NATIVE VEGETATION AND SUBSTRATE TYPE IN WETLANDS FOR WASTEWATER TREATMENT

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INTRODUCTION

In the early 1990s, the Ecological Society of America proposed The Sustainable Biosphere Initiative (SBI) in response to a call from the scientific community and policymakers to set priorities for the discipline. The response resulted in development of a framework for the acquisition, dissemination, and utilization of ecological knowledge (Lubchenco et al. 1991). The SBI focuses on the necessary role of ecological science in the wise management of resources for the maintenance of life support systems (Lubchenco et al. 1991). The SBI proposed three research priorities: global change, biological diversity, and sustainable ecological systems. After the successful launching of the broad SBI, the Freshwater Imperative (FWI) Research Agenda (Naiman et al. 1995) was envisioned as a more focused initiative concentrating on freshwater issues. The FWI agenda proposes establishment of long-term programs for freshwater research relating directly to improved watershed management and human sustainability. With the widespread misuse and alteration of watershed dynamics, watershed data acquisition is essential. This research project is connected to these agendas in that it examines biodiversity and sustainability of the native vascular plant community within constructed wetlands and allows the testing of indicators of anthropogenic stress within the vascular plant communities.

The desired functions of the vascular plant community within constructed wetlands are multifold. The objectives here include not only maintenance of high water quality, but also continued sustainability of the regional watershed. If alien species are allowed to develop within wastewater treatment facilities, they could escape and influence the downstream plant community (Decamps 1996). Understanding of the life histories of native vegetation, rather than introduced species, is needed if biological diversity is to be sustained within the watershed.

BACKGROUND

Wetlands

The multiple ecological functions provided by natural wetlands offer unique opportunities for planned management designs. These functions include: ecotones between aquatic and terrestrial systems, biogeochemical agents, and biological reservoirs (Mitsch 1996). As biological reservoirs, wetland environments may provide habitat for a wide diversity of plants, animals, and microbes. Some of the most diverse locations in the world (the Everglades of Florida, the Camargue of France, and the Pantanal in Brazil) are wetlands (Mitsch 1996). Because of the inherent biodiversity associated with wetlands, when disturbance occurs biodiversity is often lost. Although there are many theories about alien plants, there is evidence that disturbed ecosystems are most susceptible to biological invasions (Mitchell and Gopal 1991). It is essential to investigate biological invasion by alien species, as well as to analyze the relationships between productivity and species richness as they may alter ecosystem properties (Decamps 1996).

As part of the biogeochemical cycle, wetlands can enhance water quality. Over the past few decades, the role of wetlands in water quality improvement has been extensively documented (Hammer 1989; Olson 1992; Brix 1994; Kadlec 1994; Mitsch 1994; Reddy and D'Angelo 1994). The use of wetlands for wastewater treatment was stimulated by a number of studies in the early 1970s that demonstrated the ability of natural wetlands to remove suspended sediments and nutrients, particularly nitrogen and phosphorus, from domestic wastewater (Mitsch and Gosselink 1993). Early ecosystem-level studies which addressed the ability of wetlands to enhance domestic wastewater water quality were with Florida cypress swamps (Odum et al. 1977; Boyt et al. 1977; Ewel and Odum 1984). Most activity involving the use of wetlands for wastewater treatment now centers on constructing new wetlands (Hammer 1989; Knight 1990) rather than using natural systems. Mitsch (1996) notes that because wetlands are among the most biologically active ecosystems on earth, we must continually validate constructed wetlands against natural ones to ensure ecological success.

Substrate/Soil

The biosphere is made up of the atmosphere, the hydrosphere, and the pedosphere. Each of these divisions owes many of its characteristic features to the ecological reactions and interactions of organisms and to the interplay of different ecosystem components and basic cycles between them (Odum 1971). Each division is composed of a living and a nonliving component, which are not often easily separated. Biotic and abiotic components are especially intertwined in soils because by definition, soils consist of the weathered layer of the Earth's crust with living organisms and their decayed components intermingled. Soil is not only a component of the environment but is produced by it as well. In general, soil can be thought of as the net result of the action of climate and organisms, especially vegetation, on the parent material of the earth's surface. Soil is composed of a parent material, the underlying geologic or mineral substrate, and an organic component in which organisms and their products are intermingled with the particles of the parent material (Lambe and Whitman 1969). Spaces between the particles are filled with gases and water. The texture and porosity of the soil are important characteristics and largely determine the availability of nutrients to plants and soil animals.

In a wetland designed to improve water quality, the substrate plays a significant role in its ability to retain chemicals and provide the habitat for micro- and macro-flora and fauna that are involved in chemical transformations. Weider et al. (1989) suggest that subsurface flow through artificial wetlands can be through soil media (root-zone method) or through rocks and sand (rock-reed filters). Gravel is commonly added to the substrate of artificial wetlands to provide a relatively high permeability that allows water to percolate into the root zone of the plants where microbial activity is high (Gersberg et al. 1986). Past research with vinyl core media has shown the advantage of high surface area (Wolverton 1982), but vinyl core media is expensive.

A literature review of wastewater treatment substrate type has revealed past use of multiple substrate materials (Wolverton 1987; Hammer 1989; Bevis and Kadlec 1990; Patrick 1994). Manganese nodules are naturally occurring, highly porous, marine minerals (Ehrlich 1990). Based on a literature review, manganese nodules have never been utilized for wastewater treatment. However, their porosity should provide additional surface area upon which root microbes can (or might) flourish, thus possibly enhancing the effectiveness of the system to clean wastewater. Manganese concentrations range widely in soils. Some manganese may be present complexed with soil organic matter, but this association is weak. Most research on the stability of metal-humic material associations suggests that manganese is less strongly associated with humic materials than many other trace metals. Under the earth's surface conditions, manganese exists only in the 2+, 3+, and 4+ valences (Gambrell and Patrick 1978). Plant available manganese is more dependent on pH than any other factor, though levels of organic matter and soil aeration do exert some influence on availability. A change in soil pH or redox conditions may have a marked influence on transformations between readily available and potentially available forms (Gambrell and Patrick 1978). Acid and reducing soil conditions favor divalent forms that result in increased levels of dissolved and exchangeable manganese. Where manganese toxicity is a problem, the soils are commonly acidic, reducing, or both these conditions. Increasing soil pH and oxidation conditions favor the formation and stability of higher oxide minerals. Manganese deficiencies most likely occur under high pH, oxidized soil conditions. Research on more effective techniques to remove nutrients from effluents prior to release into natural waters is badly needed (Boyd 1970). As one component of this project, the effectiveness of manganese nodules as a substrate material for constructed wetlands is tested.

Vascular Plant Community

The release of human waste creates a niche in which few plant species are adapted to survive. In previous studies, evidence has shown a resulting change in wetland plant community composition and a shift to more opportunistic species after the introduction of wastewater (USEPA 1993). While wetland plants are adapted to wide ranges in water levels and nutrients (Mitsch and Gosselink 1993), it is expected that some species will be less tolerant of wastewater than others. The most obvious changes can be expected in the plant community. Whigham and Simpson (1977) found that after one growing season of wastewater application to a tidal marsh, *Impatiens capensis* was eliminated completely. *Zizania aquatica* and *Acnida cannabina* were not affected. Ewel (1976) found an increase in small floating plants such as *Spirodela oligorhiza, Azolla caroliniana,* and *Lemma perpusilla* in cypress swamps receiving wastewater. In the same study, there was a decrease in diversity of *Erechtites hieracifolia, Lyonia lucida, Nymphaea odorata,* and *Utricularia* spp. Other reports in the literature concerning the ability of aquatic plants to oxygenate the root zone are contradictory (Patrick 1994). For example, Brix (1990) concluded that common reed roots contributed little to the oxygen balance of a soil-based constructed reed bed receiving domestic sewage during the winter. In that study, plant oxygenation of the root zone was inferred from gas transport and respiratory oxygen consumption in the roots. Dunbabin, et al. (1988) found that the dissolved oxygen concentration measured in the gravel surrounding the root zone of *Typha domingensis,* was similar to that of unplanted gravel. Reddy et al. (1989) found that nine species of floating and emergent aquatic plants increased the dissolved oxygen concentration in the root zone above a control, when incubated in sewage for only eight days. This contradiction exemplifies the need for further research exploring the role of plants in water purification (Gersburg et al. 1986) and provides ample justification of the need for adequate planning, design, and monitoring of wastewater systems which utilize wetlands (Bevis and Kadlec 1990).

Productivity

Primary productivity is a key index of ecosystem function (Mitsch and Gosselink 1993). It has been shown in a number of studies of individual species (i.e. *Spartina alterniflora*; Steever et al. 1976) or ecosystems (i.e. cypress swamps; Conner et al. 1981) that productivity is directly proportional to the water renewal rate; however, when different ecosystems that have greatly different water regimes are compared, the relationship breaks down (Mitsch and Gosselink 1993). To understand productivity processes, a study should consider both the hydromechanics and nutrient chemistry of the system. Therefore, the need for baseline data in wetlands constructed for wastewater treatment before loading with sewage is essential for later meaningful comparison of productivity. There is a need to consider the following set of physical, chemical, and biological parameters: geographical location and hydrologic regime, soil regime, community type and stand history, life history, and extrinisic factors (Holland 1996; Mitsch and Gosselink 1993). Above ground productivity calculated from maximum minus minimum biomass ranged from 102 to 530 g/m^2 for northern bogs (Reader 1978) to values of 730 to 2,852 g/m^2 for prairie glacial marshes (van der Valk and Davis 1978) to 1,070 to 2,860 g/m^2 for inland freshwater marshes (Mitsch and Gosselink 1993). The constructed wetlands in this study most likely will closely resemble inland freshwater wetlands.

SITE DESCRIPTION

This research project is located at The University of Mississippi Biological Field Station (UMBFS) wastewater treatment facility at the headwaters of the Little Tallahatchie River watershed. For a number of years, UMBFS has been the site for the study of toxicology and human impacts on aquatic ecosystems (Knight 1996). It is located in northern Mississippi approximately 18 kilometers northeast of the Oxford campus. Currently, UMBFS covers 246 hectares with over 200 experimental ponds and mesocosms most of which are fed from gravitation flow of the numerous springs and seeps located at the field station. The University of Mississippi (UM) has established the Center for Water and Wetland Resources (CWWR) to be based at UMBFS. While the completion of the wastewater treatment facility designed by Dr. Bill Wolverton is anticipated by April of 1997, completion of the first building is not anticipated until May of 1998. This wastewater system will not be fully operational until the completion of the buildings. The design of the six proposed constructed wetlands for wastewater treatment systems at the CWWR complex is flexible in that the engineers designing the system are challenging UM researchers to suggest manipulations of the substrate and vegetation components.

The wastewater treatment system consists of 3 pairs of 123.1 meter raceways: 3.1, 4.3, and 4.6 meters wide (Figure 1). Waste from the buildings will first run into two 10,000 gallon septic tanks, which will be located just upslope from the constructed wetlands. The first pair of raceways is 3.1 meters wide and consists of a rock filter system in which a plastic liner and limestone rock have been installed. The other two pairs of raceways are 4.3 and 4.6 meters wide and are bentonite-lined. This research project does not focus on operation or maintenance issues of the wastewater treatment system but is designed to acquire basic ecological and physical understanding of the regionally important issues of sustainability and biodiversity.

EXPERIMENTAL DESIGN AND METHODS

Hypotheses

This research project has three fundamental hypotheses:

1. Manganese nodules will improve wastewater effluent quality in a wetland constructed for wastewater treatment.
2. The diversity of a vascular plant community will decrease over time, if subjected to wastewater effluent.
3. Vascular plant community biomass will increase over time, in wetlands constructed for wastewater treatment.

Manganese Nodules

Manganese nodule effectiveness for wastewater treatment substrate was analyzed by determining the decomposition of manganese nodules exposed to wastewater. The composition of the manganese nodules was known prior to experimentation (Buchannon 1995). The five elements: copper, manganese, arsenic, lead, and cadmium have been selected for examination based on their undesirable water qualities for the proposed wastewater system. Manganese nodule and water samples were taken in October 1996, before experimentation, to determine the metal content. Grey water was obtained from The University of Mississippi Wastewater Treatment Facility which is an accurate representation of the domestic sewage expected at the future CWWR. The arsenic, lead, and cadmium values were determined using a Varian Spectra Atomic Absorption 400 graphite furnace spectrophotometer. The copper and manganese values were determined using a Varian Flame Atomic Absorption Spectra 20 spectrophotometer. The manganese nodules were digested using a CEM 2100 MBS microwave digesting system prior to testing. The manganese nodules were combined with domestic grey water in 5 gallon buckets and sealed to simulate the septic portion of the wastewater system. The pH was monitored weekly and the buckets sat undisturbed for approximately 2 months, after which time manganese nodule and water samples were tested using the same protocols as the October samples. This experiment was conducted at The University of Mississippi Wastewater Treatment Facility, located on the Oxford campus, with water quality analyses conducted at the analytical laboratory of Dr. Bill Benson at the Research Institute for Pharmacological Science, Oxford, Mississippi.

Soil

Using the known history of UMBFS (Suedel 1993; Knight 1996), soil samples have been collected from the area surrounding the wastewater treatment system. It is assumed that seed germination will occur in the wastewater raceways similiar to that of the surrounding habitat. Soil characterization and mineral content will be analyzed under the supervision of Dr. Charles Cooper of the USDA Agricultural Research Service, National Sedimentation Laboratory, Oxford, Mississipppi.

Vegetation

Initial work on the floristic survey component of this project began in the summer of 1996, with an overall sampling of the vegetation of the vascular plant understory community of UMBFS. Standard collecting procedures were followed. Specimens were carefully collected and labeled before placement in polyethylene bags in the field then transferred to plant presses. The pressed specimens were dried for a minimum of 48 hours over portable driers using 60 watt incandescent bulbs as a heat source. Identifications were made in the field or from dried specimens and recorded and carried to the species level only if there was sufficient material to do so (Radford et al.; 1968; Britton and Brown 1970; Newcomb 1977; Searcy 1978; Timme 1989). Comparison of existing species was made based on the earlier plant list (Robertson and McCook 1996; Hunneycutt 1996) located in the UMBFS office. Confirmation of unknown species was made by Dr. M.B. Hunneycutt or Dr. Lucile McCook. The numbered specimens are filed by family name in preparation for mounting and herbarium storage in the laboratory of Dr. M.M. Holland, Department of Biology, University of Mississippi.

Beginning in March 1997, the structure of the vascular plant community within the wastewater raceways is being surveyed (Barbour et al. 1988). From these initial observations, diversity indices, species richness, and change in vascular plant biomass (Chapman 1976) can be calculated. Species composition will be determined using line transects (Bauer 1943) set up every 3.1 meters along the 123.1 meter raceways, for a total of 24 sampling sites to be rotated (Milner and Hughes 1968) 3.1 meters monthly using a quarter meter square quadrat (Figure 1). Understory species will be identified and categorized based on species type. The vascular plant communities' structure will be evaluated by detailed observations and photo-documentation of successional changes with diversity being measured monthly by calculating species richness, and determining diversity using the Shannon Weiner and Simpson Diversity Indices (Barbour et al. 1987). Vascular plant productivity will be measured monthly using the clip quadrat method for above ground biomass (Weaver and Clements 1938).

RESULTS

The results of the manganese nodules experiments revealed that cadmium and arsenic were being released into the water column from the nodules and lead, copper, and manganese were being taken up by the nodules (Table 1). Based on these findings, manganese nodules have proven to be an undesirable substrate for the proposed wastewater treatment system.

The results of the vegetation portion of this study are preliminary. The floristic survey which began in the summer of 1996, provides an overview of understory vascular plant community of UMBFS, from which predictions can be made about expected community development of the wastewater raceways. Common herbaceous plant taxa of UMBFS include members of the *Asteraceae* (asters) family, *Ipomoea purpurea* (morning glory), *Solidago* (goldenrod), *Ambrosia artemisiifolia* (common ragweed), *Tridens flavus* (purple top grass), *Andropogen scoparium* (blue stem grass), and *Parthenocissus quinquefolia* (virginia creeper). In the lowland areas, common herbaceous plant taxa are *Galium* (bed straw), *Asteraceae* (asters), *Rubus* (blackberry), *Aspidiaceae* (fern), *Iridaceae* (iris), and *Panicum*. The wetland areas commonly include specimens of the genera *Azolla, Impatiens, Juncus, Polygonum, Scirpus, Typha, and Eleocharis*. The literature indicates many of these species could be potential candidates for the proposed wastewater treatment system. The floristic survey will be useful for possible transplant of native species into the wastewater raceways. A comparison has been completed for numbers of the woody versus herbaceous species (Figure 2), and native versus introduced species (Figure 3). Overall species richness and diversity have been calculated for the intial floristic survey and will serve as a comparison for the wastewater treatment wetland community.

CONCLUSIONS

The consequences of human activities directly and indirectly affect and are affected by ecological complexity, such as diversity of species and habitats, the patterns of ecological assemblages on the landscape, and differences in productivity or storage capabilities of ecosystems. Changes that occur due to introduced species may alter photosynthetic rates, change species behavior, or alter microbial activity (Lubchenco et al. 1991) within the community. Changes in both community structure and function may ultimately be expressed as changes in ecosystem function. The preliminary results of this study have already provided insight into substrate selection in constructed wetlands. The vegetation data will serve as needed base line information essential for long term monitoring as the wastewater system becomes operational. With the unique opportunity for collection, assimilation, and distribution of information provided by UMBFS, this knowledge should be easily available to not only the scientific community, but to the general public as well.

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Table 1. Water Quality Results (Pre-Treatment)

Sample #	As (ppb)	Cd (ppb)	Pb (ppb)	Cu (ppm)	Mn (ppm)
1	ND	0.482	4.70	0.29	0.112
2	ND	0.388	2.31	0.03	0.094
3	ND	0.310	1.93	0.02	0.090
4	ND	0.341	3.88	0.04	0.096
5	ND	0.382	2.74	0.04	0.094
6	ND	0.372	3.23	0.07	0.097

Water Quality Results (Post-Treatment)

Sample #	As (ppb)	Cd (ppb)	Pb (ppb)	Cu (ppm)	Mn (ppm)
1	2.76	0.927	ND	0.02	0.058
2	7.30	0.798	ND	0.02	0.054
3	3.61	0.796	ND	0.02	0.058
4	2.24	0.373	ND	0.01	0.031
5	0.65	0.419	ND	ND	0.029
6	0.71	0.415	ND	0.01	0.034

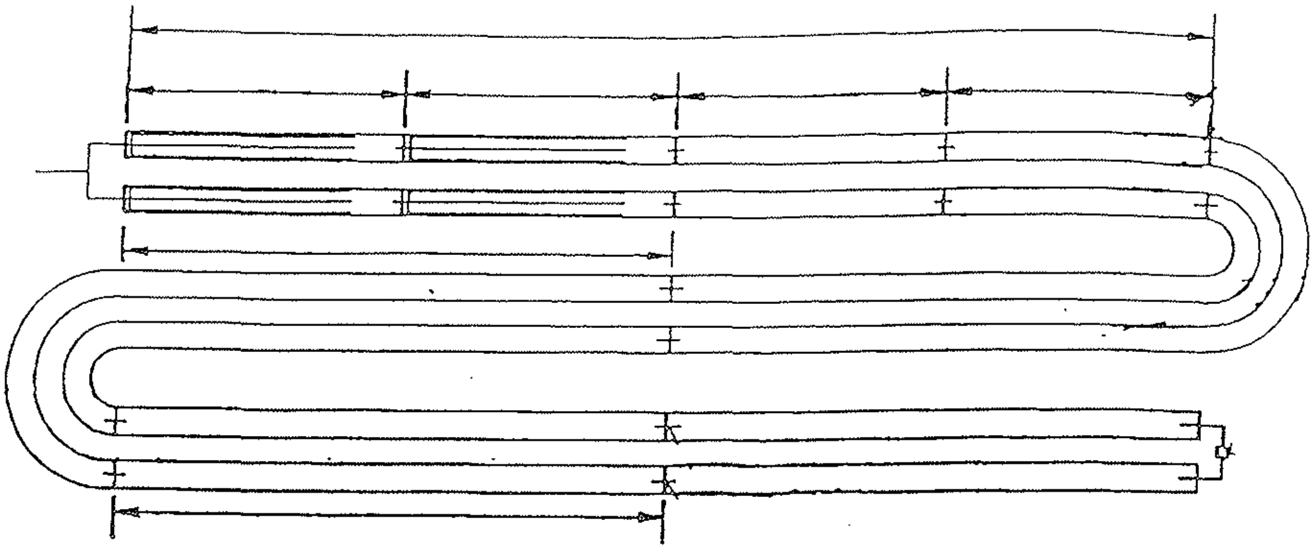

Figure 1. 123.1 meter Raceways

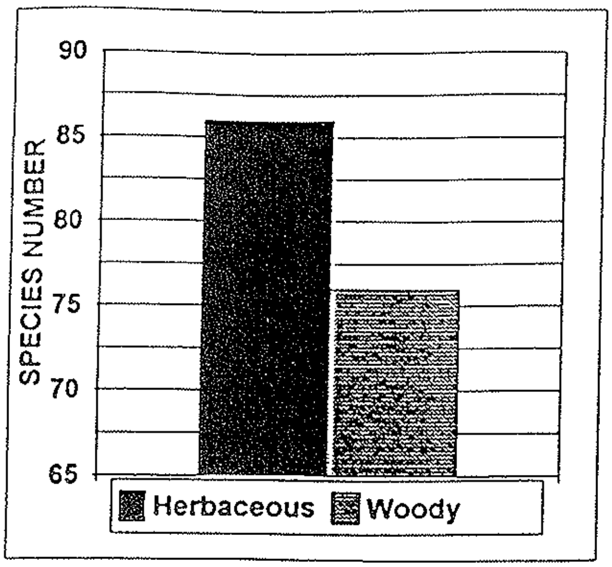

Figure 2. Woody vs Herbaceous at UMBFS

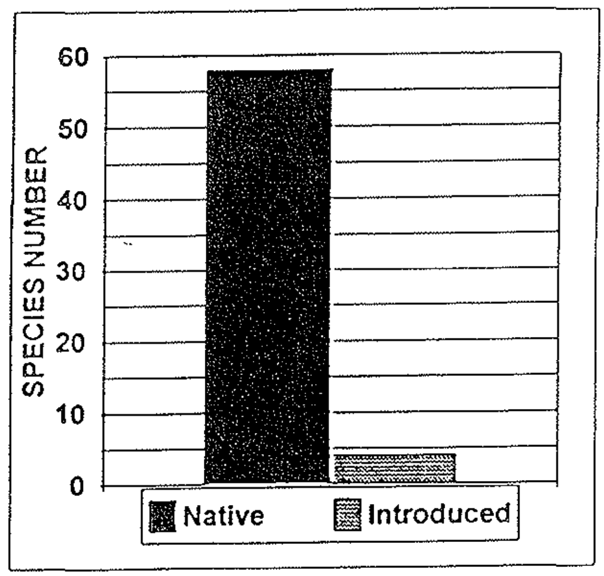

Figure 3. Native vs Introduced at UMBFS