-square
Top	29	33	-4	0.48
Middle	43	33	10	3.03
Bottom	29	33	-4	0.48
				4.00

Nitzschia spp.	Observed	Expected	(O-E)	Chi-square
Top	29	33	-4	0.48
Middle	29	33	-4	0.48
Bottom	43	33	10	3.03
				4.00

Ulothrix zonata	Observed	Expected	(O-E)	Chi-square
Top	33	33	0	0.00
Middle	33	33	0	0.00
Bottom	33	33	0	0.00
				0.00

Navicula gregaria	Observed	Expected	(O-E)	Chi-square
Top	33	33	0	0.00
Middle	33	33	0	0.00
Bottom	33	33	0	0.00
				0.00

Cladophora glomerata	Observed	Expected	(O-E)	Chi-square
Top	40	33	7	1.48
Middle	40	33	7	1.48
Bottom	20	33	-13	5.12
				8.09

Pediastrum boryanum	Observed	Expected	(O-E)	Chi-square
Top	40	33	7	1.48
Middle	40	33	7	1.48
Bottom	20	33	-13	5.12
				8.09

<i>Monoraphidium contortum</i>	Observed	Expected	(O-E)	Chi-square
Top	40	33	7	1.48
Middle	40	33	7	1.48
Bottom	20	33	-13	5.12
				8.09

<i>Cymbella tumida</i>	Observed	Expected	(O-E)	Chi-square
Top	40	33	7	1.48
Middle	40	33	7	1.48
Bottom	20	33	-13	5.12
				8.09

<i>Navicula cryptocephala</i>	Observed	Expected	(O-E)	Chi-square
Top	40	33	7	1.48
Middle	20	33	-13	5.12
Bottom	40	33	7	1.48
				8.09

<i>Stephanocyclus meneghiana</i>	Observed	Expected	(O-E)	Chi-square
Top	30	33	-3	0.27
Middle	30	33	-3	0.27
Bottom	40	33	7	1.48
				2.03

<i>Fragilaria capucina</i>	Observed	Expected	(O-E)	Chi-square
Top	33	33	0	0.00
Middle	33	33	0	0.00
Bottom	33	33	0	0.00
				0.00

<i>Spirogyra rivularis</i>	Observed	Expected	(O-E)	Chi-square
Top	38	33	5	0.76
Middle	38	33	5	0.76
Bottom	25	33	-8	1.94
				3.45

<i>Leptolyngbya sp.</i>	Observed	Expected	(O-E)	Chi-square
Top	43	33	10	3.03
Middle	43	33	10	3.03
Bottom	14	33	-19	10.94
				17.00

<i>Desmodium communis</i>	Observed	Expected	(O-E)	Chi-square
Top	43	33	10	3.03
Middle	43	33	10	3.03
Bottom	14	33	-19	10.94
				17.00

<i>Synedra</i> sp.	Observed	Expected	(O-E)	Chi-square
Top	33	33	0	0.00
Middle	22	33	-11	3.67
Bottom	44	33	11	3.67
				7.33

<i>Navicula</i> spp.	Observed	Expected	(O-E)	Chi-square
Top	43	33	10	3.03
Middle	29	33	-4	0.48
Bottom	29	33	-4	0.48
				4.00

<i>Melosira varians</i>	Observed	Expected	(O-E)	Chi-square
Top	36	33	3	0.27
Middle	27	33	-6	1.09
Bottom	36	33	3	0.27
				1.64

<i>Diatoma vulgare</i>	Observed	Expected	(O-E)	Chi-square
Top	40	33	7	1.48
Middle	30	33	-3	0.27
Bottom	30	33	-3	0.27
				2.03

<i>Ulnaria ulna</i>	Observed	Expected	(O-E)	Chi-square
Top	40	33	7	1.48
Middle	30	33	-3	0.27
Bottom	30	33	-3	0.27
				2.03

A-18. Percent (%) of nitrogen (N) and phosphorus (P) in the biomass at different sections of the aluminum
 ATS™ at Muddy Run.

Date	<u>Nitrogen</u>				<u>Phosphorus</u>				
	Repl. 1	Repl. 2	Mean	Std dev	Repl. 1	Repl. 2	Mean	Std dev	
28-Jul-08									
Top	2.64	2.55	2.60	0.06	0.35	0.36	0.36	0.01	
Mid	2.42	2.50	2.46	0.06	0.28	0.25	0.27	0.02	
Bot	1.74	1.64	1.69	0.07	0.13	0.13	0.13	0.00	
Mean			2.25	0.06			0.25	0.01	
6-Aug-08									
Top	2.81	2.87	2.84	0.04	0.37	0.36	0.37	0.01	
Mid	2.81	2.59	2.70	0.16	0.24	0.24	0.24	0.00	
Bot	1.96	1.75	1.86	0.15	0.15	0.14	0.15	0.01	
Mean			2.47	0.12			0.25	0.00	
16-Aug-08									
Top	3.05	2.89	2.97	0.11	0.31	0.29	0.30	0.01	
Mid	2.79	2.77	2.78	0.01	0.24	0.22	0.23	0.01	
Bot	2.31	1.96	2.14	0.25	0.18	0.16	0.17	0.01	
Mean			2.63	0.12			0.23	0.01	
12-May-09									
Top	1.75	1.41	1.58	0.24	0.21	0.18	0.20	0.02	
Mid	1.44	1.97	1.71	0.37	0.22	0.22	0.22	0.00	
Bot	1.89	2.02	1.96	0.09	0.21	0.23	0.22	0.01	
Mean			1.75	0.24			0.21	0.01	
21-May-09									
Top	1.79	1.67	1.73	0.08	0.16	0.17	0.17	0.01	
Mid	1.68	1.73	1.71	0.04	0.18	0.20	0.19	0.01	
Bot	1.98	2.19	2.09	0.15	0.21	0.20	0.21	0.01	
Mean			1.84	0.09			0.19	0.01	
12-Jun-09									
Top	1.96	1.82	1.89	0.10	0.17	0.18	0.18	0.01	
Mid	1.66	1.79	1.73	0.09	0.17	0.18	0.18	0.01	
Bot	1.81	1.64	1.73	0.12	0.18	0.20	0.19	0.01	
Mean			1.78	0.10			0.18	0.01	
26-Jun-09									
Top	2.56	2.60	2.58	0.03	0.25	0.27	0.26	0.01	
Mid	2.42	2.41	2.42	0.01	0.25	0.26	0.26	0.01	
Bot	2.63	2.83	2.73	0.14	0.25	0.23	0.24	0.01	

Mean			2.58	0.06			0.25	0.01
10-Jul-09								
Top	2.61	2.14	2.38	0.33	0.21	0.20	0.21	0.01
Mid	2.33	2.78	2.56	0.32	0.20	0.19	0.20	0.01
Bot	2.51	2.64	2.58	0.09	0.20	0.19	0.20	0.01
Mean			2.50	0.25			0.20	0.01
17-Jul-09								
Top	2.42	2.09	2.26	0.23	0.26	0.24	0.25	0.01
Mid	2.12	2.30	2.21	0.13	0.21	0.20	0.21	0.01
Bot	2.68	2.45	2.57	0.16	0.21	0.19	0.20	0.01
Mean			2.34	0.17			0.22	0.01
31-Jul-09								
Top	2.68	2.67	2.68	0.01	0.28	0.28	0.28	0.00
Mid	2.41	2.69	2.55	0.20	0.25	0.24	0.25	0.01
Bot	1.25	1.79	1.52	0.38	0.14	0.16	0.15	0.01
Mean			2.25	0.20			0.23	0.01
14-Aug-09								
Top	1.64	1.78	1.71	0.10	0.20	0.22	0.21	0.01
Mid	1.48	2.00	1.74	0.37	0.21	0.23	0.22	0.01
Bot	2.72	2.62	2.67	0.07	0.30	0.27	0.29	0.02
Mean			2.04	0.18			0.24	0.02
28-Aug-09								
Top	2.55	1.83	2.19	0.51	0.27	0.22	0.25	0.04
Mid	2.96	3.17	3.07	0.15	0.28	0.33	0.31	0.04
Bot	3.61	3.34	3.48	0.19	0.38	0.32	0.35	0.04
Mean			2.91	0.28			0.30	0.04
17-Sep-09								
Top	2.21	2.14	2.18	0.05	0.25	0.27	0.26	0.01
Mid	2.12	2.38	2.25	0.18	0.33	0.34	0.34	0.01
Bot	2.40	2.53	2.47	0.09	0.35	0.36	0.36	0.01
Mean			2.30	0.11			0.32	0.01
26-Sep-09								
Top	2.46	2.26	2.36	0.14	0.27	0.28	0.28	0.01
Mid	2.68	2.68	2.68	0.00	0.34	0.32	0.33	0.01
Bot	3.02	3.18	3.10	0.11	0.30	0.31	0.31	0.01
Mean			2.71	0.08			0.30	0.01
29-Oct-09								
Top	2.08	1.95	2.02	0.09	0.27	0.27	0.27	0.00

Mid	1.76	1.90	1.83	0.10	0.30	0.29	0.30	0.01
Bot	2.33	2.48	2.41	0.11	0.36	0.37	0.37	0.01
Mean			2.08	0.10			0.31	0.00

A-19. Mass nutrient uptake (grams of N or P/m²/day) for the aluminum ATS™ floway at Muddy Run.

Date	Nitrogen				Phosphorus			
	Repl. 1	Repl. 2	Mean	Std dev	Repl. 1	Repl. 2	Mean	Std dev
28-Jul-08								
Top	0.414	0.405	0.410	0.006	0.055	0.057	0.056	0.002
Mid	0.508	0.498	0.503	0.007	0.059	0.050	0.054	0.006
Bot	0.479	0.284	0.382	0.138	0.036	0.023	0.029	0.009
Mean			0.431	0.050			0.046	0.006
6-Aug-08								
Top	0.318	0.284	0.301	0.024	0.042	0.036	0.039	0.004
Mid	0.216	0.241	0.229	0.018	0.019	0.022	0.020	0.003
Bot	0.208	0.203	0.206	0.004	0.016	0.016	0.016	0.000
Mean			0.245	0.015			0.025	0.002
16-Aug-08								
Top	0.329	0.324	0.327	0.004	0.034	0.035	0.034	0.001
Mid	0.282	0.271	0.277	0.008	0.024	0.022	0.023	0.002
Bot	0.249	0.186	0.218	0.045	0.019	0.015	0.017	0.003
Mean			0.274	0.019			0.025	0.002
12-May-09								
Top	0.084	0.090	0.087	0.004	0.010	0.012	0.011	0.001
Mid	0.050	0.108	0.079	0.041	0.008	0.012	0.010	0.003
Bot	0.034	0.034	0.034	0.000	0.004	0.004	0.004	0.000
Mean			0.067	0.015			0.008	0.001
21-May-09								
Top	0.091	0.100	0.096	0.006	0.008	0.010	0.009	0.001
Mid	0.109	0.052	0.080	0.040	0.012	0.005	0.009	0.004
Bot	0.061	0.022	0.042	0.028	0.007	0.002	0.004	0.003
Mean			0.073	0.025			0.007	0.003
12-Jun-09								
Top	0.127	0.075	0.101	0.037	0.011	0.007	0.009	0.003
Mid	0.060	0.064	0.062	0.003	0.006	0.007	0.006	0.000
Bot	0.049	0.033	0.041	0.011	0.005	0.004	0.004	0.001
Mean			0.068	0.017			0.007	0.001
26-Jun-09								
Top	0.520	0.575	0.548	0.039	0.051	0.060	0.055	0.007
Mid	0.380	0.337	0.359	0.030	0.039	0.036	0.038	0.002
Bot	0.157	0.133	0.145	0.017	0.016	0.016	0.016	0.000
Mean			0.350	0.029			0.036	0.003
10-Jul-09								
Top	0.347	0.276	0.312	0.050	0.028	0.026	0.027	0.001
Mid	0.238	0.256	0.247	0.013	0.020	0.017	0.019	0.002
Bot	0.171	0.116	0.144	0.039	0.014	0.008	0.011	0.004
Mean			0.234	0.034			0.019	0.002

17-Jul-09									
Top	0.482	0.378	0.430	0.074	0.052	0.043	0.048	0.006	
Mid	0.248	0.267	0.258	0.013	0.025	0.023	0.024	0.001	
Bot	0.239	0.228	0.234	0.008	0.019	0.018	0.018	0.001	
Mean			0.307	0.032			0.030	0.003	
31-Jul-09									
Top	0.437	0.417	0.427	0.014	0.046	0.044	0.045	0.001	
Mid	0.321	0.307	0.314	0.010	0.033	0.027	0.030	0.004	
Bot	0.141	0.193	0.167	0.037	0.016	0.017	0.017	0.001	
Mean			0.303	0.020			0.031	0.002	
14-Aug-09									
Top	0.151	0.093	0.122	0.041	0.018	0.011	0.015	0.005	
Mid	0.123	0.210	0.167	0.062	0.017	0.024	0.021	0.005	
Bot	0.220	0.241	0.231	0.015	0.024	0.025	0.025	0.000	
Mean			0.173	0.039			0.020	0.003	
28-Aug-09									
Top	0.153	0.137	0.145	0.011	0.016	0.017	0.016	0.000	
Mid	0.089	0.105	0.097	0.011	0.008	0.011	0.010	0.002	
Bot	0.173	0.130	0.152	0.030	0.018	0.013	0.015	0.004	
Mean			0.131	0.018			0.014	0.002	
17-Sep-09									
Top	0.177	0.182	0.180	0.004	0.020	0.023	0.022	0.002	
Mid	0.131	0.209	0.170	0.055	0.021	0.030	0.025	0.007	
Bot	0.250	0.258	0.254	0.006	0.036	0.037	0.037	0.000	
Mean			0.201	0.021			0.028	0.003	
26-Sep-09									
Top	0.175	0.237	0.206	0.044	0.019	0.029	0.024	0.007	
Mid	0.126	0.257	0.192	0.093	0.016	0.031	0.023	0.010	
Bot	0.356	0.340	0.348	0.011	0.035	0.033	0.034	0.002	
Mean			0.248	0.049			0.027	0.006	
29-Oct-09									
Top	0.031	0.033	0.032	0.001	0.004	0.005	0.004	0.000	
Mid	0.018	0.017	0.017	0.000	0.003	0.003	0.003	0.000	
Bot	0.044	0.030	0.037	0.010	0.007	0.004	0.006	0.002	
Mean			0.029	0.004			0.004	0.001	

A-20. Percent (%) of nitrogen (N) and phosphorus (P) in the biomass at different sections of the wood
 ATS™ at Muddy Run.

Date	<u>Nitrogen</u>				<u>Phosphorus</u>			
	Repl. 1	Repl. 2	Mean	Std dev	Repl. 1	Repl. 2	Mean	Std dev
12-May-09								
Top	1.45	1.29	1.37	0.11	0.20	0.19	0.20	0.01
Mid	1.99	1.86	1.93	0.09	0.25	0.19	0.22	0.04
Bot	2.34	1.83	2.09	0.36	0.21	0.20	0.21	0.01
Mean			1.79	0.19			0.21	0.02
21-May-09								
Top	1.69	1.69	1.69	0.00	0.18	0.19	0.19	0.01
Mid	2.46	1.86	2.16	0.42	0.20	0.17	0.19	0.02
Bot	2.81	2.17	2.49	0.45	0.23	0.20	0.22	0.02
Mean			2.11	0.29			0.20	0.02
12-Jun-09								
Top	2.11	2.49	2.30	0.27	0.25	0.30	0.28	0.04
Mid	2.71	2.41	2.56	0.21	0.24	0.26	0.25	0.01
Bot	2.92	2.90	2.91	0.01	0.26	0.29	0.28	0.02
Mean			2.59	0.16			0.27	0.02
26-Jun-09								
Top	2.72	2.83	2.78	0.08	0.24	0.25	0.25	0.01
Mid	3.36	3.18	3.27	0.13	0.22	0.21	0.22	0.01
Bot	3.68	3.29	3.49	0.28	0.24	0.30	0.27	0.04
Mean			3.18	0.16			0.24	0.02
10-Jul-09								
Top	2.40	2.70	2.55	0.21	0.20	0.20	0.20	0.00
Mid	2.56	2.69	2.63	0.09	0.20	0.21	0.21	0.01
Bot	2.94	2.65	2.80	0.21	0.21	0.22	0.22	0.01
Mean			2.66	0.17			0.21	0.00
17-Jul-09								
Top	2.62	2.19	2.41	0.30	0.22	0.23	0.23	0.01
Mid	2.96	3.01	2.99	0.04	0.21	0.20	0.21	0.01
Bot	2.94	2.65	2.80	0.21	0.21	0.22	0.22	0.01
Mean			2.73	0.18			0.22	0.01
31-Jul-09								
Top	2.15	2.56	2.36	0.29	0.23	0.27	0.25	0.03
Mid	3.37	3.26	3.32	0.08	0.30	0.28	0.29	0.01
Bot	2.82	2.78	2.80	0.03	0.18	0.19	0.19	0.01
Mean			2.82	0.13			0.24	0.02
14-Aug-09								
Top	1.83	1.94	1.89	0.08	0.21	0.22	0.22	0.01
Mid	2.57	2.11	2.34	0.33	0.25	0.22	0.24	0.02
Bot	2.16	2.68	2.42	0.37	0.21	0.26	0.24	0.04

Mean			2.22	0.26			0.23	0.02
28-Aug-09								
Top	2.70	2.57	2.64	0.09	0.24	0.24	0.24	0.00
Mid	3.29	2.89	3.09	0.28	0.36	0.24	0.30	0.08
Bot	3.61	3.96	3.79	0.25	0.26	0.33	0.30	0.05
Mean			3.17	0.21			0.28	0.04
17-Sep-09								
Top	2.46	1.91	2.19	0.39	0.29	0.23	0.26	0.04
Mid	2.88	2.52	2.70	0.25	0.31	0.35	0.33	0.03
Bot	3.33	2.41	2.87	0.65	0.34	0.27	0.31	0.05
Mean			2.59	0.43			0.30	0.04
26-Sep-09								
Top	2.25	1.90	2.08	0.25	0.23	0.24	0.24	0.01
Mid	2.92	2.77	2.85	0.11	0.28	0.26	0.27	0.01
Bot	3.36	3.33	3.35	0.02	0.28	0.32	0.30	0.03
Mean			2.76	0.12			0.27	0.02
29-Oct-09								
Top	1.98	1.84	1.91	0.10	0.28	0.27	0.28	0.01
Mid	2.44	2.50	2.47	0.04	0.29	0.27	0.28	0.01
Bot	2.74	2.80	2.77	0.04	0.32	0.38	0.35	0.04
Mean			2.38	0.06			0.30	0.02

A-21. Mass nutrient uptake (grams of N or P/m²/day) for the wood ATS™ floway at Muddy Run.

Date	<u>Nitrogen</u>				<u>Phosphorus</u>			
	Repl. 1	Repl. 2	Mean	Std dev	Repl. 1	Repl. 2	Mean	Std dev
12-May-09								
Top	0.007	0.003	0.005	0.003	0.001	0.000	0.001	0.000
Mid	0.006	0.009	0.008	0.002	0.001	0.001	0.001	0.000
Bot	0.009	0.007	0.008	0.001	0.001	0.001	0.001	0.000
Mean			0.007	0.002			0.001	0.000
21-May-09								
Top	0.002	0.012	0.007	0.007	0.000	0.001	0.001	0.001
Mid	0.007	0.011	0.009	0.003	0.001	0.001	0.001	0.000
Bot	0.020	0.013	0.016	0.005	0.002	0.001	0.001	0.000
Mean			0.011	0.005			0.001	0.000
12-Jun-09								
Top	0.032	0.017	0.025	0.010	0.004	0.002	0.003	0.001
Mid	0.171	0.108	0.140	0.045	0.015	0.012	0.014	0.002
Bot	0.093	0.084	0.089	0.007	0.008	0.008	0.008	0.000
Mean			0.084	0.020			0.008	0.001
26-Jun-09								
Top	0.177	0.113	0.145	0.045	0.016	0.010	0.013	0.004
Mid	0.323	0.283	0.303	0.028	0.021	0.019	0.020	0.002
Bot	0.166	0.158	0.162	0.006	0.011	0.014	0.013	0.003
Mean			0.203	0.026			0.015	0.003
10-Jul-09								
Top	0.130	0.130	0.130	0.000	0.011	0.010	0.010	0.001
Mid	0.197	0.239	0.218	0.030	0.015	0.019	0.017	0.002
Bot	0.132	0.233	0.183	0.071	0.010	0.019	0.014	0.007
Mean			0.177	0.034			0.014	0.003
17-Jul-09								
Top	0.178	0.099	0.138	0.056	0.015	0.010	0.013	0.003
Mid	0.246	0.259	0.253	0.009	0.017	0.017	0.017	0.000
Bot	0.162	0.249	0.206	0.062	0.012	0.021	0.016	0.006
Mean			0.199	0.042			0.015	0.003
31-Jul-09								
Top	0.056	0.059	0.057	0.002	0.006	0.006	0.006	0.000
Mid	0.256	0.140	0.198	0.082	0.023	0.012	0.017	0.008
Bot	0.130	0.181	0.155	0.036	0.008	0.012	0.010	0.003
Mean			0.137	0.040			0.011	0.004
14-Aug-09								
Top	0.064	0.052	0.058	0.008	0.007	0.006	0.007	0.001
Mid	0.147	0.091	0.119	0.039	0.014	0.010	0.012	0.003
Bot	0.136	0.097	0.116	0.028	0.013	0.009	0.011	0.003
Mean			0.098	0.025			0.010	0.002

28-Aug-09									
Top	0.035	0.064	0.050	0.021	0.003	0.006	0.005	0.002	
Mid	0.211	0.090	0.150	0.086	0.023	0.007	0.015	0.011	
Bot	0.090	0.111	0.101	0.015	0.007	0.009	0.008	0.002	
Mean			0.100	0.040			0.009	0.005	
17-Sep-09									
Top	0.118	0.126	0.122	0.006	0.014	0.015	0.015	0.001	
Mid	0.050	0.043	0.046	0.005	0.005	0.006	0.005	0.000	
Bot	0.047	0.089	0.068	0.030	0.005	0.010	0.007	0.004	
Mean			0.079	0.014			0.009	0.002	
26-Sep-09									
Top	0.117	0.148	0.133	0.022	0.012	0.019	0.015	0.005	
Mid	0.137	0.072	0.105	0.046	0.013	0.007	0.010	0.005	
Bot	0.134	0.190	0.162	0.039	0.011	0.018	0.015	0.005	
Mean			0.133	0.036			0.013	0.005	
29-Oct-09									
Top	0.055	0.053	0.054	0.001	0.008	0.008	0.008	0.000	
Mid	0.046	0.045	0.046	0.001	0.006	0.005	0.005	0.000	
Bot	0.063	0.092	0.078	0.021	0.007	0.013	0.010	0.004	
Mean			0.059	0.008			0.008	0.001	

A-22. Permutation-based nonparametric MANOVA calculated with the method of Anderson (2001) on the top (Level 1), middle (Level 2), and bottom (Level 3) sections of algal community at Muddy Run.

Groups were defined by values of: Setor

Main matrix has: 30 Linhas by 31 Colunas

Distance measure = Euclidean (Pythagorean)

Evaluation of differences in Colunas between groups.

Design: One-way

Randomization test of significance of pseudo F values

Number of randomizations: 4999

Random number seed: 3635 selected by time.

Source	d.f.	SS	MS	F	p *
Setor	2	27.600	13.800	2.2943	0.003000
Residual	27	162.40	6.0148		
Total	29	190.00			

Statistics from randomizations

Source	F Observed	F from randomized groups			Number > or = observed F	p *
		Mean	Maximum	S.Dev		
Setor	2.29433	1.01067	2.75475	0.00211	14	0.003000

* proportion of randomized trials with indicator value equal to or exceeding the observed indicator value.

$$p = (1 + \text{number of runs} \geq \text{observed}) / (1 + \text{number of randomized runs})$$

Variance components estimated for random effects model (Model II)

Ignore variance components if you consider the factor to have fixed effects.

COMPONENTS OF VARIANCE

Source	Variance	% of variation
Setor	0.77852	11.460
Residual	6.0148	88.540
Total	6.7933	100.000

Setor has 3 levels.

PAIRWISE COMPARISONS for factor Setor

Note: p values are not corrected for multiple comparisons.

Level vs. Level	t	p
1 vs. 2	1.1591	0.177200
1 vs. 3	2.0896	0.000200
2 vs. 3	1.1308	0.196200

A-23. List of taxa and their botanical authority according to Algaebase.org.

Taxon	Authority
<i>Achnanthes brevipes</i>	Agardh
<i>Achnanthes</i> sp.	Bory de Saint-Vincent
<i>Achnantheidium minutissimum</i>	(Kützing) Czarnecki
<i>Achrochaete</i> sp.	Pringsheim
<i>Actinocyclus octonarius</i>	Ehrenberg
<i>Actinocyclus subtilis</i>	(W.Gregory) Ralfs
<i>Actinoptychus senarius</i>	(Ehrenberg) Ehrenberg
<i>Acutodesmus acuminatus</i>	(Lagerheim) Tsarenko
<i>Acutodesmus obliquus</i>	(Turpin) Hegewald & Hanagata
<i>Adlafia drouetiana</i>	(R.Patrick) D.Metzeltin & Lange-Bertalot
<i>Alexandrium</i> sp.	Halim
<i>Amphipleura</i> sp.	Kützing
<i>Amphora libyca</i>	Ehrenberg
<i>Amphora</i> cf. <i>pediculus</i>	(Kützing) Grunow ex A.Schmidt
<i>Amphora ovalis</i>	(Kützing) Kützing
<i>Amphora</i> sp.	Ehrenberg ex Kützing
<i>Anaulus</i> sp.	Ehrenberg
<i>Aphanocapsa holsatica</i>	(Lemmermann) Cronberg & Komárek
<i>Aphanocapsa rivularis</i>	(Carmichael) Rabenhorst
<i>Aphanocapsa</i> sp.	Nägeli
<i>Aphanothece minutissima</i>	(West) Komárková-Legnerová & Cronberg
<i>Aphanothece</i> sp.	Nägeli
<i>Asterionellopsis</i> sp.	Round in F.E. Round, R.M. Crawford & D.G. Mann
<i>Asterocapsa</i> sp.	Chu
<i>Aulacoseira granulata</i>	(Ehrenberg) Simonsen
<i>Aulacoseira italica</i>	(Ehrenberg) Simonsen
<i>Auliscus</i> cf. <i>sculptus</i>	(W. Smith) Brightwell
<i>Auliscus</i> sp.	Ehrenberg
<i>Bacillaria paxillefer</i>	(O.F.Müller) T.Marsson
<i>Bacteriastrum</i> sp.	Shadbolt
<i>Bacularia vermicularis</i>	(Federov) Komárek & Anagnostidis
<i>Berkeleya fennica</i>	Juhlin-Dannfelt
<i>Berkeleya fragilis</i>	Greville
<i>Berkeleya rutilans</i>	(Trentepohl ex Roth) Grunow
<i>Brachysira brebissonii</i>	R.Ross
<i>Bulbochaete</i> sp.	Agardh
<i>Caloneis aemula</i>	Schultz
<i>Caloneis</i> sp.	P.Cleve
<i>Calothrix</i> sp.	Agardh ex Bornet & Flahault
<i>Campylodiscus</i> sp.	Ehrenberg ex Kützing
<i>Catenula</i> sp.	Mereschkowsky
<i>Ceramium</i> sp.	Roth
<i>Ceratium</i> sp.	Schrank
<i>Chaetoceros aequatorialis</i>	Cleve
<i>Chaetoceros compressus</i>	Lauder
<i>Chaetoceros danicus</i>	Cleve
<i>Chaetoceros deciepens</i>	Cleve

<i>Chaetoceros lorenzianus</i>	Grunow
<i>Chaetoceros</i> sp.	Ehrenberg
<i>Chlamydomonas</i> sp.	Ehrenberg
<i>Chlorella</i> sp.	Beijerinck
<i>Chromulina</i> sp.	Cienkowski
<i>Chroococcus minor</i>	(Kützing) Nägeli
<i>Chroococcus minutus</i>	(Kützing) Nägeli
<i>Chroococcus</i> sp.	Nägeli
<i>Cladophora glomerata</i>	(Linnaeus) Kützing
<i>Cladophora</i> sp.	Kützing
<i>Closteriopsis acicularis</i>	(Chodat) Belcher & Swale
<i>Closterium</i> cf. <i>sublaterale</i>	Ruzicka
<i>Closterium</i> sp.	Nitzsch ex Ralfs
<i>Cocconeis placentula</i>	Ehrenberg
<i>Cocconeis</i> sp.	Ehrenberg
<i>Coelastrum astroideum</i>	De Notaris
<i>Coelastrum microporum</i>	Nägeli
<i>Coelastrum pulchrum</i>	Schmidle
<i>Colponema</i> sp.	Stein
<i>Coscinodiscus radiatus</i>	Ehrenberg
<i>Coscinodiscus</i> sp.	Ehrenberg
<i>Cosmarium formosulum</i>	Hoff
<i>Cosmarium</i> cf. <i>margaritatum</i>	(Lundell) Roy & Bisset
<i>Cosmarium monomazum</i> var. <i>polymazum</i>	Lundell
<i>Cosmarium perforatum</i>	Lundell
<i>Cosmarium</i> cf. <i>pseudoconnatum</i>	Nordstedt
<i>Cosmarium</i> cf. <i>pseudoexiguum</i>	Raciborski
<i>Cosmarium</i> cf. <i>subtumidum</i>	Nordstedt
<i>Cosmarium</i> cf. <i>trilobulatum</i>	Reinsch
<i>Cosmarium vexatum</i> var. <i>lacustre</i>	Messikommer
<i>Cosmarium</i> sp.	Corda ex Ralfs
<i>Ctenophora</i> sp.	(Grunow) D.M.Williams & Round
<i>Cyanobium</i> sp.	Rippka & Cohen-Bazire
<i>Cyanodictyon</i> sp.	Pascher
<i>Cyanosarcina</i> sp.	Kováčik
<i>Cyclotella</i> cf. <i>caspia</i>	Grunow
<i>Cylindrocapsa</i> sp.	Reinsch
<i>Cylindrotheca closterium</i>	(Ehrenberg) Reimann & J.C.Lewin
<i>Cymatopleura solea</i>	(Brébisson) W.Smith
<i>Cymatosira</i> sp.	Grunow
<i>Cymbella</i> cf. <i>affinis</i>	Kützing
<i>Cymbella cistula</i>	(Hemprich & Ehrenberg) O.Kirchner
<i>Cymbella</i> cf. <i>parva</i>	(W.Smith) Cleve
<i>Cymbella lanceolata</i>	Kirchner
<i>Cymbella leptoceros</i>	(Ehrenberg) Kützing
<i>Cymbella tumida</i>	(Brébisson) van Heurck
<i>Cymbella</i> sp.	Agardh
<i>Cymbellonitzschia</i> sp.	Hustedt in A. schmidt
<i>Cymbopleura</i> sp.	(K.Krammer) K.Krammer
<i>Dactyliosolen</i> sp.	Castracane

<i>Delphineis</i> sp.	G.W.Andrews
<i>Denticula</i> sp.	Kützing
<i>Desmodesmus communis</i>	(Hegewald) Hegewald
<i>Desmodesmus denticulatus</i>	(Lagerheim) An, Friedl & Hegewald
<i>Desmodesmus granulatus</i>	(West & West) Hentschke & Torgan
<i>Desmodesmus intermedius</i>	(Chodat) Hegewald
<i>Desmodesmus opoliensis</i>	(Richter) Hegewald
<i>Desmodesmus polyspinosus</i>	(Hortobágyi) Hegewald
<i>Desmodesmus</i> sp.	(Chodat) An, Friedl & Hegewald
<i>Diacanthos belenophorus</i>	Korshikov
<i>Diademsis</i> cf. <i>contenta</i>	(Grunow ex Van Heurck) Mann
<i>Diatoma ehrenbergii</i>	Kützing
<i>Diatoma</i> cf. <i>mesodon</i>	(Ehrenberg) Kützing
<i>Diatoma monoliformis</i>	Kützing
<i>Diatoma tenuis</i>	C.Agardh
<i>Diatoma vulgaris</i>	Bory de Saint-Vincent C
<i>Dimeregramma minor</i>	(Gregory) Ralfs ex Pritchard
<i>Dinophysis</i> sp.	Ehrenberg
<i>Diploneis</i> sp.	Ehrenberg ex Cleve
<i>Ditylum brightwellii</i>	(T.West) Grunow
<i>Encyonema</i> cf. <i>caespitosum</i>	Kützing
<i>Encyonema</i> cf. <i>gracile</i>	Ehrenberg
<i>Encyonema minutum</i>	(Hilse) D.G.Mann
<i>Encyonema prostratum</i>	(Berkeley) Kützing
<i>Encyonema</i> sp.	Kützing
<i>Entomoneis</i> sp.	Ehrenberg
<i>Epithemia</i> sp.	Kützing
<i>Euastrum sublobatum</i>	Brébisson ex Ralfs
<i>Eucampia</i> sp.	Ehrenberg
<i>Eucapsis carpatica</i>	Komárek & Hindák
<i>Eucapsis parallelepipedon</i>	(Schmidle) Komárek & Hindák
<i>Euglena</i> sp.	Ehrenberg
<i>Eunotia</i> sp.	Ehrenberg
<i>Eunotogramma laevis</i>	Grunow
<i>Fallacia</i> sp.	Stickle & D.G.Mann
<i>Fogedia</i> sp.	A.Witkowski, Lange-Bertalot, D.Metzeltin & G.Bafana
<i>Fragilaria capucina</i>	Desmazières
<i>Fragilaria capucina</i> var. <i>vaucheriae</i>	(Kützing) Lange-Bertalot
<i>Fragilaria pulchella</i> var. <i>constricta</i>	(B.Liebetanz) Witkowski
<i>Fragilaria</i> sp.	Lyngbye
<i>Fragilariopsis</i> sp.	Hustedt in Schmidt
<i>Frustulia vulgaris</i>	(Thwaites) De Toni
<i>Frustulia rhomboides</i>	(Ehrenberg) De Toni
<i>Frustulia</i> sp.	Rabenhorst
<i>Geitlerinema amphibium</i>	(Agardh ex Gomont) Anagnostidis
<i>Geitlerinema</i> sp.	(Anagnostidis & Komárek) Anagnostidis
<i>Gloeocystis</i> sp.	Nägeli
<i>Gloeotheca</i> sp.	Nägeli
<i>Gomphoneis</i> cf. <i>minuta</i>	(Stone) Kociolek & Stoermer
<i>Gomphonema</i> cf. <i>angustatum</i>	(Kützing) Rabenhorst

<i>Gomphonema cf. brasiliense</i>	Grunow
<i>Gomphonema capitatum</i>	Ehrenberg
<i>Gomphonema cf. hastatum</i>	(Wislouch) Lange-Bertalot & Reichardt
<i>Gomphonema olivaceum</i>	(Hornemann) Brébisson
<i>Gomphonema truncatum</i>	Ehrenberg
<i>Gomphonema sp.</i>	Ehrenberg
<i>Grammatophora sp.</i>	Ehrenberg
<i>Guinardia flaccida</i>	(Castracane) H.Peragallo
<i>Gyrodinium sp.</i>	Kofoid & Swezy
<i>Gyrosigma cf. attenuatum</i>	(Kützing) Rabenhorst
<i>Gyrosigma fasciola</i>	(Ehrenberg) J.W.Griffith & Henfrey
<i>Gyrosigma sp.</i>	(Ehrenberg) J.W.Griffith & Henfrey
<i>Hantzschia sp.</i>	Grunow
<i>Haslea sp.</i>	Simonsen
<i>Hippodonta capitata</i>	(Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski
<i>Hippodonta cf. hungarica</i>	(Grunow) Lange-Bertalot, Metzeltin & Witkowski
<i>Hippodonta sp.</i>	Lange-Bertalot, Witkowski & Metzeltin
<i>Hydrodictyon reticulatum</i>	(Linnaeus) Bory de Saint-Vincent
<i>Jaaginema sp.</i>	Anagnostidis & Komárek
<i>Johannesbaptista pellucida</i>	(Dickie) Taylor & Drouet
cf. <i>Katodinium sp.</i>	Fott
<i>Kirchneriella lunaris</i>	(Kirchneer) Möbius
<i>Lagerheimia genevensis</i>	(Chodat) Chodat
<i>Leibleinia epiphytica</i>	(Hieronymus) Compère
<i>Lepocinclis globulus</i>	Perty
<i>Leptocylindrus danicus</i>	Cleve
<i>Leptocylindrus minimus</i>	Gran
<i>Leptolyngbya boryana</i>	(Gomont) Anagnostidis & Komárek
<i>Leptolyngbya subtilis</i>	(West) Anagnostidis
<i>Leptolyngbya sp.</i>	Anagnostidis & Komárek
<i>Licmophora sp.</i>	Agardh
<i>Lunella sp.</i>	P.Snoeijs
<i>Luticola sp.</i>	D.G.Mann in F.E. Round, R.M. Crawford & D.G. Mann
<i>Lyngbya salina</i>	Gomont
<i>Lyrella sp.</i>	Karajeva
<i>Martyana martyi</i>	(Héribaud-Joseph) Round
<i>Mastogloia sp.</i>	Thwaites ex W.Smith
<i>Melosira moniliformes</i>	(O.F.Müller) C.Agardh
<i>Melosira nummuloides</i>	Agardh
<i>Melosira varians</i>	Agardh
<i>Meridion circulare</i>	(Greville) C.Agardh
<i>Merismopedia tenuissima</i>	Lemmermann
<i>Meuniera membranacea</i>	(Cleve) P.C.Silva
<i>Meuniera sp.</i>	P.C.Silva
<i>Microspora floccosa</i>	(Vaucher) Thuret
<i>Microspora quadrata</i>	Hazen
<i>Microspora wittrockii</i>	(Wille) Lagerheim
<i>Minidiscus sp.</i>	Hasle
<i>Monactinus simplex</i>	(Meyen) Corda
<i>Monoraphidium arcuatum</i>	(Korshikov) Hindák

<i>Monoraphidium contortum</i>	(Thuret) Komárková-Legnerová
<i>Monoraphidium griffithii</i>	(Berkeley) Komárková-Legnerová
<i>Navicula arenaria</i> var. <i>rostellata</i>	Lange-Bertalot
<i>Navicula bottnica</i>	Grunow
<i>Navicula capitoradiata</i>	Germain
<i>Navicula celinei</i>	A.Witkowski, D.Metzeltin & Lange-Bertalot
<i>Navicula cryptocephala</i>	Kützing
<i>Navicula duerrenbergiana</i>	Hustedt
<i>Navicula</i> cf. <i>fonticola</i>	Grunow
<i>Navicula gregaria</i>	Donkin
<i>Navicula</i> cf. <i>margalithii</i>	Lange-Bertalot
<i>Navicula lanceolata</i>	Ehrenberg
<i>Navicula rhynccephala</i>	Kützing
<i>Navicula vaneei</i>	Lange-Bertalot
<i>Navicula</i> sp.	Bory de Saint-Vincent
<i>Neidium</i> sp.	Pfitzer
<i>Neocalyptrella robusta</i>	(G.Norman ex Ralfs) Hernández-Becerril & Meave del Castillo
<i>Neodelphineis</i> sp.	Takano
<i>Netrium</i> sp.	(Nägeli) Itzigsohn & Rothe in Rabenhorst
<i>Nitzschia acicularis</i>	(Kützing) W.Smith
<i>Nitzschia</i> cf. <i>agnita</i>	Hustedt
<i>Nitzschia amphibia</i>	Grunow
<i>Nitzschia angustatula</i>	Lange-Bertalot
<i>Nitzschia brevissima</i>	Grunow
<i>Nitzschia dissipata</i>	(Kützing) Rabenhorst
<i>Nitzschia draveillensis</i>	Coste & Ricard
<i>Nitzschia fasciculata</i>	(Grunow) Grunow
<i>Nitzschia filiformis</i>	(W.Smith) Hustedt
<i>Nitzschia frustulum</i>	(Kützing) Grunow
<i>Nitzschia fusiformis</i>	Grunow
<i>Nitzschia linearis</i>	West
<i>Nitzschia longissima</i>	(Brébisson) Ralfs
<i>Nitzschia nana</i>	Grunow
<i>Nitzschia obtusa</i>	W.Smith
<i>Nitzschia palea</i>	(Kützing) W.Smith
<i>Nitzschia paleacea</i>	Grunow
<i>Nitzschia</i> cf. <i>radicula</i>	Hustedt
<i>Nitzschia scalpelliformis</i>	Grunow
<i>Nitzschia sigma</i>	(Kützing) W.Smith
<i>Nitzschia sigmaformis</i>	Hustedt
<i>Nitzschia sigmoidea</i>	(Nitzsch) W.Smith
<i>Nitzschia tryblionella</i>	Hantzsch
<i>Nitzschia valdestriata</i>	Aleem & Hustedt
<i>Nitzschia ventricosa</i>	Kitton
<i>Nitzschia vermicularis</i>	(Kützing) Hantzsch
<i>Nitzschia</i> sp.	Hassall
<i>Nodularia</i> sp.	Mertens ex Bornet & Flahault
<i>Ochromonas</i> sp.	Vysotskii
<i>Odontella granulata</i>	(Roper) R.Ross
<i>Odontella mobilensis</i>	(J.W.Bailey) Grunow

<i>Odontella obtusa</i>	Reinsch
<i>Oedogonium</i> cf. <i>pluvioporum</i>	Link ex Hirn
<i>Opephora burchardtia</i>	Witkowski
<i>Opephora marina</i>	(Gregory) Petit
<i>Opephora</i> sp.	P.Petit
<i>Oscillatoria curviceps</i>	Agardh ex Gomont
<i>Oscillatoria princeps</i>	Vaucher ex Gomont
<i>Oscillatoria</i> sp.	Vaucher ex Gomont
<i>Pandorina</i> sp.	Bory de Saint-Vincent
<i>Paralia sulcata</i>	(Ehrenberg) Cleve
<i>Parapediastrium biradiatum</i>	(Meyen) Hegewald
<i>Parlibellus</i> sp.	E.J.Cox
<i>Parmidium</i> sp.	Christen
<i>Pediastrium duplex</i>	Meyen
<i>Peridinium</i> sp.	Ehrenberg
<i>Phacus</i> sp.	Dujardin
<i>Phormidium autumnale</i>	(Agardh) Trevisan ex Gomont
<i>Phormidium fonticola</i>	Kützing ex Gomont
<i>Phormidium interruptum</i>	Kützing ex Gomont
<i>Phormidium lividum</i>	Nägeli
<i>Phormidium retzii</i>	(Agardh) Kützing ex Gomont
<i>Phormidium simplicissimum</i>	(Gomont) Anagnostidis & Komárek
<i>Phormidium stagninum</i>	(Kützing ex Gomont) Anagnostidis
<i>Phormidium</i> sp.	Kützing ex Gomont
<i>Pinnularia</i> sp.	Ehrenberg
<i>Plagiogramma</i> sp.	Greville
<i>Plagiotropis</i> sp.	Pfitzer
<i>Planktolyngbya brevicellularis</i>	Cronberg & Komárek
<i>Planotaenium interruptum</i>	(Brébisson ex Ralfs) Petlovany & Palamar-Mordvintseva
<i>Planothidium</i> sp.	Round & L.Bukhtiyarova
<i>Pleurosigma</i> sp.	W.Smith
<i>Podocystis</i> sp.	J.W.Bailey
<i>Polysiphonia</i> sp.	Greville
<i>Proboscia alata</i>	(Brightwell) Sundström
<i>Prorocentrum</i> sp.	Ehrenberg
<i>Protoperidinium</i> sp.	Bergh
<i>Psammothidium</i> sp.	L.Buhtkiyarova & Round
<i>Pseudanabaena galeata</i>	Böcher
<i>Pseudanabaena limnetica</i>	(Lemmermann) Komárek
<i>Pseudanabaena</i> sp.	Lauterborn
<i>Pseudendoconium submarinum</i>	Wille
<i>Pseudocharacium</i> sp.	Korshikov
<i>Pseudonitzschia fraudulenta</i>	(Cleve) Hasle
<i>Pseudonitzschia</i> cf. <i>multiseries</i>	(Hasle) Hasle
<i>Pseudonitzschia pungens</i>	(Grunow ex Cleve) G.R.Hasle
<i>Pseudonitzschia</i> sp.	H.Peragallo in H. & M. Peragallo
<i>Pseudopediastrium boryanum</i>	(Turpin) Hegewald
<i>Quadricoccus</i> sp.	Fott
<i>Rhaphoneis amphiceros</i>	(Ehrenberg) Ehrenberg
<i>Rhaphoneis</i> sp.	Ehrenberg

<i>Rhizoclonium hieroglyphicum</i>	(Agardh) Kützing
<i>Rhizosolenia setigera</i>	Brightwell
<i>Rhizosolenia setigera</i> f. <i>pungens</i>	(Cleve-Euler) Brunel
<i>Rhoicosphenia abbreviata</i>	(C.Agardh) Lange-Bertalot
<i>Rhopalodia</i> sp.	Otto Müller
<i>Scenedesmus arcuatus</i>	Lemmermann
<i>Scenedesmus balatonicus</i>	Hortobágyi
<i>Scenedesmus bicaudatus</i>	Dedusenko
<i>Scenedesmus brevispina</i>	(Smith) Chodat
<i>Scenedesmus ecornis</i>	(Ehrenberg) Chodat
<i>Scenedesmus ellipticus</i>	Corda
<i>Scenedesmus obliquus</i>	(Turpin) Kützing
<i>Scenedesmus obtusus</i>	Meyen
<i>Scenedesmus subspicatus</i>	Chodat
<i>Scenedesmus</i> sp.	Meyen
<i>Schroederia</i> sp.	Lemmermann
<i>Sellaphora</i> sp.	Mereschowsky
<i>Sieminskia</i> sp.	D.Metzeltin & Lange-Bertalot
<i>Skeletonema costatum</i>	(Greville) Cleve
<i>Skeletonema marinoi</i>	Sarno & Zingone
<i>Sphaerocystis schroeteri</i>	Chodat
<i>Spirogyra</i> cf. <i>rivularis</i>	Hassall
<i>Spirulina subsala</i>	Oerstedt ex Gomont
<i>Staurastrum alternans</i>	Brébisson
<i>Stauridium tetras</i>	(Ehrenberg) Hegewald
<i>Stauroneis</i> sp.	Ehrenberg
<i>Stauronella</i> sp.	Mereschkowsky
<i>Staurosirella leptostauron</i>	(Ehrenberg) D.M.Williams & Round
<i>Staurosirella</i> sp.	D.M.Williams & Round
<i>Stephanocyclus meneghiniana</i>	(Kützing) Skabichevskii
<i>Stigeoclonium tenue</i>	(Agardh) Kützing
<i>Striatella</i> sp.	Agardh
<i>Surirella brebissonii</i>	Krammer & Lange-Bertalot
<i>Surirella elgans</i> f. <i>elongata</i>	Skvortzov
<i>Surirella minuta</i>	Brébisson
<i>Surirella</i> sp.	Turpin
<i>Synedra formosa</i>	Hantzsch
<i>Synedra</i> sp.	Ehrenberg
<i>Synedropsis</i> sp.	G.R.Hasle, L.K.Medlin & E.E.Syvertsen
<i>Tabellaria</i> cf. <i>flocculosa</i>	(Roth) Kützing
<i>Tabularia fasciculata</i>	D.M.Williams & Round
<i>Tabularia tabulata</i>	(C.Agardh) Snoeijs
<i>Tetraedron caudatum</i>	(Corda) Hansgirg
<i>Thalassionema nitzschioides</i>	(Grunow) Mereschkowsky
<i>Thalassiosira nordenskiöldii</i>	Cleve
<i>Thalassiosira</i> sp.	Cleve
<i>Trachelomonas volvocina</i>	(Ehrenberg) Ehrenberg
<i>Trachysphenia acuminata</i>	Peragallo
<i>Ulnaria acus</i>	(Kützing) M.Aboal
<i>Ulnaria ulna</i>	(Nitzsch) P.Compère

<i>Ulothrix cf. tenerrima</i>	(Kützing) Kützing
<i>Ulothrix cf. variabilis</i>	Kützing
<i>Ulothrix zonata</i>	(Weber & Mohr) Kützing
<i>Ulothrix</i> sp.	Kützing
<i>Ulva intestinalis</i>	Linnaeus
<i>Uronema elongatum</i>	Hodgetts

A-24. Sequences used for generating phylogenetic trees in Chapter 4.

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tgca

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