New Jersey Water Resources Research Institute

Annual Technical Report

FY 1999

Introduction

Introduction The New Jersey Water Resources Research Institute funded a diverse set of research projects during Fiscal Year 1999, and also supported a substantial number of undergraduate and graduate students in this research. Proposals were designed to respond to the list of priority issues, which had been previously identified in meetings of academic and governmental scientists; the list of research priorities follows this brief overview of the research and information transfer programs. Three projects were designed and carried out faculty members. In one project (Gimenez), the fractal geometry of soil pores was documented, and its significance to the transport of pollutants in unsaturated media was demonstrated. In another project (Weis), the ability of litter from native and invasive wetland plants to support the growth of intertidal meiofauna was studied; the results showed that the justification for numerous very expensive wetland restoration projects may not be valid. The third faculty-based project (Hatfield) used spatial and geographic analytical techniques to examine the riparian vegetation of stream corridors, in order to assess their invasibility by exotic species. The Institute also awarded several grants-in-aid to graduate students. These projects represent research that is initiated and designed by the students, and is not supported by other sources. These grants-in-aid provide crucial support to a variety of graduate students who seek to enter water-resource-related fields. The projects included a study of the effects of water pollution on thyroid function in intertidal fishes, with consequences for their behavior and survival, a study of the effects of mosquito ditching of coastal wetlands on the productivity of mussels, a study which demonstrated that fish parasites in degraded streams of the New Jersey Pinelands have a different species composition that parasites in fish from unimpacted streams, a study of the sorption of MTBE vapors on soil solids, quantifying the diffusivity of this material in vertical soil columns. Finally, the research program of the Institute included several grants made to faculty in support of undergraduate internships. The goal of this program is to introduce undergraduate students to water resources-related fields at a formative time in their education. Through these grants, students were supported to study the sorption of non-ionic surfactants to soil soil materials and the effects of invasive exotic plants on species richness in tidal freshwater wetlands. The Institute developed a web site (http://njwrri.rutgers.edu/) to facilitate our communication to the general public. The web site includes summaries of recently completed research, a list of the advisory council members, the requests for proposals for both the in-state program and the national competitive program, an extensive list of links to national, state, and local water-related organizations, and a searchable database of water-resource academic scientists in the state. RESEARCH PRIORITIES (October 1999) I. Integrity of aquatic and water-associated ecosystems (a) indicators of "normal" ecosystem function and structure (i.e., indicators of ecosystem "health"), including methods to establish and calibrate indicators (b) mechanisms of action and effects of contaminants on organisms and ecosystems (c) linkages between indicators and causal factors of ecosystem degradation (d) impacts and control of exotic and invasive species (e) methods to establish reference conditions of ecosystems (f) linkage of hydrology to ecosystem structure and function II. Socioeconomic and planning issues (a) improvements in watershed-based planning and management (b) development of integrated cross-disciplinary methods for planning and management (c) evaluation of the efficacy of existing laws and programs; reasons for effectiveness or lack thereof (d) methods of integrating science into planning, policy development and implementation (e) methods of full-cost accounting and integration of such methods into the legal framework for water resource management (f) socioeconomic and other barriers to implementation of BMPs and

existing programs III. Technology and methods of analysis (a) on-site and innovative methods of remediation, especially for anaerobic environments and complex mixtures (b) safe uses of water treatment residuals (c) methods of pollution prevention (d) landscape-scale models for fate and transport of contaminants, including non-point source pollutants (e) forecasting effects of global climate change on regional hydrology (e.g., changes in storm frequency and intensity, probability of droughts, etc.) (f) integration of models (e.g., surface water and ground water model linkage, 3-dimensional modeling, models at different spatial scales, water quantity or flow and water quality models) IV. Information transfer (a) methods of educating public to increase water conservation (b) methods of increasing public participation in water resource protection programs (c) methods of improving communication among the public, government regulators, and scientists (d) methods of effectively communicating science to public and managers (e) methods of altering human behavior (e.g. implementing BMPs, altering lawncare practices, etc.) (f) methods of improving collaboration between government agencies and NGOs, for both public education and water resource management activities

Research Program

Basic Project Information

Basic Project Information	
Category	**Data**
Title	Differences in Thyroid Morphology and Function of Fundulus heteroclitus from Polluted and Nonpolluted Sites
Project Number	07
Start Date	03/01/1999
End Date	02/29/2000
Research Category	Biological Sciences
Focus Category #1	Toxic Substances
Focus Category #2	Ecology
Focus Category #3	Water Quality
Lead Institution	Rutgers University

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
Mary Anne Carletta	Student	Rutgers University	01
Judith Weis	Professor	Rutgers University	02

Problem and Research Objectives

This research addresses "mechanisms of action and effects of contaminants on organisms and ecosystems", specifically the connections between contaminants, thyroid dysfunction, and alterations in behavior that can affect the normal structure and function of ecosystems. While there has been a great deal of attention focused on endocrine disruption resulting from exposure to environmental contaminants, there has been relatively little attention paid to thyroid function. The disruption of thyroid function potentially has as much or more effect on the developing organism as the disruption of the reproductive hormone function, including: changes in metabolism that may affect body weights and cardiac function, changes in development that may affect, for example, maturation of the skeleton and nervous system, rate of mortality of eggs and larval fish, and behavioral effects that may cause differences in interspecies interactions and in population dynamics Researchers have found that various pollutants can cause abnormal thyroid function in fish (Hontela et al. 1995, Stephens et al. 1997,Fok et al. 1990, Hontela et al. 1996, Bleau et al. 1996, Pandey & Shukla 1983, Alkindi et al. 1996). Other studies, concentrating primarily on physical development, have found that externally-applied thyroid hormones have various and sometimes contradictory effects on fish, for example, accelerating yolk resorption, growth and survival in larval tilapia (Lam 1985), increasing larval survival and accelerating gut development in Pacific threadfin (Brown & Kim 1995; Kim & Brown 1997), and decreasing growth and survival oflarval striped bass (Huang et al. 1996). This work focuses on disruption of thyroid function specifically in estuarine wildlife. The research organism, the mummichog Fundulus heteroclitus, is found throughout estuaries on the east coast of the United States and Canada and is frequently studied as a key organism in the estuarine food web. We know that there are behavioral differences between Fundulus heteroclitus that reside in some polluted areas (e.g., Piles Creek in Linden, NJ) and those that reside in relatively pristine areas (Weis & Khan 1991, Smith & Weis 1997). These differences make these fish less active and less competent at avoiding predation and at feeding themselves, which changes interspecies interactions in the ecosystem. Their "slowness" might be associated with altered thyroid function. Work in our lab has found that there are also differences in the morphology of thyroid follicles and the level of thyroid hormone between these populations of adult Fundulus (Zhou et al. submitted). This research explores at what point in development these thyroid differences arise and the possibility that disruption of normal thyroid function is the cause of the behavioral differences. This research explores when in development thyroid differences occur in two different Fundulus heteroclitus populations, examining morphological, hormonal, and behavioral differences. It also explores the effect of externally-applied thyroid hormone on behavior, contrasting fish from polluted and non-polluted sites in New Jersey. The results could lead to a better understanding of the effects of thyroid dysfunction on wildlife and how that may affect individual behavior and hence interspecies interactions. If thyroid dysfunction is a factor in behavioral differences, future research could help us determine what pollutants are most responsible. This will aid New Jersey in protecting its coastal wetlands and in setting priorities for cleaning up polluted estuaries. The specific objectives of this study are to investigate development of thyroid follicles in Fundulus and thyroid follicle differences between juvenile and larval fish from polluted and nonpolluted sites, differences in levels of thyroid hormone between juvenile and larval fish from polluted and nonpolluted sites, and behavioral differences between juvenile and larval fish from polluted and nonpolluted sites when dosed with thyroid hormone

Methodology

Juvenile fish were collected from the unpolluted marsh at the Rutgers marine field station at Tuckerton, NJ, and from an extensively polluted site at Piles Creek in Linden, NJ. Histological sections were used to inspect microscopic differences between the thyroid follicles of fish from the two locations. The heads of fish 30-45 mm long (approximately 6 months old) have already been sectioned and compared,

and the whole bodies of the smaller fish will be compared in the same manner. Radioimmunoassay was used to examine differences in levels of thyroxine (T4) and triiodothyronine (T3) in fish 30 mm long and less (less than 6 months old). A prior study with yearlings using blood plasma (Zhou et al. submitted) had found significantly greater T4 in adult fish from Piles Creek. Because of the smaller size (and younger age) of the fish in this study, it was necessary to use tissue of the whole body, excluding the digestive tract for fish 15 mm long or greater. Juvenile fish (yearlings and young-of-the-year, approximately 3-4 months old) were exposed to T3 and propylthiouracil (a thyroid suppressor) in their aquarium water. Since T3 and propylthiouracil are not very soluble in water, a small amount of sodium hydroxide solution was used to dissolve them. The controls were exposed to the same concentration of sodium hydroxide solution without the thyroid-affecting compound. Behavioral (activity) differences between fish exposed to the various concentrations of T3 or propylthiouracil were determined by two behavioral tests. One test measured the number of times grid lines were crossed in a timed test of activity and the amount of time spent motionless during the same period. The other test measured prey capture by counting the number of brine shrimp eaten in a timed period.

Principal Findings and Significance

Histology: The thyroid follicles of Piles Creek young-of-the-year (approximately 40 mm and six months old) were found to be significantly larger ($p<0.0019$) in area than those of Tuckerton young-of-the-year. This tells us that thyroid morphological differences between the two populations develop during the summer they are born, before the fish experience their first winter. Originally, we thought it possible that the differences would develop during the first winter, when the fish experience extended exposure to the heavily polluted sediments, as opposed to the relatively unpolluted water in which they develop during the summer. This is not the case, since the differences begin before the first overwintering. The histological comparison of follicles for fish less than 30 mm long is not yet complete.
Radioimmunoassay: Length was used as a surrogate for age. Comparing Tuckerton vs. Piles Creek, no significant differences in whole body concentrations of thyroid hormone were found for three categories of length: 20.5-30 mm, 15-20 mm, and 12-14.5 mm. Although not significantly different, the average concentrations of hormone in tissue for the 20.5-30 mm fish appeared to follow the same pattern as that of the adult fish plasma, with the Piles Creek having higher T4 and lower T3 concentrations than Tuckerton fish. This was not true for the next two size categories. For fish 15-20 mm long, Piles Creek fish had higher concentrations of both T4 and T3 than did Tuckerton fish. For fish 12-14.5 mm long, Tuckerton had higher T4 concentrations and Piles Creek had higher T3 concentrations. This changing pattern may indicate when the two populations begin to diverge, so that they become significantly different in T4 plasma concentrations by the time they reach adulthood. Behavior: Tuckerton yearlings exposed to T3 spent significantly more time in motion than control Tuckerton yearlings. The Piles Creek yearlings appeared to become less active but the difference was not statistically significant. Tuckerton young-of-the-year exposed to a low concentration of T3 crossed significantly fewer lines than those exposed to a high concentration, but both the control fish and those exposed to a medium concentration were intermediate in activity. The Piles Creek young-of-the-year showed no significant differences in activity between any of the levels of exposure. Neither population showed a significant difference in a bility to capture prey in response to T3 exposure. Neither the Piles Creek nor the Tuckerton yearlings appeared to be affected by exposure to propylthiouracil, in terms of level of activity (time in motion and number of lines crossed). However, the Tuckerton oung-of-the-year exposed to a high concentration spent significantly more time in motion than the Tuckerton controls or those exposed to a low concentration. Those exposed to a medium concentration were intermediate in activity. This increase in activity is unexpected, since we would expect a decrease in thyroid hormone to be linked to a decrease in activity. The Piles Creek young-of-the-year behaved similarly, but it was the medium concentration that induced a significantly higher amount of time in motion than the controls, with the

low and medium exposures producing intermediate activity levels. The effect of propylthiouracil on prey capture is less clear. For the yearlings, it appears that both populations eat fewer brine shrimp when exposed to propylthiouracil, but the result is not significant for either population by itself. It is significant only when both populations are included together. For the young-of-the-year, there is no significant effect on either population, although the Tuckerton fish appear to eat less at the higher exposures. To summarize the results of the behavioral experiments, behavior is affected by exposure to T3 and to propylthiouracil. However, the effect is not always as predicted. In addition, the two populations respond differently, with the Tuckerton fish responding more frequently as expected. The Piles Creek fish, the ones that have abnormal thyroid follicles and hormone levels as adults, respond less frequently as we would expect.

Descriptors

endocrine disruption, thyroid, fish, pollution

Articles in Refereed Scientific Journals

Book Chapters

Dissertations

Water Resources Research Institute Reports

Conference Proceedings

Carletta, M.A., J.S. Weis, and P. Weis. 1999. Thyroid Function in Juvenile Mummichogs (Fundulus heteroclitus) from a Polluted vs. a Reference Site. Abstract book for the 20th annual meeting of the Society of Environmental Toxicology and Chemistry (Sustaining Global Environmental Integrity), Philadelphia, Pennsylvania, 14-18 November 1999. Presented part of this work as a platform presentation at that conference.

Other Publications

Basic Project Information

Basic Project Information	
Category	**Data**
Title	Differences in ribbed mussel population dynamics at different locations in natural and grid-ditched tidal salt marsh networks.
Project Number	06
Start Date	03/01/1999
End Date	02/29/2000
Research Category	Biological Sciences
Focus Category #1	Ecology

#1	
Focus Category #2	Hydrology
Focus Category #3	Wetlands
Lead Institution	Rutgers University

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
Marlene Cole	Student	Rutgers University	01
Richard Lathrop	Professor	Rutgers University	02

Problem and Research Objectives

There has been great interest in salt marshes as nursery habitat for economically important fishery species (Boesch and Turner 1984), as habitat for resident and migratory water birds, and as zones of high primary productivity (Nixon 1980). The coastal salt marshes, most notably in the northeastern United States, have been greatly altered by mosquito management. The construction of parallel, tidally-connected grid ditches to drain the waters used by breeding mosquitoes and to promote access by larvivorous fish is controversial yet widespread. By 1938, approximately 90 percent (562,500 acres) of the total area of tidewater marsh along the Atlantic coast from Maine to Virginia had been grid-ditched for mosquito control (Bourn and Cottam 1950). Some research has linked grid ditching to a reduction in both populations of invertebrates and invertebrate species diversity (Bourn and Cottam 1950), and found it detrimental to marsh birds (Meredith and Saveikis 1987). However, very little research has addressed the effects of grid ditching on ecological structure or function. While New Jersey's salt marshes have undergone extensive alterations by modern society, science still lacks an understanding of the intricacies of salt marsh ecological structure and function to evaluate ecosystem health and design sound restoration plans. My overall research addresses the ecological consequences of large scale mosquito control alterations on ecosystem structure and function, with a focus on the habitat of land-water interface. Many of these changes involve the interface of land and water, where the highly productive tall form of Spartina alterniflora and the ribbed mussel, Geukensia demissa, occur. My previous research with Dr. Richard Lathrop found that marshes with mosquito control ditches differ from otherwise unaltered marshes in several measures of the amounts and arrangements of water bodies and marsh surface patches, including greater amounts of interpatch edge in the ditched marsh, indicating more interface between water and marsh surface (Lathrop et al. In press). However, the additional narrow and straight ditches in the highly connected grid ditched marshes differ from the typically sinuous and tapering marsh creeks and may function differently with respect to tidal flow and as habitat and corridors of movement for marsh organisms. Subsequent field work addressed spatial patterns of the abundance of tall form S. alterniflora and G. demissa, how their distributions relate to landscape patterns of aquatic habitats and how expected levels of these species differ between unaltered and ditched salt marsh conditions. A landscape scale model of the empirical data predicted ditched marsh areas to have higher overall mussel abundance, but lower variability in mussel abundance across space. The previous studies linked mosquito control ditching to differences in the spatial pattern of habitats and patterns of distribution of essential intertidal species. The current study provides information that is

helping us understand the differences in dynamics that are associated with alterations of the tidal network. This research directly addresses research priorities that involve developing indicators of normal ecosystem structure and function, establishing ecosystem reference conditions and linking hydrology to ecosystem structure and function. It provides novel information linking spatial patterns with ecological processes. Since subtidal aquatic habitats are generally the source of predatory crabs (Kneib 1984), phytoplankton (Kreeger, personal communication) and young G. demissa propagules (Nielsen and Franz 1995), changing the structure of the tidal network, such as through mosquito control ditching, may affect potential travel distance of these elements to the various locations of the marsh. Mussel growth is a function of tidal inundation period (potential feeding period), as well as food quantity and quality, with higher quality food such as phytoplankton associated with subtidal habitats (Kreeger, personal communication). Tidal inundation varies along and between the channels in the tidal network (Van der Molen 1997). Mussel larvae develop in the bay and other subtidal areas, later returning largely planktonically, to the marsh via the flooding tides into the network and onto the marsh. They settle during a certain developmental window when the find themselves in suitable habitat (Nielsen and Franz 1995). Crabs, the primary predators of G. demissa are natant predators who move toward the marsh surface with the incoming tide and retreat to subtidal waters at low tide (Kneib 1984). Although G. demissa is one of the most tolerant organisms known, it suffers mortality when conditions such as drought or heat stress are too extreme or when energetic loss outweighs gains (e.g. Lent 1967). Thus, the subtidal areas seem to serve as sources for food, young, and predators. Places that are less likely to be flooded will be associated with drier conditions and flood water containing less and lower quality food. The four contributing factors in mussel dynamics may vary depending on travel distance from subtidal habitats. Alterations to the network structure, such as those associated with ditching for mosquito control, may affect levels of these processes. This study was designed to determine how location in the tidal channel network influences mussel dynamics through the juvenile recruitment, growth, predation and non-predation mortality.

Methodology

This study was designed to look at four aspects of mussel population dynamics as they vary according to location in the channel network of ditched and unaltered marshes in the Jacques Cousteau National Estuarine Research Reserve (New Jersey). Juvenile recruitment and growth are the two processes that add to the mussel population (in number and/or biomass), while predation and non-predation mortality represent the loss terms. The experimental unit consisted of 8 mussels of different size classes, measured to the nearest 0.1 mm and uniquely color coded, set into marshmud in a 3 in diameter flowerpot. The watersheds of four main channels were used in the experiment, two in unaltered and two in ditched marsh areas. In each of the study sheds I selected two side channels: one far from the bay and one near to the bay (as one travels along the main channel from the bay). Along those side channels I then chose two distances from the junction of the main channel. Then, at both of those locations I chose two places to install the experimental pots with respect to the edge: near and far from the edge. Both of these received four pots, two of which were caged and two of which were not caged, totaling 128 pots with nearly 1100 mussels in a nested, factorial design. Pots remained in the marsh for most of the growing season (June – October). The pots were then removed and sieved and each mussel was recorded and re-measured. I used a highly conservative analysis of variance test to determine the relationships among all the factors (distance from bay, distance from junction with the main channel, distance from edge, as well as management type, study shed and cage) and changes in biomass associated with the four responses (juvenile recruitment, growth, predation, mortality) as measured in dry weight mussel body (estimated from allometric relationships with shell height; Lent 1967).

Principal Findings and Significance

Increase in biomass due to juvenile recruitment was nearly six times higher near the edge than far from it (p = 0.0045). While change in biomass due to growth varied significantly among the study sheds (p = 0.0002), the variation did not correspond to geographical arrangement or management type. Growth was higher near edges (p = 0.0001). Growth was also higher nearer to the junctions with the main channel (p = 0.0001). Figure 1shows that growth differences with distance from the main channel were more extreme in the unaltered marsh than in the ditched marsh (p = 0.0109). Figure 1. Change in biomass due to growth at two distances along the side channel from the main channel in unaltered and ditched marshes. The graph shows average biomass in grams per pot, plus/minus standard error. Predation was higher near the bay (p = 0.0009), near the junctions with the main channel (p = 0.0146), and near the edges (p = 0.0001) compared to the respective far locations. Change in biomass due to predation was also synergistically higher nearer to both the bay and to edges (p =0.0021). Non-predation mortality was higher at locations far from the edge (p = 0.0285). Change in biomass due to non-predation mortality was higher in the unaltered marsh than in the ditched marsh, but this test was not statistically significant to the standard threshold level (p = 0.0551). Comparing all replicates in each management type, unaltered marshes had a net loss in biomass from all four processes combined, while ditched marshes had a net gain (p = 0.0495). While both management types had the same gain in biomass over the study period (p = 0.5658), the unaltered marshes experienced greater loss in biomass (p = 0.0109). Higher growth near edges may be due to the fact that these places are inundated longer than places far from the channel edge. Nearer to the main channel quality food may be in higher relative proportions than far from the junctions with the main channel. Growth differences with distance from the main channel in the unaltered marsh were significantly more extreme than in the ditched marsh (Figure 1). This suggests that the ditched marsh is more homogeneous in this respect, and perhaps that the unaltered marsh habitat is more complex than the ditched marsh. Predation was higher everywhere we would expect predators coming from the subtidal water to have shorter travel distances and better access. Higher non-predation mortality far from edges may be due to shorter inundation periods than we would expect closer to edges, corresponding to less potential feeding time. This could also relate to increased heat and/or drought stress. In summary, most of the dynamics tend to occur at higher levels at locations that should have better access from subtidal habitats—nearer to the bay, main channel and edges. A gross comparison of dynamics between unaltered and ditch-managed marshes shows that, while an equal amount of biomass appear to be entering the mussel sector, the unaltered marsh loses much more. This may suggest a greater trophic transfer from mussels in the unaltered marsh than in the ditched marsh. It also helps explain the higher overall mussel abundance predicted by the model in my previous study. This study offers more support for the idea that mosquito ditching homogenizes the landscape, not just in spatial pattern, but in ecological process, as well. This study will provide new information for restoration and wetland creation. Managers, engineers and researchers will find the results of this study valuable as it links landscape scale patterns in the marsh to hydrological effects and population, community and ecosystem processes. Since the spatial configuration of tidal creek and ditch networks is an aspect of restoration design that can be controlled, this study will provide essential understanding of the impacts of such configurations on ecological processes involving the land-water interface as well as the interaction between open water in the estuary and the marsh ecosystem.

Descriptors

Articles in Refereed Scientific Journals

Book Chapters

Dissertations

Water Resources Research Institute Reports

Conference Proceedings

Other Publications

Basic Project Information

Basic Project Information	
Category	**Data**
Title	TRANSPORT OF NONIONIC SURFACTANTS IN POROUS MEDIA
Project Number	11
Start Date	03/01/1999
End Date	02/29/2000
Research Category	Ground-water Flow and Transport
Focus Category #1	Solute Transport
Focus Category #2	Groundwater
Focus Category #3	Models
Lead Institution	Rowan University

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
Kauser Jahan	Associate Professor	Rowan University	01

Problem and Research Objectives

This proposal aims at studying the transport and sorptive properties of common commercial nonionic surfactants specifically the nonionic surfactants in the environment. This research will also help address the federal mandate for integrating research and teaching at undergraduate institutions. Research experiences expose students to the creativity of the research process and enable them to apply their acquired knowledge from required coursework. Involving undergraduates in research will also encourage them to pursue an advanced degree. Lastly, this research will be instrumental in seeking funds from NSF and EPA and also in involving the state regulatory agencies, local industries and municipalities. Therefore the specific goals of this research are: · To involve undergraduate students in research experiences that enhance their understanding of engineering fundamentals, · To conduct batch and column sorption studies on nonionic surfactants, · To conduct mathematical modeling of experimental data, nd finally · To stimulate undergraduate students in pursuing graduate studies by becoming involved in meaningful research in their early years.

Methodology

Surfactants were purchased from Sigma Chemicals, St. Louis, MO. and are listed in Table 1. Nonionic surfactants are characterized by higher hydrocarbon solubilizing power, weaker adsorption to charged sites, less toxicity to bacteria, poor foaming properties and compatibility with other types of surfactants. Surfactants were used without further purification as they would be in any large-scale application. Table 1: List of Surfactants Name Structure CMC mg/L Molecular Weight Tergitol NP-10 $C_9H_{19}-C_6H_4-O-(CH_2CH_2)_nH$ n=9.8 40 652 Triton X-100 $C_8H_{17}-C_6H_4-O-(CH_2CH_2)_nH$ n=9.5 130 628 The critical micelle concentrations reported in Table 1 were determined by using a surface tensiometer (VWR, Bridgeport, NJ) at room temperature. Penn sand (Ricci Brothers Sand Co., Port Norris, NJ), which is almost pure quartz and characterized by a very low organic carbon content (foc=0.01%) was used for sorption studies. The sand used in these studies was the size fraction passing sieve #30 and retained on sieve #120, in order to remove any fine materials and large sand particles that may result in non-homogenous packing. Before each experiment, the sand was washed with deionized distilled water and autoclaved. Autoclaving was carried out at a temperature of 121oC and 15 psi pressure. Physical characteristics of this soil are presented in Table 2. Table 2: Penn Sand Characteristics SiO_2 99.40% Al_2O_3 0.13% Fe_2O_3 0.03% CaO 0.03% MgO 0.003% Na_2O 0.01% K_2O 0.020% TiO_2 0.02% MgO 0.01% SrO <0.01% BaO <0.01% Loss on Ignition 0.21% Organic Carbon 0.01% CEC (cation exchange capacity) 0.2 meq/100g Total 99.93% pH (water extract) 7.1 Data provided by Ricci Brothers Sand Co., Port Norris, NJ Batch and Column Sorption Experiments Sorption experiments were conducted for all surfactants. Sorption of surfactants is an extremely important factor for surfactant enhanced soil remediation procedures. Surfactants are amphiphiles with spatial variations in polarity; they adsorb at the solid-liquid interface. Batch sorption experiments were conducted to determine the sorptive properties of the selected surfactants. Batch tests were carried out in 25 mL Corning glass centrifuge tubes containing 2g of Penn sand and 25 mL of the selected surfactant solution varying in concentration. Mercuric chloride was added to suppress bacterial growth. The tubes were shaken on a rotary shaker for 24 hours. After equilibration the suspensions were centrifuged and the supernatant was analyzed for surfactant concentrations using a spectrophotometer (HACH DR-4000, Loveland, CO.). Blanks containing sand and surfactant only were also maintained to assess loss of surfactant to the glass surfaces or by volatilization. Glass chromatography columns 15 cm long and 2.5 cm in diameter (Kontes, Vineland, NJ) were used for column experiments. The column ends were fitted with stainless steel screens to prevent physical straining of fine particles of sand. Equal mass of Penn sand was dry packed in the glass columns with gentle tapping to ensure elimination of air entrainment. Columns were saturated with 0.01N $CaCl_2$ solution until steady state hydrodynamic conditions were established. Equal mass of the sand ensures similar porosity, bulk density and pore volume in the columns. Columns were saturated with deionized water. The effluent from the column was collected in 1-ml fractions and analyzed for surfactant concentration using a spectrophotometer (HACH DR-4000, Loveland, CO.). Experiments were conducted in duplicates at room temperature (20+1.5oC). A pulse of sodium nitrate, a conservative tracer was also introduced into the columns. Tracer experiments helped elucidate the transport characteristics in the columns. A schematic diagram of all column experiments is presented in Figure 1.

Principal Findings and Significance

Batch sorption of surfactants were adequately described by linear isotherms. The sorption coefficent for Tergitol NP-10 was determined to be 0.0069 L/g and that of Triton X-100 was 0.0021 L/g. These values indicate that Tergitol NP-10 has a greater affinity for Penn sand than Triton X-100. Based on these findings and those from other studies (Liu et. al., 1992; Urano et. al., 1984) it is reasonable to expect that sorption of surfactants is adequately described by linear isotherms at low concentrations. Linear adsorption isotherms simplify the representation of the adsorption process in mathematical

models and therefore enhance the predictive capablities of such models. Sorption of surfactants onto soil may increase the fractional organic carbon content of the soil, thereby modifying its sorptive capabilities. Sorption of surfactants onto soil may also affect the bioavailability of the surfactant for microbial degradation. In sorption studies with sediments and soils it has been shown that $K_p = f_{oc} K_{oc}$ where f_{oc} = weight fractionof organic carbon in the sorbent and K_{oc} = partition coefficient normalized for organic content The K_{oc} values for Triton X-100 and Tergitol NP-10 were calculated as 21 and 67 L/g respectively. Figures 2, 3: Sorption Isotherms for Tergitol NP-below and above the CMC Figure 4: Sorption Isotherm for Triton X-100 Column Studies: The transport of the surfactants was measured by continuous delivery at a constant pore water velocity of a solution containing the surfactant of interest. The solution was delivered by a multichannel, peristaltic cassette pump (Barnant Co.) through Teflon tubing. Experiments were run in the dark to inhibit photolysis. Parameters of the column experiments are given in Table 3. Table 3: Initial Parameters of Soil Column Experiments Column Length cm 15 Column Diameter cm 2.5 Bulk Density g/cm3 1.65 Volumetric Flow mL/min 0.45 Surfactant Concentration mg/L 25 Wet pore volume mL 25.76 Prior to the start of each column experiment, approximately 20 pore volumes of the calcium sulfate-sodium azide solution was applied in a upflow mode to equilibrate the column packing. Sodium azide was used to inhibit biodegradation. The input also contained a nonsorbing tracer sodium nitrate with which the surfactant breakthrough was compared. By weighing the column at the start and end of the experiment, it was determined that the column remained saturated during the tests. The average transport of a solute (v_{av}) relative to that of water (v_w) is defined asthe retardation factor, R, such that $R = v_{av}/ v_w$. The retardation factor is also defined in the advection-dispersion equation as $R = 1 + r_b K_p/n$ where K_p is the partition coefficient, n is the effective porosity and r_b is the bulk density of the porous medium. Retardation factors were determined for column experiments by where C is the column effluent concentration, C_o is the column influent concentration, q are the pore volumes, and q_{max} are the total pore volumes displaced when C= C_o. The area above the breakthrough curve up to $C/C_o = 1$ thus provided a measure of retardation. The breakthrough curve for the tracer is shown in Figure 5. By measuring the area above the breakthrough curve up to $C/C_o = 0.97$, R wasestimated at 1indicating that nitrate behaved as a nonsorbing tracer. The breakthrough curves (BTC) for Tergitol NP-10 and Triton X-100 are presented in Figures 6 and 7. The figures indicate that both surfactants were retarded compared to the tracer. The measured R values for Tergitol NP-10 and Triton X-114 are 10.71 and 4.88 respectively. Triton X-100 eluted more quickly as compared to Tergitol NP-10. The breakthrough for Triton X-100 was very asymmetric, with initial rapid breakthrough and a much slower elution during the duration of the experiment. Both BTCs exhibit a long slow increase in eluent surfactant concentration, indicating non-ideal sorption i.e., failure to conform to the assumption of local equilibrium. It is likely that the sorption of the surfactants involve a fast and a slow kinetic component. The slow component may involve surfactant diffusion to sorptive sites within sand particles or within sand organic matter. Furthermore diffusion of surfactants into polymeric matrix of the Teflon retainers on either end of the column may have contributed to the slow approach to $C/C_o = 1$. Using the batch sorption coefficient values for Triton X-100 and Tergitol NP-10, the R values were predicted for the column study. This data is presented in Table 3. Table 3: Comparison of R values for the Select Surfactants Surfactant R (Column Studies) R (Predicted from Batch Studies) Triton X-100 4.88 10.9 Tergitol NP-10 10.7 32.5 The above table indicates disparity in the column and batch test results. However these differences are consistent with the trend observed by other researchers (MacIntyre and Stauffer, 1988; Lion et al., 1990). These studies indicate that column R values averaged approximately 0.5 times batch values. The difference between the batch and column results for these surfactants maybe for a number of reasons. If sorption isotherm of the surfactants is assumed to be linear, there should be in theory, one single partition coefficient governing surfactant sorption in both types of experiments. Common explanations for inconsistent batch and column partition coefficients include: (a) Equilibrium was not attained in batch studies (b) Solids effects may have existed in batch experiments (c) Removal of fines, organic carbon in the solid phase occurred during column flow experiments; and (d) Column data was improperly interpreted. As noted by Brusseau and Rao

(1989), if tailing occurs, calculation of the column R values as the point at which C/Co = 0.5, or through the use of a spatial first moment will result in erroneous values. Conclusions: The results indicate that both nonionic surfactants can adsorb to soils with a low organic carbon content. Sorption of surfactants may retard the transport of the surfactant relative to that of a carrier fluid flowing through a soil, as well as decrease the amount of surfactant available for enhanced transport of hydrophobic compounds in porous media. The Tergitol NP-10 surfactant had higher sorption coefficient as compared to the Triton X-100.

Descriptors

Articles in Refereed Scientific Journals

Transport of Nonionic Surfactants, in preparation for Environmental Technology

Book Chapters

Dissertations

Water Resources Research Institute Reports

Conference Proceedings

Other Publications

Fate and Transport of Nonionic Surfactants, 1st Prize, Student Poster Competition, Annual Conference of the New Jersey Water Environment Association, May 2000, Atlantic City. Fate and Transport of Nonionic Surfactants, Poster Presentation, STEM (Science, Technology, Engineering and Mathematics) Symposium, Rowan University, April 1999.

Basic Project Information

Basic Project Information	
Category	Data
Title	Removal of the Invasive Exotic, Lythrum salicaria (Purple
Project Number	10
Start Date	03/01/1999
End Date	02/29/2000
Research Category	Biological Sciences
Focus Category #1	Ecology
Focus Category #2	Wetlands
Focus Category #3	Treatment
Lead Institution	New Jersey Water Resources Research Institute

Principal Investigators

Principal Investigators			
Name	Title During Project Period	Affiliated Organization	Order
Karin L. Licsko	Student	Rider University	01
Mary Allessio Leck	Professor	Rider University	02

Problem and Research Objectives

Our wetlands today are in danger of being destroyed by invasive plants, such as the Lythrum salicaria, known as Purple Loosestrife. Lythrum salicaria flourishes in wetland habitats that have been disturbed, or degraded from draining, bulldozing, shore manipulation, or dredging (Bedford, 1999). Lythrum salicaria is so aggressive that it crowds out native plants that are used by wildlife for food and shelter. It has no wildlife food or shelter value, so where it invades, wildlife habitat is destroyed. Once established it can destroy marshes, wet prairies, and choke waterways (Missouri Department of Conservation, 1996). Invasion of Lythrum salicaria into a wetland system results in suppression of resident plant community and the eventual alteration of the wetland's structure and function, such as threatening and endangering native wetland plants and wildlife like local bulrush, spike rush, and the bog turtle (Malecki et al., 1993). Three commonly cited factors have been attributed to the invasiveness and negative impact of Lythrum salicaria. These factors are (1) it is not used by native fauna either as a food source or as habitat, (2) it has no natural predators to regulate its population growth, (3) it out-competes native vegetation and thereby reduces diversity (Treberg & Husband, 1999). Thus, species richness should be lower in areas where Lythrum salicaria has become established. Diversity is measured in terms of number of species and their relative abundance. If diversity is a function of the diversity of wetland templates in a given region, then measuring landscape diversity means identifying the kinds, numbers, and abundance, which would reveal the wetlands that have suffered the most extensive losses (Bedford, 1999). The control of invasive species has become one of the most important battles in the fight to maintain the earth's biodiversity (Muth & Hamburg, 1998). Developing an effective control program for Lythrum salicaria has important implications for wetland management throughout the continent (Gabor et al., 1996). The Hamilton/Trenton Marsh, located in an ancient meander just south of Trenton, NJ, is the northernmost tidal freshwater wetland on the Delaware River, NJ. To compensate for loss of ~15 ha of tidal and non-tidal wetlands due to highway construction between 1984 and 1994, a 38.9 ha wetland was created adjacent to the Delaware River on Duck Island. This new wetland site is within 1 km of an extensively studied natural marsh (e.g., Leck & Simpson, 1987). Creation of this wetland was begun in 1993 and completed in 1994. When completed, there were edge marsh areas, eight islands of varying sizes, 1 km of tidal channels, and four short inlets connecting the channels to the Delaware River. Construction of the east marsh was completed in fall 1993, with some flooding and deposition of flotsam occurring during January floods. The south marsh was completed during November 1994. By summer 1995, Lythrum salicaria was widely established and a conspicuous component of the vegetation. Our objective was to document the impact of Lythrum salicaria on plant species diversity and plant biomass (reproduction potential) at the Duck Island constructed wetland. Based on the report in the literature (e.g., Bedford, 1999), one would expect Lythrum salicaria to cause significant reduction in the diversity and reproduction potential of other species in the sites; however, the impact will be greater in the south marsh where it was so dense during the previous growing season.

Methodology

Two methods of reducing Lythrum salicaria cover were used: removal of adult plants including standing dead from 1998 growing season and new growth and the clipping of all above ground shoots. The

following treatments were used; each was replicated five times (n = 25): 1. Clipping- once, early in growing season (May 17, 1999) 2. Clipping- twice, early in growing season (May 17, 1999) and mid season (July 26, 1999) 3. Clipping- biweekly (9 times) 4. Litter removal 5. Control The entire experiment was set up in both the east and south marsh sites that are accessible by foot and had a high cover of Lythrum salicaria during 1998 as determined by the presence of litter. Grids were located parallel to tidal channels and where Lythrum salicaria density was uniform. A grid 8 m x 18 m with 2 m x 2 m plots was flagged on May 17, 1999. Individual plots for treatment were selected on the grid for both marshes. The plots were monitored until August 31, 1999. After the four-month period, a 1 m2 hula-hoop was placed in the center of each plot and the percent cover or presence of each species within it was recorded. All species within the hula-hoop were then cut out at ground level and placed in plastic trash bags to be transported back to Rider University. Each species within a bag was separated and wrapped in newspaper to be dried in large drying ovens at Rutgers University. Once dried, the plants were weighed and recorded. Data were analyzed using an unpaired t-Test to compare the mean percent cover and dry weights of the south and east marsh. A two-way ANOVA was used to determine if the five treatments had an effect on the species present at each marsh site. Spearman Correlation Coefficient test was used to determine if the percent cover of Lythrum salicaria had an effect on the total number of species present or the percent cover of species in both marshes.

Principal Findings and Significance

Unpaired t-Tests, comparing species percent cover and dry weights showed that dry weights in the south and east marsh were not significantly different from each other. This is probably due to the high degree of variability in the south marsh samples. However, percent cover data of south and east marsh were significantly different. Two-way ANOVA tests were then performed to compare both marshes and to test the effect of treatment on dry weights and percent cover. These tests showed: a significant difference in dry weights between the south and east marsh; no significant effect of treatment or interaction between location and treatments; significant difference between the south and east marsh with respect to percent cover; and no significant difference between each treatment or between location and treatments. Spearman Correlation Coefficient tests were also used to determine for both marshes the relationship of Lythrum salicaria percent cover versus total number of species and percent cover species. There was no significant correlation between percent cover of Lythrum salicaria and the total number of species nor with percent cover species in the south marsh. There also was no significant correlation between percent cover of Lythrum salicaria and the total number of species nor with percent cover species in the east marsh. The percent frequency of the cover plant species in both the south and east marsh showed that the east marsh was more diverse and had a greater number of cover species. However, Lythrum salicaria had a greater percent frequency in the south marsh. Overall, the east marsh had greater species richness than the south marsh when comparing the different treatments to the total number of species and the cover species. Compared to the control, clipping twice, clipping biweekly, and litter removal had a greater affect on the mean percent cover of Lythrum salicaria in the east marsh than in the south marsh. However, clipping once had the greatest affect on Lythrum salicaria in the south marsh. The mean productivity of the south marsh without Lythrum salicaria included was greater for clipping biweekly and the control compared to the east marsh where clipping once, clipping twice, and litter removal had the highest productivity without Lythrum salicaria. Overall, the removal treatments caused a significant reduction in mean productivity of Lythrum salicaria in the south marsh than in the east marsh, except for clipping twice and clipping biweekly. Removal treatments of Lythrum salicaria in two locations in a tidal freshwater marsh showed no effect on either productivity or species richness of other species. Dry weights in the south and east marsh were not significantly different from each other. However, when one examines the mean dry weights separately for the south and east marsh, the disparity between them is quite apparent. The lack of an impact of Lythrum salicaria removal on

productivity was related to the very high degree of variance in the dry weights of the south marsh. The percent cover of non-Lythrum salicaria species was significantly lower in the south marsh. This is probably due to Lythrum salicaria having a greater impact in the south marsh where it was so dense. In contrast, the east marsh is subject to more deposition of water borne flotsam that affects vegetation dynamics and Lythrum salicaria density from year to year (personal observation). The ANOVA tests show that there was a significant difference between the south and east marsh with respect to dry weights and percent cover of all species. This contradicts the t-Test dry weight statistics, but shows that the high degree of variance in the south marsh affected the results of the t-Test. The dry weights and percent cover did not vary among treatments and there was no significant difference between the locations and treatments. This means that the effect of treatments in both marshes were similar. The Spearman Correlation Coefficient test shows that the percent cover of Lythrum salicaria is not directly correlated with the total number of species or the percent cover species. The coefficients are negative values, so there should be an inverse relationship between percent cover of Lythrum salicaria and total number of species and percent cover of species. There is no significant trend in the south or east marsh. However, the number of total and cover species in the east marsh increases when percent cover of Lythrum salicaria increases. This could be due to the east marsh having an impact of flotsam and a greater opening of Lythrum salicaria cover, allowing for greater layering than the south marsh. Overall, the east marsh was more diverse and had the highest species richness in all treatments than the south marsh. The treatments in the south marsh affected the productivity of Lythrum salicaria and other species more than in the east marsh probably due to the location of the south marsh. Our study showed that the location of the marsh affected the percent cover and dry weights of Lythrum salicaria and other species. The five treatments also had an effect on Lythrum salicaria and other species that varied depending on the marsh location.

Descriptors

Purple Loosestrife Lythrum salicaria Plant diversity Hamilton/Trenton Marsh Marsh Biomass

Articles in Refereed Scientific Journals

Book Chapters

Dissertations

Water Resources Research Institute Reports

Conference Proceedings

Other Publications

Basic Project Information

Basic Project Information	
Category	**Data**
Title	Scaling of saturated hydraulic conductivity and dye-stained flow pathways
Project Number	02
Start Date	03/01/1999

End Date	02/29/2000
Research Category	Climate and Hydrologic Processes
Focus Category #1	Sediments
Focus Category #2	Solute Transport
Focus Category #3	Hydrology
Lead Institution	Rutgers University

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
Daniel Gimenez	Associate Professor	Rutgers University	01

Problem and Research Objectives

Modeling transport processes in structured (heterogeneous) soils is of capital importance for a range of applications from hydrology to environmental planning. For instance, regulation of pesticide use and impact of present and future releases of nuclear waste to the environment rely increasingly on simulation models that predict transport and fate of contaminants in the soil subsurface. Models currently used by consultants and regulatory agencies to predict the fate and transport of chemicals in soils were generated from laboratory data using homogeneous soils, and do not perform satisfactorily under field conditions (Jury and Flühler, 1992). Saturated hydraulic conductivity, ksat, is a transport coefficient used as an indicator of pore sizes and connectivity. Spatial variability of ksat may also be an indicator of preferential flow of water in soil, i.e., highly variable measurements may reveal that certain areas of soil offer less resistance to water movement than others. If the scaling properties of ksat and preferential flow of water in soil are similar, ksat could be used to predict the potential for preferential flow of water of a given soil. Typically, scaling of ksat has been studied using semivariograms with separation intervals much larger than the diameter of the samples. Statistical properties of ksat measurements are a function of the soil volume used for determination (Anderson and Bouma, 1973; Zobeck et al., 1985; Lauren et al., 1988; Mallants et al., 1997). Liu and Molz (1997) showed that vertical measurements of ksat presented a multiscaling distribution evidenced by higher variability at small scales than at larger scales. Giménez et al. (1999) used the method of the moments to study scaling of ksat from the data sets in Anderson and Bouma (1973); Lauren et al. (1988); and Mallants et al. (1997). In this project we are working with a soil of the Freehold/Collington series to: · integrate models and observations of saturated hydraulic conductivity and dye-stained flow pathways over scales ranging from a few cm to several meters. · develop functional relations between model parameters characterizing saturated hydraulic conductivity and dye-stained flow pathways in soil.

Methodology

The experimental part of this project did not start as planned because of the drought that affected New Jersey during the summer of 1999. The experiment will be carried out during the summer of 2000 in The Rutgers Plant Science Research and Extension Farm in Adelphia (Monmouth County) on a soil of the Freehold/Collington series. The experimental work will be divided into two parts: · Determination of dye-stained flow pathways will be achieved in the field applying the dye Brilliant Blue FDF on plots of about 1 m2. Images of dye stained areas will be captured with a digital camera under controlled light

conditions. Image analyses will be used to separate areas of different concentration according to the technique of Ewing et al. (1999). · Determination of ksat will also be done in the field using single-ring infiltrometers of different sizes. Saturated hydraulic conductivity will be obtained using the technique recently proposed by Wu et al. (1999). Measurements will be taken in a spatial pattern (Fig. 1) that will allow the constructions of semivariograms with a maximum lag of about 8 meters (Zavattaro et al., 1999). Variability from the smallest infiltrometer area will be integrated using a combination of a semivariogram and the quotient of the variability of infiltration measured with several infiltrometer sizes (Zhang et al., 1990). Data Analyses During the first stage of this project, study of applications of multifractal theory in relation to scaling of saturated hydraulic conductivity (see below) was completed. In this context, we used Matlab 5.3.1 to develop software to calculate a multifractal spectrum from spatial data. Matlab 5.3.1 will be used for image analyses of dye stained patterns. Figure 1. Diagram of measurement locations (after Zavattaro et al., 1999)

Principal Findings and Significance

Our interest is in studying scaling properties of saturated hydraulic conductivity at small scales. Multifractal techniques are promising tools that have been applied to the characterization of the scaling properties of various geophysical properties (Muller and McCauley, 1992; Cheng and Agterberg, 1996). Liu and Molz (1997) applied a multifractal technique to the distribution of saturated hydraulic conductivity, but covering scales of meters to kilometers. As a first step, we decided to use data published in the literature to study the applicability of multifractal methods to the characterization of the scaling properties of saturated hydraulic conductivity at small scales. A literature survey revealed three publications that contained data on saturated hydraulic conductivity suitable for this objective: Mallants et al. (1996), Mallants et al. (1997), and Lauren et al. (1988). The last two publications were also analyzed by Giménez et al. (1999) using a different technique than the one presented here. The technique of Chhabra and Jensen (1989) was used to obtain the multifractal spectrum of ksat sampled along transects from: a) the A horizon of a well-drained sandy soil using three samples of increasing length, b) the A, B, and C horizons of the same soil, using a small sample volume, and c) the B horizon of a silty clay loam soil using five sample sizes of increasing area perpendicular to the flow (see Table 1 for details on sample dimensions). Table 1. General characteristics of the analyzed data bases. Reference Sample Soil horizon Sample area (m2) Sample length (m) Mallants et al. (1996) M96-I Ap 2.0x10-3 5x10-2 60 M96-II C1 2.0x10-3 5x10-2 60 M96-III C2 2.0x10-3 5x10-2 60 Mallants et al. (1997) M97-I Ap 2.0x10-3 5x10-2 60 M97-II Ap 3.0x10-2 2x10-1 30 M97-III Ap 7.2x10-2 1 30 Lauren et al. (1988) L-I B2t 1.5x10-2 6.0x10-2 35 L-II B2t 3.0x10-2 2x10-1 37 L-III B2t 2.5x10-1 2x10-1 37 L-IV B2t 9.0x10-1 2x10-1 36 L-V B2t 1.2 2x10-1 37 The multifractal properties of a distribution of sample values were evaluated examining the multifractal spectrum as well as variations on the generalized fractal dimensions for order moments varying between -10 and +10. The multifractal spectrum is defined as the relationship between the fractal dimension f(a) that corresponds to the region characterized by a scaling coefficient a. The generalized fractal dimensions Dq are obtained from the scaling of the moment of order q. The f(a) and Dq are interrelated. For instance, f(a=1) is the fractal dimension Dq=1 known as the entropy dimension. The Dq=1, or D1, characterizes the degree of disorder present in a distribution. Values of D1 close to 0 represent heterogeneous distributions, whereas D1 with values close to 1 are typical of homogeneous distributions. Due to space limitations only entropy dimension will be discussed here. The multifractal properties of a distribution were function of both sample length and sample area (Fig. 2 and Fig. 3). Smaller volumes, resulting from shorter samples or smaller area perpendicular to flow, exhibited more heterogeneous distributions and, therefore, stronger multifractal properties than larger sample volumes. Since D1 is a measure of heterogeneity, it offers the potential to be used as a scaling parameter. Values of D1 calculated from the Lauren at al. (1988) and Mallants et al. (1997) data sets, increased as a function of sample volume, in

agreement with the notion that increasing sample size decreases the variability of the measurements (Fig. 4). Given the well-defined relationship between D1 and sample volume, D1 can potentially be used to scale distributions. It should be noted that changes in volume are caused mainly by either variation of sample length (Mallants et al., 1997) or sample diameter (Lauren et al., 1988). The multifractal spectrum was also sensitive to the different soil horizons present in a profile (M96). The large heterogeneity, typical of surface horizons, is manifested in the wider spectrum of the Ap horizon of M96 as compared to the spectra of either C1 or C2, which show very little difference between them (Fig. 5). In summary, during the first part of the project we have implemented and applied multifractal analyses to the study of scaling properties of saturated hydraulic conductivity. The results are promising and will be reported in a peer-reviewed publication. The experience gained through this exercise will be applied to the field experiment in the Freehold/Collington soil series to analyze both dye-stained patterns and infiltration data.

Descriptors

Multifractal, spatial variability, hydraulic conductivity, infiltration, dye, scaling

Articles in Refereed Scientific Journals

Giménez, D. and A. Posadas. Multifractal properties of saturated hydraulic conductivity (in preparation).

Book Chapters

Dissertations

Water Resources Research Institute Reports

Conference Proceedings

Other Publications

Basic Project Information

Basic Project Information	
Category	**Data**
Title	The role of riparian habitats and stream networks in facilitating the spread of exotic species
Project Number	04
Start Date	03/01/1999
End Date	02/29/2000
Research Category	Biological Sciences
Focus Category #1	Conservation
Focus Category	Ecology

Focus Category #2	Ecology
Focus Category #3	Wetlands
Lead Institution	Rutgers University

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
Colleen A. Hatfield	Associate Professor	Rutgers University	01

Problem and Research Objectives

Few if any ecosystems remain that have not been affected by invading species, either through natural invasions or by anthropogenic introductions. While the paleological records reveal that invasions are not uncommon (Graham 1988, Vermeij 1991), what has changed in the recent past is the acceleration of invasion events, often anthropogenically induced. Invading species can alter ecosystem function (D'Antonio and Vitousek 1992), population dynamics (Pulliam 1988) and community structure (Olsen et al. 1991, Nalepa and Schloesser 1993). Considerable effort has been directed towards trying to better understand invasion dynamics in an attempt to improve our ability to identify what makes a system, community or specific species more susceptible to invasion, or how and when invading species might disrupt system function (Crawley 1986, Drake et al. 1989). We are beginning to gain some insight into certain aspects of invasion dynamics, such as common traits that frequently characterize successful invading species (Townsend 1991, Lodge 1993), but there still remains a large disparity between what we do know about invasion dynamics and what we need to know in order to understand and effectively manage invading species in ecological systems. The spatial distribution of habitat resources is integral to the abilityand propensity of invading species to become established and spread through the system, across systems and over the landscape. In addition, the physical characteristics and biotic processes that closely link a particular community to the environment are important considerations in determining a system's susceptibility to invading species as well as the potential for the organism to spread to the surrounding environment (Case 1991, Hengeveld 1994). This proposed research will focus on if and how the spatial configuration and associated characteristics of a habitat might facilitate the spread of exotic species. Stream networks and associated riparian habitats will be used as model systems to study how the spatial connectivity and configuration of habitat resources might influence the extent of exotic riparian plant distributions in drainage networks. In heavily populated regions such as New Jersey, protected areas set aside in preserves, parks, watersheds, greenways and forests continue to experience multiple stressors including declines in water quality and species biodiversity, and increased fragmentation in bordering land. Each of these stressors can potentially prime the system for the establishment and spread of invading species. Thus understanding how features of the system potentially increase or decrease its susceptibility to invading species are important in the ability to manage and protect the biodiversity and ecological functioning of an area. The primary objectives of this research are to: · examine the role of stream network geometry in facilitating the invasion of exotic species. Emphasis will be placed on exotic riparian species since their tight association with the riparian zone will provide the best indicators of the role of stream network configuration. Upland species will be enumerated but not used in considering the role of network geometry since they could potentially enter the system from either the riparian zone or the adjacent upland. Within this objective we will test the hypothesis that the spatial configuration of habitat resources influences the extent of habitat occupied by

exotic species. · assess the vegetation community composition of the riparian zone and how species patterns shift in relation to network position. This information will help assess the relative magnitude of influence invading species may have on riparian communities. The information gathered in this objective will test some of the hypotheses that have been found in other riparian systems, specifically that riparian communities are more species rich than the surrounding habitat, that riparian zones tend to support greater exotic species, and that exotic species can potentially alter species diversity. · relate the physical environment to community characteristics. Physical features (flow dynamics, soil composition, etc.) can be important factors in determining a system's susceptibility to invading species. This objective is essential in studying the relationship between community composition and the environment and allows me to test the hypothesis that exotic species distributions are related to the stream network versus the local physical environment.

Methodology

The Wawayanda watershed was chosen as the study watershed since it was relatively undisturbed by development, a large proportion of the watershed was within a state park and the stream network was well developed and drainage patterns definable. Fieldwork was conducted from June to August 1999. A total of fifty-eight plots were sampled along the main stream channel and 9 tributaries associated with Wawayanda River (Table 1, Figure 1). Study sites were placed every 250m along the main channel and on all tributaries. A 25x10m plot was laid out with the long axis paralleling the stream channel and one side of the plot adjacent to the stream bank. The side of the stream to place the plot was randomly selected except in situations where one side of the stream channel was too steep or not indicative of riparian habitats. Vegetation was measuring using the Modified Whittaker Plot (Fig 2, Stohlgren et al. 1998). Percent cover was determined for herbs in the 1m2 subplots and presence/absence recorded in each of the larger subplots. Also in the larger subplots, tree and shrub species were identified, dbh and height recorded for trees and height, width and depth as well as number of stems recorded for shrubs. Canopy cover was determined using adensiometer at each of the 1m2 subplots and averaged to provide an average canopy cover for the study site. The percent of the plot covered with rocks or woody debris was approximated to the nearest 10% for the plot and distance and direction to disturbance was recorded. GPS readings were also taken at each site. Composite soil samples to a depth of 10 cm were collected in a minimum of nine locations throughout the sample plot. Soil samples were weighted, air dried and again weighted to determine percent moisture content. Soils were analyzed for organic matter content by loss on ignition (Storer, D.A. 1984), and soil texture was determined by the hydrometer method (Bouyoucos 1951). Soil pH, phosphorous and total nitrogen were also determined for the composite soil samples for each site (SCS 1988). Liter depth was recorded and averaged across the plot and profiles for the valley and stream channel were determined. The slopes of the riparian zone and stream channel were also measured.

Principal Findings and Significance

Data analysis To date efforts have been concentrated in characterizing the Waywayanda drainage system and trying to understand patterns in species distributions. This base-line understanding is essential and will be used to place into context the influence of the drainage system on the distribution and potential susceptibility to invasive species. The plots were classified into one of five vegetation categories based primarily on vegetation characteristics: forest, forested wetland, marsh, shrub, and shrub-carr. Forest sites were those where the tree canopy was the dominant vegetation strata. These sites were more typical of floodplain forested communities. Forested wetlands (swamps) had a high percentage of sub-canopy and canopy trees, but also a high percentage of herbaceous wetland vegetation. Marshes were wetlands in which the herb layer was greater than 60% of the vegetation, and

may have include a high proportion of low shrubs, but very few taller plants. In the shrub category, low and high shrubs including Vaccinium corymbosum, Lindera benzoin, Berberis thunbergii, and Hamamelis virginiana dominated the study plots. Shrub-carr wetlands, had a very high herb and medium shrub layer, but was also mixed with a relatively high percentage of small understory trees, such as Acer rubrum, Alnus rugosa, and Betula populifolia. The majority of the sites were classified as forested (35 sites) and frequently vegetation classes were interspersed with other vegetation classes on the main channel as well as on the tributaries. Species richness varied along the main channel from the upper reaches of the stream network to the basin outlet. A moving window procedure, which averaged richness for a site and its upstream and downstream neighbor, was used to examine general trends in species richness from upstream to downstream (Fig 2). Herb species richness (13.2±5.5) was greater at the majority of the sites with the highest herb richness in the mid-portion of the main channel and the downstream portion of the study area. Shrub richness (4.2±2.5) was generally lower than tree species richness (5.96±2.5). Previous studies have shown that species richness tends to increase from headwaters downstream (Tabacchi et al. 1995 , Gregory et al. 1991). Such a trend was not observed for the Waywayanda drainage possibly due to the relatively small size of this drainage compared to other studies that have examined large drainage systems. The larger drainage systems also had a stronger anthropogenic influence in the lower reaches of the drainage systems than was present in this study system. Species richness in the tributaries was generally higher than in the main channel (Fig. 3) which contrasts with previous studies which have found that species richness was higher in the main channel (Nilsson 1994). Main channels are thought to support higher species richness since there is generally greater habitat heterogeneity along the main channel and it also acts as a species pool for upstream contributions from both the main channel and the tributaries. For the Waywayanda drainage network however, tributaries tended to have more rare species that do not occur in the main channel and in some instances are found in only one tributary. Nonparametric ordination techniques are useful for examining how community composition varies between sites. I used detrended correspondence analysis (DCA - Hill and Gauch 1980) to examine how species composition varied by a number of attributes including tributaries versus main channel, stream order and wetland vegetation class. I performed DCA's for each of the vegetation strata using Canoco (Version 4.02, ter Braak 1991). For the tree stratum there was no separation in ordination space by tributary or main channel with respect to species composition (Fig 4A). The main channel sites were concentrated on the right of the tree ordination and several tributaries were tightly clustered in ordination space indicating similarity in species composition between sites located on the same tributary (e.g. Tributary C, E and I). For vegetation class, forested sites separated from other wetland types on DCA axis 2 (Fig 4B). Otherwise there was considerable scatter in the data for vegetation class indicating that there was considerable overlap in species composition between sites in different vegetation classes and the vegetation at sites within a class was not more similar to each other than sites in other classses (Fig 4C). For the shrub and herb strata, there was also considerable scatter in the data (Figures 5 and 6). Some sites on the same tributary clustered more tightly for shrubs (e.g. Trib A, D, E and H for shrubs - Fig 5A) and others for herbs (Trib A, E and H - Fig 6A). However, the majority of the sites were not distinct with respect to species composition. Shrub carr was the only vegetation class that showed similarity between the sites for the herb stratum (Fig 6B). The ordination results indicated that in general, the species composition did not distinguish sites with respect to where they were located in the drainage, which vegetation class characterized the site, or the size of the stream (order). In many instances there was considerable overlap between sites indicating that sites had many species in common. I used Sorenson's Index (Ludwig and Reynolds 1988) to examine if sites next to each other on the main stream channel were similar in species composition. The index compared similarity in species composition between a site and its upstream neighbor. In general, adjacent sites were quite different in species composition for all three strata (Fig 7). Not surprisingly, tree species composition was more similar between sites and herb composition was least similar of the three strata. Trees have a wider dispersal envelope while herbs often tend to be more localized and site specific. Although the ordination results indicated considerable overlap in species composition, this measure

would suggest that sites next to each other are not necessarily the ones driving this pattern. Further analysis need to be done to tease apart this pattern. Future Analysis: As mentioned previously, the descriptive analysis of the Waywayanda watershed will be important in understanding the influence of the physical environment including the configuration of the stream network in the distribution of plants. Further analysis is to be done to relate the vegetation patterns to soil properties and stream and valley geomorphic features. Once we have an understanding of what factors are important in determining vegetation distributions throughout the network, we will be able to examine if invasive species respond in a similar manner as native vegetation and if not what factors might contribute to this variation.

Descriptors

stream networks, riparian vegetation community

Articles in Refereed Scientific Journals

None to date, but a minimum of two articles are anticipated from this work

Book Chapters

Dissertations

Water Resources Research Institute Reports

Conference Proceedings

Presented at the following meetings: Hatfield, C.A. Changes in species diversity at the scale of the stream network. 15th Annual Symposium. U.S. Regional Association of the International Association of Landscape Ecology. April, 2000 Fort Lauderdale, Florida Hatfield, C.A. The role of riparian habitats and stream networks in facilitating the spread of invasive species. Ecological Society of America Annual Meeting. August, 2000. Snow Bird, Utah.

Other Publications

Basic Project Information

Basic Project Information	
Category	**Data**
Title	Source Area Diffusivity of Methyl Tert-butyl Ether (MTBE) in Groundwater Systems
Project Number	08
Start Date	03/01/1999
End Date	02/29/2000
Research Category	Ground-water Flow and Transport
Focus Category #1	Groundwater

Focus Category #2	Models
Focus Category #3	Solute Transport
Lead Institution	Rutgers University

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
Daniel K. Lefkowitz	Student	Rutgers University	01
Christopher G. Uchrin	Professor	Rutgers University	02

Problem and Research Objectives

This research focuses on the development of a laboratory fate and transport model, which will be critical for predicting source area concentration levels of the gasoline additive, Methyl tert-Butyl Ether (MTBE), in the soil atmosphere. Based on the data generated on fate and transport from an experimental laboratory model, it is possible to develop a mathematical model on the movement of MTBE to human receptors in a variety of soil types. Furthermore, the model developed here could be the focal point for risk assessments or exposure studies that would cover effects on human health and environmental health. The model will be able to provide estimations of the unsaturated zone concentration downgradient of an MTBE source, such as a leaking underground storage tank. The advantage of the proposed model is that important parameters can be validated in the laboratory system, which reduces uncertainty in mathematical models. These predicted soil gas concentrations could also be important for effective treatment processes such as soil vapor extraction and air sparging.

Methodology

In order to model the volatilization of MTBE from a source area into the soil atmosphere, we will conduct a number of experiments. These experiments will each deal with particular elements of the model. Upon completion of these elements, we will attempt to piece them together to build the three-dimensional model. To study all of the transport and loss mechanisms, the following experiments will be conducted: an extensive adsorption batch study on all of the different aquifer solids, an extraction study where a method is developed for the extraction of MTBE from soil, and flow-through column studies that attempt to account for area source diffusivity and soil moisture effects. The first study to be done is a batch study. A batch study involves placing a known amount of soil, water, and MTBE into a sealable vial of known volume. The soil only partially fills the vial, leaving free space above the soil, which is called the headspace. The headspace can be analyzed for MTBE(which volatilizes into the headspace from the liquid) by using a syringe to draw out a gaseous sample and then injecting it into a gas chromatograph (GC; HP 5890, with Flame Ionization Detector). Typically, only a gaseous sample is injected, and then the liquid/soil concentrations are back-calculated using Henry's Law. However, we have developed a method using a Suppelcowax column in the GC which allows us to inject both gaseous and liquid samples. The basic premise behind a batch study is to determine the soil concentration, that is, MTBE that has sorbed onto the solids. This is accomplished by using a simple mass balance: the difference between the initial liquid concentration and the MTBE in the headspace + liquid concentration is the mass on the solids. Initial results and previous studies have shown that

MTBE can and will adsorb to some high organic matter soils. A number of different soil types will be used in this study, which were selected to give a representation of the general soil series found in New Jersey. The first soil used in most of the experiments is Cohansey sand. This is a well-studied sand with a relatively high organic matter content (1.44%). Other soils may include the following: Neshaminy sand, an undetermined shale soil, a farm soil, an acid washed sand, and glacial till taken from the overburden of a fractured rock aquifer in Sussex county. The final experiment proposed by this research is a flow-through column study. This phase actually consists of several experiments. The first experiment is an attempt to model the source area diffusivity of MTBE through the soil atmosphere. Here, four glass columns are set up of three different heights: 2', 6', and 8' (two sets of each heights). An example of one of these series of columns is pictured in Figure 6. MTBE is injected into the base of the column (through the bottom sealable port), and samples are taken over time using a syringe from the top of the column (through a sealable port at the top) and immediately injected into the GC. The study will be done at two different soil moistures: 2%, which is represented by air-dried soil (used to maximize porosity), and 33%, which represents field capacity, i.e., close to field conditions. It is important to note that in the column systems, biodegradation will not be considered. As is shown in the literature due to time/kinetic considerations, as well as the high concentrations that are associated with a source area, we will assume that the loss due to biodegradation will be minimal compared to volatilization and adsorption. The next column experiment will be done with the columns in a horizontal position. This will allow for the incorporation of gravity effects into the model, and can account for the horizontal movement of MTBE with groundwater. Extraction Method Development Since many studies have shown the ubiquity of MTBE throughout New Jersey, it is important to ensure that the soil samples we have taken contain levels of MTBE below detection limits. Unfortunately, no standard method exists for the determination of MTBE from soil samples, so a method must be developed. The method involves a multi-step approach, which includes the determination of the best solvent and column, and to spike actual samples and determine the recovery/detection. After the determination of the best solvent and column, a simple liquid-solid extraction is used. Soil samples are spiked with pure MTBE, and then the extraction solvent is added. The sample is vortexed and allowed to stand for 15 minutes. Then the supernatant liquid is removed using Pasteur pipettes and immediately discharged into GC vials. The vials are then sealed and the sample is ready to be injected into the GC. The experiment scenario is as follows: PHASE I 1. Standard Curve, using dedicated syringes First set of standards in water Second set in toluene Then inject hexane, methylene chloride, ether, octanol, 2-propanol, methanol 2. Spike 10 ml of water with 25ul of MTBE. Then add extraction solvent, vortex the sample, extract off supernatant liquid, and inject into GC using 2ul injections. Preparations: 1. Phase I BOTTLE max = (10 ml DI water + 25 ul MTBE + 5ml of solvent) Each done in quadruplicate: 1. 5 ml extraction solvent + 25 ul MTBE, cap, do not shake (no water) 2. 10 ml DI + 5 ml extraction solvent 3. 10 ml DI + 25 ul MTBE + 5 ml extraction solvent Repeat with the Suppelcowax and RTX-5 100m columns PHASE II To 5 g of soil, add 25ul of MTBE, vortex with extraction solvent, allow to settle and run on best column Each done in quadruplicate: 1. 5 g of soil + 5 ml of extraction solvent 2. 5 g of soil + 25ul of MTBE + 5ml of extraction solvent 3. 5 g of soil + 25ul of MTBE + 5ml of water 4. 5ml of extraction solvent + 25ul of MTBE 5. 5ml of water + 25 ul of MTBE 6. water blank 7. solvent blank Repeat with various soils Soil Sampling Extensive soil sampling will be done at the Cranberry Lake site. Soil samples will be taken from seven locations that are either around the lake or near the homes. These samples attempt to represent the major soil types in the area. All are surface samples (depending on the rockiness, no more than 2' deep) from the overburden above the fractured rock aquifer. Most of the sampling will be done with a hand agar. The samples will then be placed in sealable jars, put in plastic bags, placed in an ice chest and returned immediately to the lab to be analyzed. A trip blank will be brought along for quality control. In addition, we have developed a method of sampling soil gas. The method consists of building a welded steel pipe about 2" in diameter and 24" long, with a wider 6" long barrel on one end. The narrower end is inserted into the round, and a heavy mallet is used on the barrel end to drive the pipe down. The pipe is rotated and the sample is pulled up and sealed.

Principal Findings and Significance

Several of the proposed experiments have preliminary results. As is seen in Figure 1, MTBE partitions both to the water and vapor phase. As the concentration in the headspace decreases, the aqueous concentration generally increases until equilibrium (following Henry's Law). Figures 2 and 3 demonstrate the uptake of MTBE to two different soil types. The data in Figure 2 are from experiments done using Cohansey sand, and in Figure 3, Neshaminy soil. Results from the column study, in which MTBE vapor diffused through different lengths of glass columns filled with Cohansey sand, can be seen in Figure 4. It is interesting to note that the breakthrough times of MTBE were not linear with respect to length of column. Whereas the four foot column showed breakthrough of MTBE vapor at about five hours, the six and eight foot columns had breakthrough at 20 and 55 hours, respectively. This experiment will be run again at different temperatures, soil moistures and column lengths. To further quantify the diffusivity of MTBE from a source area, more column experiments will be performed. The first is to change the soil type. We intend to use not only the Cohansey, but also a Neshaminy sand and a glacial till taken near Cranberry Lake in Byrum Twp., NJ. The column experiments at the different lengths (including duplicates of each) and soil moistures will be repeated for each soil type. Following the vertical diffusivity experiments, we will orient the columns horizontally to determine the effect of gravity, and to investigate horizontal flow. The experiments will be repeated as before.

Descriptors

groundwater, models, methyl tert-butyl ether, fate and transport, source area

Articles in Refereed Scientific Journals

Daniel K. Lefkowitz, Mark Zambrowski, and Christopher G. Uchrin, Spring 2000, Fate and Transport of Methyl Tert-Butyl Ether in Groundwater systems: Preliminary Results, Effluents, Volume: 33, #5.

Book Chapters

Dissertations

Water Resources Research Institute Reports

Conference Proceedings

Lefkowitz, D.K., Zambrowski M., Uchrin C.G., Rutgers University, New Brunswick, NJ. Fate and transport modeling of methyl tert-butyl ether in groundwater systems. In Proceedings from the Society of Environmental Toxicology and Chemistry (SETAC), 20th Annual Meeting: Sustaining Global Environmental Integrity, November 14-18th 1999, Philadelphia, PA. pg 263, #PWA239.

Other Publications

Basic Project Information

Basic Project Information	
Category	**Data**
Title	WATERSHED DISTURBANCE IN THE NEW JERSEY PINELANDS:
Project Number	05
Start Date	03/01/1999
End Date	02/29/2000
Research Category	Water Quality
Focus Category #1	Ecology
Focus Category #2	Methods
Focus Category #3	Water Quality
Lead Institution	Rutgers University

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
Michael V.K. Sukhdeo	Associate Professor	Rutgers University	01
Alexander D. Hernandez	Student	Rutgers University	02

Problem and Research Objectives

In New Jersey, the Pinelands is a region of over a million acres of forests and farms nestled in the center of one of America's most populous regions. Introduced plants, mammals, birds, reptiles, insects, and fish are common, and are often associated with human habitation (Forman, 1998). It has been suggested that non-native species can displace native species through biotic interactions (Smith, 1953). However, more recently, situations in which exotic species had apparently displaced native species were instead directly linked to the degradation of native species habitat (Graham, 1993). The use of bioindicators to monitor changes within particular habitats is a concept that has longed appealed to conservation biologists (McGeoch and Chown, 1998). However, good indicators must be sensitive to environmental alteration so that changes in their numbers can be used as a warning of deteriorating conditions before the majority of less sensitive organisms are seriously affected. In addition, communities found at reference sites representing minimally impacted areas are desired so that they can be compared to communities affected by human disturbances, and the gravity of the disturbance can be assessed (Karr, 1981;Brinson and Rheinhardt, 1996). Many indicators of biological systems health have been tested over the years (see Karr, 1991 for review). Some of the biomonitors most widely used to assess the health of freshwater systems include benthic invertebrates and fish (Berkman et al., 1986). However, recently, it has been suggested that the integration of different measures of river health should be explored (Karr, 1991; Boulton, 1999; Fairweather, 1999; Karr, 1999). The study of river health must recognize the value of multiple scientific disciplines, rather than being primarily rooted in one scientific tradition or in one particular group of taxa (Fairweather, 1999). Parasites have been used for almost a century as biological tags, or markers, to provide information on various aspects of host biology including fish stock separation, fish recruitment migrations, fish diet and feeding behavior, and host

phylogenetics and systematics (Williams et al., 1992). In addition, parasites may also rank among the most sensitive bioindicators, because parasite infections of fish reflect the health of the entire aquatic community (MacKenzie et al., 1995; Marcogliese and Price, 1997; Marcogliese and Cone, 1997). Fish parasites have complex life cycles, e.g., a typical parasite life cycle may include the fish definitive host, and one or more intermediate invertebrate hosts; for the parasite to survive, all hosts must co-occur in a stable community structure (Marcogliese and Cone,1997). Thus, changes in environmental conditions that affect any of the hosts (directly or indirectly) will have a significant effect on the prevalence and intensity of infection (MacKenzie et al., 1995; Marcogliese and Cone, 1997), and on the diversity of parasites infecting fish. The objectives of this study are to compare diversity of fish parasites between disturbed and undisturbed streams in the Mullica River Basin located in the New Jersey Pinelands. A second goal is to develop and calibrate methods of using fish parasites as bioindicators of environmental changes and pollution.

Methodology

Characterization of study sites: The Mullica River watershed is a 1473 km2 basin located within the New Jersey Pinelands and consists of several coastal plain streams that are usually slow flowing. We selected 4 stream stations at the extremes of a complex watershed disturbance gradient characterized by increasing pH, specific conductance, and the percentage of developed and agricultural land. These streams were part of a related stream fish study (Zampella and Bunnell, 1998), and vegetation study (Zampella and Laidig, 1997). Two streams, Great Swamp Branch and Muskingum Brook, are degraded sites with a high median pH (5.9 and 6.1, respectively), high median specific conductance (124 and 117 mS/cm, respectively), and a high percentage of developed and agricultural land (63.5 and 57.2 %, respectively). Tulpehocken Creek and Skit Branch are low impact streams, and are regional reference sites with a low median pH (4.8 and 4.6, respectively), low median specific conductance (27 and 31 mS/cm, respectively), and a high percentage of forest land (97.1 and 95.3 %, respectively). Characterization of fish fauna: A total of 33 freshwater fish species has been reported from NJ Pinelands waters, and these fish have been characterized as either restricted native, widespread native, or introduced (Hastings, 1984; Zampella and Bunnell, 1998). Restricted native species are limited to the Pinelands within the state of New Jersey. Widespread native species occur in all water types (acid or alkaline) in other regions of the state. Introduced species are generally found outside of the Pinelands, and include species that are native and non-native to New Jersey. Fish sampling: Fish species richness may increase with stream length sampled (Angermeier and Karr, 1986; Angermeier and Smogor, 1995), but a 100-m sample is usually adequate for small streams provided all major habitats are sampled (Karr, 1981; Karr et al., 1986). All habitat types along a 100-m long stretch at each sampling station were sampled using a 4-mm mesh nylon seine. Muskingum Brook, Tulpehocken Creek, and Skit Branch were sampled for 1 h on 3 separate occasions between 1992 and 1993. Great Swamp Branch was sampled on 3 separate occasions between 1994 and 1995. Fish were killed, and preserved and stored in 70% alcohol in the laboratory until examination for parasites. At least 3 voucher specimens of each fish species from each stream station were kept for future reference. This prevented examination for parasites of every fish species reported from each stream station in the related stream fish study (Zampella and Bunnell, 1998), especially of fish species for which less than 3 individuals were collected. As a result, we made another collection from each of the 4 stream stations during 1998, and in 1999 we sampled Skit Branch on 5 occasion, Tulpehocken Creek on 2 occasions, Great Swamp Branch on 3 occasions, and Muskingum Brook on 1 occasion. The 1999 samples have not been processed completely, and therefore results from those collections are not reported here. Aquatic invertebrate sampling: Invertebrates that can potentially serve as intermediate hosts for the fish parasites are being examined for the appropriate parasite developmental stages. Invertebrate samples were collected from June to November 1999. Samples were taken at each sampling station using a D-shaped aquatic dip net dragged over 2 meters.

The samples were then passed through a sieve series, and brought to the lab where they were preserved and stored in 70% alcohol. Bengal rose dye was added to each jar to stain macroinvertebrates and allow for easier sample processing. Samples have not been all processed, but macroinvertebrates are being identified using the keys of Edmondson (1959) and Pennak (1978). Examination for parasites: Each fish was given a unique accession number based on its species name and site of collection. Fish sex, total length (mm) and weight (g) were recorded before necropsy, when the entire fish was examined for parasites. Parasites were identified to genus when possible, and otherwise to family using the keys of Hoffman (1999). Data analysis: Each host was considered a patch within a site (Bush and Holmes, 1986). Therefore, each host sampled was considered a replicate within each site. We calculated a parasite community diversity value for each patch (host), and subsequently, the mean parasite community diversity (and its variance) for each site. Species richness (R), Shannon-Wiener diversity (H'), and Simpson's diversity (Ds) indices were calculated. Diversity values were compared between sites regardless of fish species. Statistical comparisons were made using a non-parametric Kruskal-Wallis test because we had uneven sample sizes, and data was not normally distributed. Significance for all comparisons was set at a=0.05. Parasite ecology terms are defined according to Bush et al. (1997). Mean intensity is the average intensity of a particular species of parasite among the infected members of a particular fish species. Prevalence is the number of fish infected with 1 or more individuals of a particular parasite species divided by the total number of fish examined for that parasite species, and is expressed as a percentage. The component community is defined here as referring to the parasite populations associated with a particular fish species at a particular site, and the supracommunity refers to the parasite populations associated with all fish species at a particular site.

Principal Findings and Significance

Results from the fish surveys reported here are based on 1993, 1994, 1995, and 1998 samples. Results from the fish and macroinvertebrate samples taken during 1999 are not reported. Fish community: We found a total of 14 fish species during our survey of these 4 sites (Table I). Eight of 10 fish species that occur at Tulpehocken Creek, 7 of 9 fish species that occur at Skit Branch, 12 of 16 fish species that occur at Great Swamp Branch, and 9 of 15 fish species that occur at Muskingum Brook were examined for parasites (Table I). A total of 126 fish from low impact sites (50 from Tulpehocken Creek and 76 from Skit Branch), and 180 fish from degraded sites (50 from Great Swamp Branch and 130 from Muskingum Brook) were examined for parasites. Parasite community: We found a total 11 different parasite species in fish examined from all 4 sites: 1 cestode, Caryophyllidea in the intestine; 2 acanthocephalans, Acanthocephalus sp. and Fessisentis sp. both in the intestine; 4 trematodes, Crepidostomum sp. in the intestine, Phyllodistomum sp. in the urinary bladder, blackspot (Neascus spp.) on the skin and fins, and an unidentified larval trematode encysted in several visceral organs; 4 nematodes, Rhapidascaris sp. in the intestine, Gnathostoma sp. in the intestine, an unidentified larval nematode in the fishes' swimbladder, and cysts outside of visceral organs containing 1 to several individual unidentified nematode larvae. Prevalence of infection of each parasite in each fish species from each site is summarized in Tables II-V. Fish from Tulpehocken Creek and Skit Branch both harbored 7 of the 11 parasite species, while fish from Great Swamp Branch and Muskingum Brook harbored 10 and 7, respectively, of the 11 parasite species. Parasites were found in 6 of the 8 fish species examined from Tulpehocken Creek, while 6 of the 7 fish species examined from Skit Branch were infected. Ten of the 12 fish species examined from Great Swamp Branch, and 8 of the 8 fish species examined from Muskingum Brook were infected with parasites. There was a significant difference in parasite supracommunity richness (R) between sites (H=56.32, DF=3, P<0.001). Degraded and low-impact sites differed significantly, but there were no differences between the 2 degraded sites (Skit Branch and Tulpehocken Creek) or the 2 low-impact sites (Great Swamp Branch and Muskingum Brook) (Dunn's multiple comparison procedure, P>0.05) (Figure 1). Shannon-Wiener (H') and

Simpson's (Ds) diversity indices place emphasis on the abundance of species being compared, but it was not possible to accurately count the number of nematode larvae during necropsy. Therefore, nematode larvae found in the swimbladder and encysted in the viscera were not included in the calculation of either of these diversity indices. There was a significant difference in parasite supracommunity diversity (H') between sites (H=12.890, DF=3, P=0.005). However, a multiple comparisons test (Dunn's Method) was not able to reveal which group varied from the others (Figure 2). There was a significant difference in parasite supracommunity diversity (Ds) between sites (H=11.823, DF=3, P=0.008). However, a multiple comparisons test (Dunn's Method) was not able to reveal which group varied from the others (Figure 3). Our results demonstrate that there are significant differences in fish parasite community diversity. In particular, species richness (R) reveals that there are signicant differences between degraded and low-impact sites. All parasites found in Pinelands fish are transmitted via trophic interactions or habitat association of fish with certain types of intermediate host. The presence of particular parasites in fish suggests that all the required intermediate hosts for the parasites to persist exist in these streams. The acanthocephalans, Acanthocephalus sp. and Fessisentis sp. require the presence of crustaceans for transmission to occur. Acanthocephallus sp. adults are not host specific and live in the intestine of a wide variety of fish species (Hoffman, 1999); larvae infect isopods and/or amphipods, which are then ingested by fish. Fessisentis sp. adults can be found in the intestine of a wide variety of fish species, and infective larvae are found in isopods. Adults have also been reported in salamanders (Siren intermedia) (Hoffman, 1999). Our preliminary invertebrate data include both isopods and amphipods from all sites and an isopod containing 1 Acanthocephalus sp. was recovered from the stomach of a pirate perch. This suggests that isopod and amphipods populations can exist in both disturbed and low-impact streams. The infective larvae of the nematode Gnathostoma sp. are found in copepods, which are ingested by the fish definitive host. Adults of this nematode species has been reported from various species of fish (Hoffman, 1999). It has also been reported from reptiles and mammals (Hoffman, 1999). Gnathostoma sp. is only found in swamp darters in the low-impact sites, but this species of fish only occurs in those sites. Zooplankton are commonly found in the stomach of our fish, including cladocera and copepods. Rhapidascaris sp. first infect chironomid fly larvae and later are found in the viscera of fish as third- and fourth-stage larvae (Hoffman, 1999). Larvae have also been reported in toads (Bufo raddei) from Siberia (Hoffman, 1999). Adults of Rhapidascaris sp. are usually found in predatory fish and have been reported from muskellunge (Esox masquinongy) which is related to the 2 pickerel species found in the Pinelands. Our results show that Rhapidascaris sp. adults are only found in top carnivores such as the largemouth bass from Great Swamp Branch and the chain pickerel from Skit Branch. Largemouth bass and pickerel have been found with fish, and on one occasion, with a small toad in the stomach. Identification of the nematode larvae commonly found in cysts from fish in both degraded and low-impact sites has been difficult. However, it may be possible that it is the Rhapidascaris sp. infective stage. Given that these larvae are common in most fish that could serve as a prey to top carnivores, it is surprising that Rhapidascaris sp. adults do not occur more frequently in our top predators. However, our small top predator sample sizes may be responsible for this result. Nematodes found in the swimbladder of many fish from our study have not been identified yet. However, very few species of nematodes are commonly found in this fish organ. Although not confirmed yet, larvae found in swimbladders from our fish may be Cystidicola sp. (Hoffman, 1999). Cystidicola sp. larvae infect copepods before being ingested by the fish definitive host. Copepods occur in all of our sites. Cestodes of the family Caryophyllidea are host specific, and only infect suckers (family Catostomidae) or minnows (family Cyprinidae) (Hoffman, 1999). The life cycle of many caryophyllids is unknown, but some of the reported potential intermediate hosts are oligochates such as tubifex worms. Creek chubsuckers are the only fish species infected with this cestode. This fish species occurs in both degraded sites and in one of the low-impact sites (Tulpehocken Creek). However, only the chubsuckers from the degraded sites were infected with this parasite. This may be indicative that the required intermediate host for this parasite only occurs in degrades sites. Blackspot (Neascus spp.) and the other digenetic trematode larva found in fish from Great Swamp Branch (a degraded site), are

infective larvae that, when ingested, become adults in the intestine of birds. The first intermediate hosts for both of these parasites are snails that release free-swimming infective larvae. When a larva comes in physical contact with a fish, it either encysts on the skin (forming a blackspot) or penetrates and encysts in visceral organs (Hoffman, 1999). Snails have been found in some of our invertebrate samples and in the stomach of some fish from degraded sites. Both degraded sites are surrounded by a high percentage of developed and agricultural land (63.5% in Great Swamp and 57.2% in Muskingum Brook), with very little forest tree cover (Zampella and Bunnell. 1998). The presence of open areas may be attractive to piscivorous birds that can feed on fish infected with these infective trematode larvae. At the same time, birds infected with the adult worms may defecate in the water, thereby releasing the free-swimming stages that infect snails. Adult trematodes infected fish from both degraded and low-impact sites. Adults of Crepidostomum sp. and Phyllodistomum sp. infected a smaller number of fish individuals from low-impact sites, relative to the number of individual fish found infected in degraded sites. All trematodes require a mollusc as a first intermediate host. Specifically, Crepidostomum sp. and Phyllodistomum sp. use fingernail clams as a first intermediate host, and various kinds of invertebrates as second intermediate hosts (mayfly larvae and amphipods by Crepidostomum sp., and caddisfly and damselfly larvae by Phyllodistomum sp.). Mayfly and damselfly larvae and amphipod adults have been found in our invertebrate samples from both degraded and low-impact sites. However, fingernail clams have only been found in degraded site samples, and not from low-impact sites. That fish from degraded sites are infected with these 2 trematode species is not surprising since all of the intermediate hosts required for life cycle completion are present. However, fingernail clams appear to be absent from low-impact sites. This raises the question of how fish from these sites are becoming infected with trematode parasites given that all of the required intermediate hosts, especially the mollusc intermediate host, are not present. The type of water in low-impact streams (acidic), may explain why molluscs are absent from these sites. Many molluscs are sensitive to acidity (Kinsman, 1984; Rooke and Mackie, 1984) and this may be due to the scarcity of shell building calcium in acid streams (McCormick, 1970). However, this does not explain why trematodes are present in fish communities from acidic waters. Several explanations to why trematodes are present in fish communities from acidic water, despite the absence of the required mollusc intermediate host, may be possible. It may be that we have not found the fingernail clams (which are not bigger than 3 mm) that are necessary for the completion of the Crepidostomum sp. and Phyllodistomum sp. life cycle. However, we have not had a problem finding these small molluscs from degraded sites, and other larger molluscs (e.g. snails) are also conspicuously absent from low-impact sites. A second explanation for why trematodes are present in fish communities from acid waters is that, if fingernail clams are present in the low-impact acidic streams, then it may be that their population size is small. This may explain why such few individual fish from low-impact sites are infected with trematodes, relative to the number infected in degraded sites. However, this can also be interpreted to mean that water chemistry is changing in the sites presently classified as low-impact. If true, then it may be possible to use trematodes as a bioindicator to monitor disturbance in these and other Pinelands streams. Finally, acidity decreases from upstream to downstream along stretches of the Pinelands landscape (R. Zampella, pers. comm.). It may be possible that individuals in low-impact sites that are infected with trematodes may have picked up the infection in other streams that have higher pH values further downstream from the sites sampled. Although all of these hypotheses may be plausible, they still need to be tested. In conclusion, we present evidence that parasite supracommunity richness is greatest in degraded sites when compared to low-impact streams. Our results suggest that parasites can be indicators of biotic integrity, and that it may be possible to include parasites in studies that aim to assess the health of freshwater systems. The presence of parasites in fish can be indicative of how well the system is functioning because successful parasite transmission means that energy is being transferred effectively across all trophic levels within that ecosystem. Once all fish and invertebrate samples are processed, we will be able to get a better picture of how well parasites can indicate biological integrity within Pinelands streams. In addition, further studies that examine some of the hypotheses postulated

about trematode transmission biology and the potential use of trematodes as bioindicators to monitor disturbance, need to be tested.

Descriptors

Parasite; Bioindicators; Biotic integrity

Articles in Refereed Scientific Journals

Hernandez, A.D., J. Bunnell, R. Zampella and M.V.K. Sukhdeo (In Prep). Parasite community diversity as an indication of biotic integrity of New Jersey Pinelands streams. (To be submitted to Freshwater Biology).

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Basic Project Information

Basic Project Information	
Category	**Data**
Title	Habitat and nutritional value of the invasive plant Phragmites australis for estuarine animals, as compared with that of Spartina alterniflora.
Project Number	03
Start Date	03/01/1999
End Date	02/29/2000
Research Category	Biological Sciences
Focus Category #1	Wetlands
Focus Category #2	Toxic Substances
Focus Category #3	Ecology
Lead Institution	Rutgers University

Principal Investigators

Principal Investigators			
Name	Title During Project Period	Affiliated Organization	Order
Judith Weis	Professor	Rutgers University	01

Problem and Research Objectives

Marsh vegetation plays an important role in trophic ecology of estuaries. Once broken down to detritus, it is an important food source for many organisms. The physical grass structure also provides important habitat for small estuarine organisms. In Atlantic Coast marshes, the reed Phragmites australis has been invading many areas once dominated by salt cordgrass, Spartina alterniflora. Invasion by Phragmites australis into tidal marshes previously dominated by Spartina alterniflora is viewed as a serious environmental threat along the Atlantic coast of the United States, but little is known about the relative habitat or nutritional value of the two plants for most estuarine species. This study was designed to investigate behavioral responses, in the laboratory, of three species to the two plants and to investigate the growth of and trophic transfer of metals to estuarine invertebrates when fed diets of detritus from these different plant species.

Methodology

For the behavioral studies, fiddler crabs, Uca pugnax, grass shrimp, Palaemonetes pugio, and larval mummichogs Fundulus heteroclitus were introduced into aquaria with a bare area, an area with dead Phragmites stems, and an area with dead Spartina stems. The side chosen by organisms placed originally in the central bare area was recorded. The behavior of larval mummichogs in the tanks with predators was observed. Additional experiments were performed in microcosms containing blocks of "real marsh" containing mud, litter, and small organisms as well as living plants of each species. Individuals were again introduced into the bare central area of the microcosm and the side chosen by individuals of the same species was recorded. Additional experiments were performed on survival of grass shrimp in microcosms of Spartina alone and Phragmites alone, when Fundulus predators were present. A field experiment on survival of tethered grass shrimp at a field site where marshes of each of the two plant species were on opposite sides of a tidal creek in the Hackensack Meadowlands was also conducted. For the nutritional studies, decaying leaves from populations of Phragmites, natural Spartina and restored Spartina from both the Hackensack Meadowlands, NJ (HM) and the more pristine Accabonac Harbor of East Hampton NY (AC) were collected from the marsh surface in the spring. Each type of decaying leaves was pureed and fed to the fiddler crabs Uca pugnax and U. pugilator, and to the grass shrimp Palaemonetes pugio. In fiddler crabs we monitored limb regeneration, molting and weight, and in the grass shrimp we monitored growth and survival. Nutritional quality was assessed by comparing carbon and nitrogen concentrations of each plant species . Detrital leaves of Phragmites, natural Spartina, and restored Spartina from HM were oven-dried and finely ground with a Wiley mill (#40 mesh), and percentages of carbon and nitrogen measured with a CarloErba elemental analyzer (CHNS). Metal analyses were performed on the detritus samples and fiddler crabs.

Principal Findings and Significance

In the behavioral studies, all species distributed themselves equally between the Spartina and the Phragmites. In the presence and absence of stems, the larval fish utilized the surface of the water as a refuge, as well as the stems, when present. This behavior was equally as effective as being among the stems in promoting larval survival. In microcosms with blocks of marsh with living plants, fiddler crabs

and grass shrimp again did not show a preference for either species of plant, while juvenile and adult mummichogs were not consistent. Small fish chose Spartina when in the small microcosm and had no preference in the large one. Large fish chose Spartina in the small microcosm and Phragmites in the large one. Predation by adult mummichogs on grass shrimp was comparable in Spartina and Phragmites microcosms, and predation on tethered shrimp was equivalent in adjacent Spartina and Phragmites marshes in the field. If our lab results can be extrapolated to the field, they suggest that these species will use Phragmites marshes as well as Spartina, and that the refuge/habitat functions of the marsh will not be harmed by the replacement of Spartina by Phragmites. Data from field seems to indicate site-specific differences in use of Phragmites vs Spartina. While Meyer and Gill (1998) indicate equivalent nekton use in the Chesapeake Bay and Rilling et al. (1998) indicated equivalent fish numbers and biomass in a lower Connecticut River Phragmites site and a nearby restored site, Able (personal communication) indicates reduced nekton use of Phragmites in Delaware Bay. Meyer and Gill (1998) suggest that their findings, along with those of Fell et al. (1998) and Rozas and Hackney (1984) indicate that environmental and physical factors are more important in determining nekton use of a marsh than the presence or absence of a particular plant species. As new data are produced, the general perception that regularly flooded Phragmites marshes are less functional than the Spartina marshes they replace does not appear to be supported. In the feeding experiments, U. pugilator regenerated limbs and molted equally well on all six diets. Most of the U. pugnax arrested growth midway through regeneration on all 6 diets. A repeat experiment with smaller crabs, which did complete the process, found no consistent differences among the six diets and control food, although control food and Phragmites detritus had higher N concentrations than the Spartina detritus. Grass shrimp fed all six diets did not survive beyond 3 weeks, indicating that none of the detritus diets were adequate for them. In another experiment using HM sediments from each vegetation type (containing detritus, meiofauna, and microflora), survival was equally high among treatments and the shrimp fed sediments from the restored Spartina site or control food grew better than those fed sediments from the Phragmites or natural Spartina sites. This is probably due to enhanced populations of meiofauna and/or microflora at the restored site (Mill Creek), rather than to the quality of the detritus. Although metal concentrations in detritus varied between sites and plant species, the crabs of each group did not differ in metal concentrations after the feeding experiment. In general, the detritus from the HM had, as expected, higher levels of the metals than the detritus from AC, but levels in the crabs were unrelated to the levels in their diets. This probably reflects the relatively short duration of the feeding experiment. In general, the data obtained in this study do not support the general assumption that Phragmites detritus is inferior to Spartina detritus as a food for invertebrate detritus feeders. In the case of the sand fiddler, Uca pugilator, detritus from both species of plants from both sites provided adequate nutrition to support regeneration and completion of the molt cycle within a normal time period. It was interesting to find that the larger individuals of U. pugnax were not supported adequately by any of the diets, and many ceased regeneration about midway through the process. This did not appear to be due to an inadequate quantity of food, since all detritus was not consumed between feedings, and the crabs did gain weight comparable to U. pugilator. Survival was very high on all diets in both trials, and in trial 2 the small U. pugnax did complete regeneration and molt on all diets, at a rate comparable to that previously noted with this species fed a control ("Fly Chow") diet (Callahan and Weis, 1983). Efforts to restore salt marsh areas by replacing the undesired Phragmites with the desired Spartina, are often justified by the assumption that the productivity of animal populations will be enhanced. Yet, evidence from this study and others (Fell et al., 1998, Wainright et al., 1998) does not support the general assumption that Phragmites leaf detritus is of poorer nutritional quality than that of Spartina to estuarine consumers.

Descriptors

Fundulus, habitat, marsh, nutrition, Palaemonetes, Phragmites, predation, refuge, Spartina, Uca

Articles in Refereed Scientific Journals

Behavioral responses and interactions of estuarine animals with an invasive marsh plant: A laboratory analysis. Accepted in Biological Invasions Growth, survival, and metal accumulation by marsh invertebrates fed diets of detritus from Spartina alterniflora Loisel. and Phragmites australis Cav. Trin. ex Steud. from metal-contaminated and clean sites. Submitted

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Information Transfer Program

Information Transfer Program

(a) Website development

The major effort in information transfer during this fiscal year was the setting up a web site for the institute (http://njwrri.rutgers.edu/). The homepage of the site describes the overall program and mission of the New Jersey institute, the Federal program of institutes and a statement of the need for research and training in water resources. The site provides links to the following subpages;

1) members of the Advisory Council

2) summaries of recently completed research projects

3) an extensive list of links to national, state, and local organizations involved in water resources

4) a searchable data base of researchers involved with all aspects of water resources in the state.

5) upcoming meetings

 (b) Common Waters Initiative

We also agreed to serve as the coordinating group for a new initiative at Rutgers University, termed "Common Waters", which aims to bring together academics, government scientists and representatives of nonprofit organizations to identify research needs and to develop mechanisms for obtaining funding for these research efforts. As part of this effort, we helped to organize two meetings:

(1) an informal meeting of Rutgers scientists to discuss areas of common interest and perceptions of research needs

concerning the waters of the state. As a result of this meeting, a mailing list of over 30 people was developed. This list is now incorporated into a listserve. Another result of this meeting was the decision to hold a series of meetings on each of the major watersheds of the state, in coordination with the large-scale watershed planning effort being undertaken by the NJ Dept. of Environmental Protection.

(2) In accordance with the meeting described above, a meeting was held to discuss the Raritan River Watershed. The meeting involved representatives of the NJ Water Supply Authority, the USDA-NRCS, and the NJDEP, as well as representatives of nonprofit watershed associations and academic researchers.

(3) Meetings are planned for the next fiscal year focussing on the Passaic River watershed, the Mullica/Great Bay watershed, and the Hackensack River Watershed.

USGS Internship Program

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 RCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	6	N/A	N/A	N/A	6
Masters	N/A	N/A	N/A	N/A	N/A
Ph.D.	5	N/A	N/A	N/A	5
Post-Doc.	N/A	N/A	N/A	N/A	N/A
Total	11	N/A	N/A	N/A	11

Awards & Achievements

Mary Anne Carletta's work has also been accepted for presentation in a poster session at the Atlantic Coast Contaminants Workshop entitled "Endocrine Disruptors in the Marine Environment: Impacts on Marine Wildlife and Human Health", 22-25 June 2000, in Bar Harbor, Maine. The workshop is sponsored by the Marine Environmental Research Institute and the University of Connecticut Department of Pathobiology in association with the Jackson Laboratory. Attendance at this workshop is limited to 100 participants, and work to be included in the poster session was selected on a competitive basis. MERI awarded a travel grant so that the work could be presented. Daniel K. Lefkowitz's and Christopher G. Uchrin's research, funded by the NJWRRI, was used as the basis of a successful application for a research-based individual scholarship given by the Air and Waste Management Association, Mid Atlantic Region. The Air Pollution Education and Research Program (APERG) scholarship is one of the largest of its kind in the country, and includes an award of $25,000. Karen L. Licksko's project was presented to Rider University as a senior thesis along with a poster and received an A. Dr. Kauser Jahan, P.E. was awarded a research grant titled Fate and Transport of Nonionic Surfactants funded by the Northeast Hazardous Substance Research Center ($55, 160) and Rowan University.

Publications from Prior Projects

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