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Editors

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ABSTRACT

Nine studies were conducted within the Hudson River estuary under the auspices of the Tibor T. Polgar Fellowship Program during 1997. Major objectives of these studies included: (1) population assessment of diamondback terrapins of the area of Piermont Marsh; (2) comparison between adult fecundity and egg and larval production of alewives in Quassaic Creek; (3) investigation of cadmium resistance in *Fundulus* from Foundry Cove; (4) evaluation of a new approach to quantify environmentally-induced genetic damage to Hudson River Atlantic tomcod; (5) comparison of historical soil erosion and sediment delivery to two tributaries of the Tivoli Bays; (6) characterization of demographics and attitudes toward watershed management of Dutchess County farmers; (7) analysis of New York Harbor dredging policies; (8) evaluation of two alternative biotic integrity indices applied to the Saw Kill; and (9) comparison of fish communities between open and occluded freshwater tidal Hudson River wetlands.

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PREFACE

The Hudson River estuary stretches from its tidal limit at the Federal Dam at Troy, New York, to its merger with the New York Bight, south of New York City. Within that reach, the estuary displays a broad transition from tidal freshwater to marine conditions that are reflected in its physical composition and the biota it supports. As such, it presents a major opportunity and challenge to researchers to describe the makeup and workings of a complex and dynamic ecosystem. The Polgar Fellowship Program provides funds for students to study selected aspects of the physical, chemical, biological, and public policy realms of the estuary.

The Tibor Polgar Fellowship Program was established in 1985 in memory of Dr. Tibor T. Polgar, former Chairman of the Hudson River Foundation Science Panel. The 1997 program was jointly conducted by the Hudson River Foundation for Science and Environmental Research and the New York State Department of Environmental Conservation and underwritten by the Hudson River Foundation. The fellowship program provides stipends and research funds for research projects within the Hudson estuary and is open to graduate and undergraduate students.

Prior to 1988, Polgar studies were conducted only within the four sites that comprise the Hudson River National Estuarine Research Reserve, a part of the National Estuarine Reserve Research System. The four Hudson River sites, Piermont Marsh, Iona Island, Tivoli Bays, and Stockport Flats exceed 4,000 acres and include a wide variety of habitats spaced over 100 miles of the Hudson estuary. Starting in 1988, the Polgar program has supported research carried out at any location within the Hudson estuary.

The work reported in this volume represents the nine research projects conducted by Polgar Fellows during 1997. These studies meet the goals of the Tibor Polgar Fellowship Program to generate new information on the nature of the Hudson estuary and to train students in estuarine studies.

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A POPULATION STUDY OF DIAMONDBACK TERRAPINS OF PIERMONT MARSH, HUDSON RIVER, NY

A Final Report of the Tibor T. Polgar Fellowship Program

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ABSTRACT

The Hudson River Estuary is home to the diamondback terrapin (*Malaclemys terrapin*), a unique estuarine species of turtle harvested to very low numbers at the turn of the century. Although the turtle has slowly recovered from this decimation, loss of feeding and nesting habitats may impair the terrapin's ability to maintain healthy populations in the Hudson River. This research investigated the size and structure of the population of diamondback terrapins inhabiting Piermont Marsh in Rockland County, New York. From June 6 through August 24, 1997, thirty-nine surveys were made into the marsh, yielding information on terrapin population structure, feeding habitat and nesting potential. Trammel nets were set up in Crumkill and Sparkill Creeks and areas surrounding Piermont. Only eight terrapins were captured - six males and two females - suggesting that a relatively small population inhabits Piermont. All terrapins were trapped near sandy areas just north of the Piermont Marsh complex. Terrapins were neither trapped nor observed in the marsh creeks, indicating that terrapins are not using the marsh system for foraging or nesting during the summer months. Rather, terrapins are utilizing the open waters of the Hudson River, swimming and basking near the shores surrounding the Pier. Open sandy areas near Piermont Pier were the traditional nesting sites of the terrapins and may still be used, but recent development, soil subsidence, and *Phragmites australis* growth make these areas extremely poor nesting sites. In addition to the diamondback terrapin, the variety of estuarine species which inhabit the marsh complex make Piermont Marsh an important site for ongoing wildlife conservation.

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INTRODUCTION

Diamondback terrapin (*Malaclemys terrapin*) is a unique species of turtle that inhabits euryhaline coastal environments situated along the east coast from Cape Cod to the Gulf of Mexico. Large populations occur in the expansive barrier island marshes of southern New Jersey (Roger Wood, Stockton State College, pers. comm.), but smaller populations are more typical in the small isolated marshes of New York and coastal Connecticut (Victoria 1994). In New York and elsewhere along the eastern seaboard, diamondback terrapins are a species of management concern (Garber 1989; Roosenberg 1990; Seigel and Gibbons 1995), yet data on the population status of terrapins in different coastal environments is lacking. A survey of the terrapin populations of the State of New York has not been performed since 1991 (Seigel and Gibbons 1995).

Despite the wide spatial distribution and reduced size of the wetlands used by terrapins along the Lower Hudson River, a number of terrapins are known to inhabit the Piermont Marsh complex in Rockland County, New York (C. Nieder, HRNERR, pers. comm.; P. Warny, private herpetologist, pers. comm.). Terrapins have been observed swimming in Sparkill Creek, crawling up onto a small sand pit adjacent to the marsh and sunning on rocks along Piermont Pier, but the size, sex and age structure of this population is unknown. Informal surveys of the existing habitat surrounding the marsh indicate that the nesting habitat is poor, owing to ongoing development and a general lack of undisturbed and unvegetated sandy soils (C. Nieder, HRNERR, pers. comm.).

The main objective of this project was to complete a population study of the diamondback terrapins of Piermont Marsh during the summer of 1997. It was anticipated that a survey of the terrapins in this marsh would yield estimates of total population size, terrapin age and size structure, terrapin sex ratios and terrapin nesting potential. Ultimately, the results of this work were expected to assist the development of species management plans for the Piermont Marsh complex.

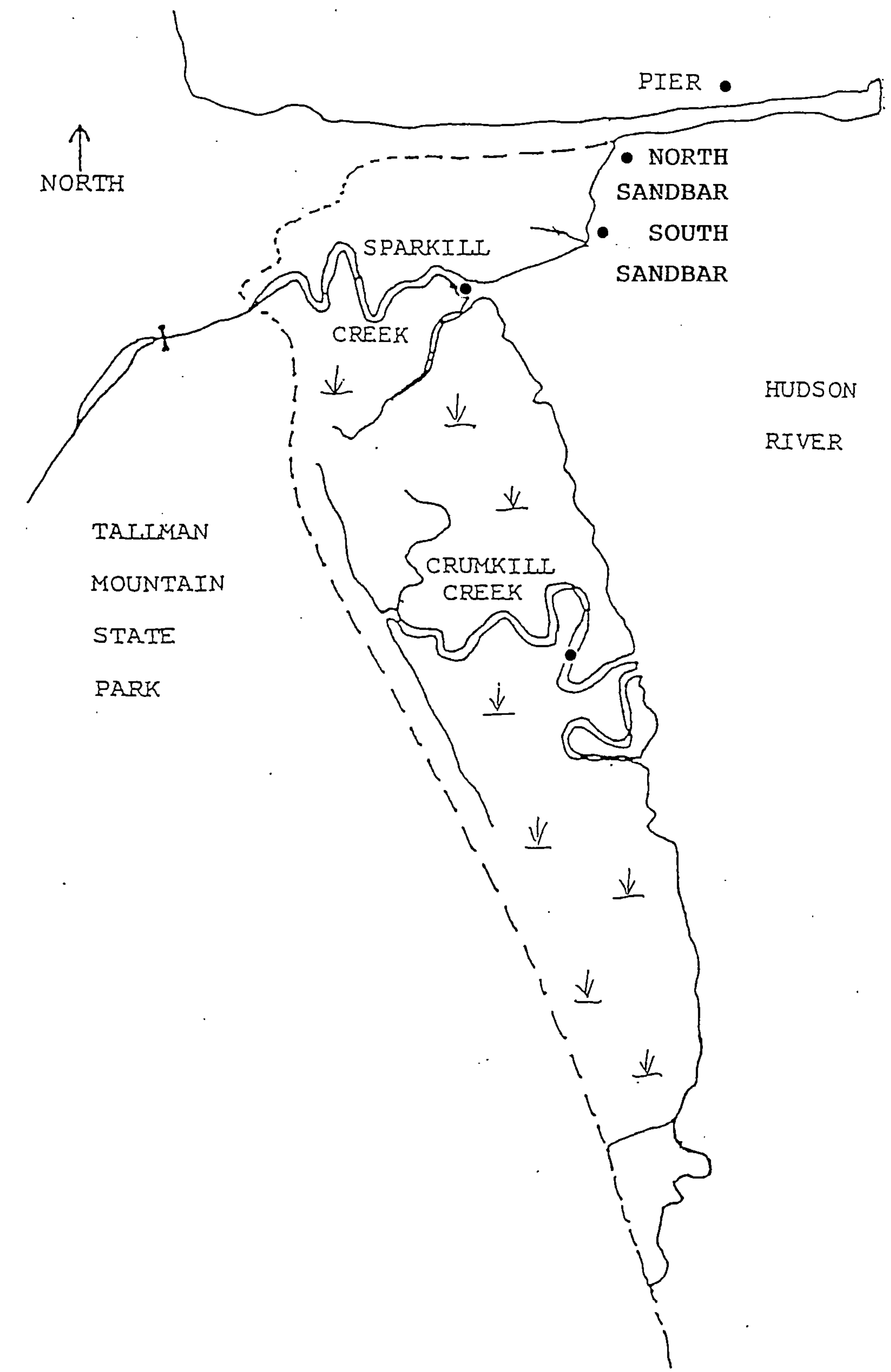
METHODS

<u>Study Site</u>

Piermont Marsh is located at approximately river mile twenty-three, on the western edge of the Hudson River just south of the Tappan Zee Bridge (Figure 1). The marsh is part of the Hudson River National Estuarine Research Reserve. The marsh is mesohaline with an average salinity of eight ppt during summer. This thousand-acre marsh is traversed by two major tidal creeks, the Crumkill and Sparkill. Crumkill Creek has slightly lower levels of dissolved oxygen than Sparkill Creek, with more silts than sand (Ramnarace et al. 1988). Salinity tends to be lower in Sparkill Creek due to greater freshwater runoff (Perrone and Knizeski 1988).

Areas surrounding the marsh are becoming increasingly urbanized. Upland areas adjacent to the marsh complex are part of Tallman Mountain State Park, managed by the Palisades Interstate Park Commission. However, the area just north of the marsh lies within the jurisdiction of the Town of Piermont and is undergoing intense development. Several condominiums are being constructed along and adjacent to the pier. The marsh creeks are regularly visited by jet skiers and fishermen, and the subtidal areas surrounding the marsh are used by local crab trappers.

Figure 1. Piermont Marsh, 1997, showing the Five Sampling Locations: Pier, North Sandbar, South Sandbar, Sparkill Creek and Crumkill Creek.



Despite the human disturbance, Piermont Marsh supports a variety of estuarine fauna. Between June and August 1997, avian species were observed utilizing the habitat in and around the marsh, including great blue herons, mallards, swans, Canada geese, marsh wrens, barn swallows, Baltimore orioles, and red-winged blackbirds. Deer and muskrat were spotted along the banks of the marsh and fiddler crabs could be seen among stalks of *Phragmites australis* (common reed). In sections of marsh, common reed almost completely covered the surface of the marsh, but *Sagittaria latitilia, Zizania aquatica,* and *Spartina alterniflora* were also found growing on the banks of the creeks.

Five sampling stations were identified and two potential nesting areas were investigated for this study (Figure 1). Turtle sampling was performed in Crumkill and Sparkill Creeks. In addition, terrapins were surveyed in the waters off two small sandy beaches located just south of Piermont Pier, named North Sandbar and South Sandbar. Diamondback terrapins frequently were observed swimming next to these potential nesting habitats. The fifth sampling area was located just north of the Pier next to rocks on which terrapins were seen basking. The upland areas adjacent to the marsh in Tallman Mountain State Park and the sandy areas just south of the pier were studied as potential nesting habitats. They were the only areas found in Piermont Marsh that could possibly have the open, sandy unvegetated environments in which terrapins prefer to nest (Burger and Montevecchi 1975; Roosenburg 1994).

<u>Population Sampling</u>

The primary method of sampling adult terrapins was via net capture using 50' and 75' trammel nets with four-inch outer mesh and two-inch inner mesh. These nets were strung across the five sampling locations in the Piermont Marsh complex during selected

strung across the five sampling locations in the Piermont Marsh complex during selected
tidal periods between June 6 and August 24. This sampling strategy was chosen in order to yield adequate seasonal coverage both before, during and after the nesting season and to ensure that sampling was completed during different tidal stages. A trapping period consisted of setting a single net at a location over a complete flooding or ebbing tidal cycle. Nets were strung out across a location, then sampled by canoe every forty-five minutes for the duration of a six-hour tidal cycle. Terrapins and all other by-catch became entangled in the net and were removed long before experiencing hypoxic stress. The length and weight of all by-catch was recorded when possible and the organisms were subsequently freed. All collected terrapins were held in the canoe and released at the end of the sampling interval. Attempts to capture terrapins using baited hoop nets and crab pots were unsuccessful. Observations of terrapins swimming or basking were also noted.

At the end of each trapping period, a "Terrapin Field Form" was filled out for each captured terrapin (Figure 2). Weather conditions and air temperature were noted. Time, location and method of capture were also recorded. All adult terrapins were sexed, then weighed using a hanging tube scale. Tree calipers were used to measure the maximum length and width of the carapace and plastron of all turtles. Females were palpated for the presence of eggs. Terrapin age was estimated based on the number of annular growth rings on the plastron, a feature which was sometimes obscured on terrapins whose plastrons were excessively worn. Physical damage and unusual markings on the shell or skin were noted. Captured terrapins free of distinctive markings were marked before release using a file to notch the marginal scutes in unique "codes."

Figure 2. Terrapin Field Form used in Piermont Marsh from June 6 to August 24, 1997.

Terrapin ID Number:______ Terrapin ID Code:_______

TERRAPIN FIELD FORM

Date:______________________ Air Temp:_______

Weather:______________________________ Water Temp:_____

Location: Crumkill Sparkill Sandbar Pipe Describe:________________

Method of Capture: Trammel Net Hoop Net Scoop Net Hand ________

Time of Capture:____ Recapture? Yes No Tides High:______ Low:______

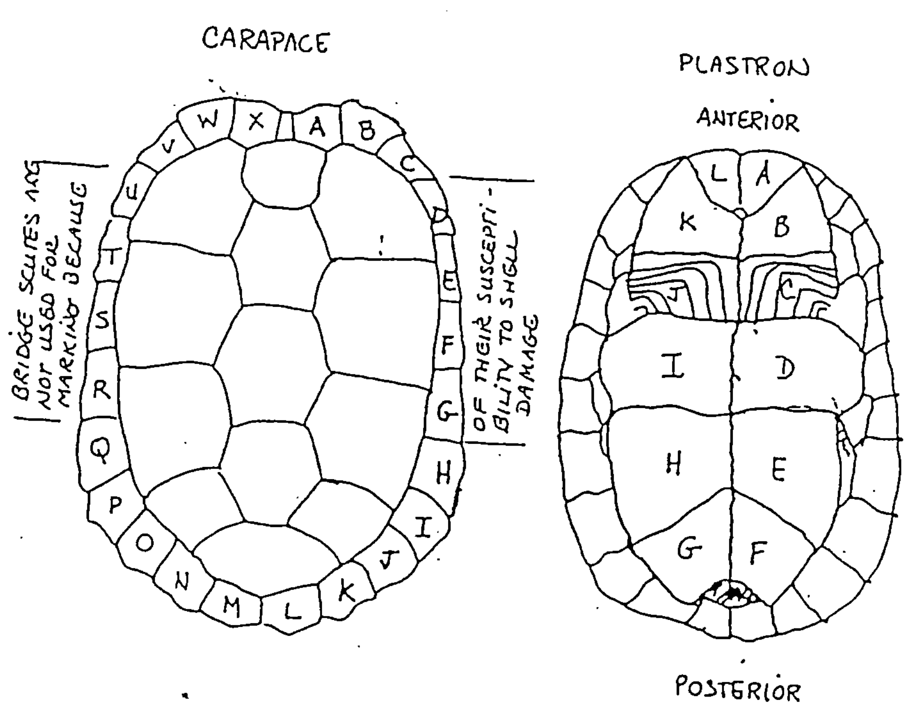
Carapace Length (mm):_________ Carapace Width (mm):________

Plastron Length (mm):_________ Plastron Width (mm):________

Weight (g):_________ Sex: Male Female Unknown Gravid? Yes No

Age:______ Can't be determined Terrapin Activity:________________

Placement of ID Notches and Identifying Features:



A total of thirty-nine trapping periods were completed between June 6 and August 24. Every survey required two persons to paddle out to the designated sites at the beginning of a tidal cycle, set up the nets, check those nets every forty-five minutes, remove terrapins and by-catch, make the appropriate measurements, dismantle the nets at the end of the tidal cycle and travel back out of the marsh. This took approximately seven hours per trapping period. To sum, over five hundred man-hours were spent at the study site during the three months of the project.

RESULTS

Terrapins

Eight diamondback terrapins were captured with the trammel nets, two females and six males (Table 1). There were no recaptures. The males averaged 382 ± 68g sd (standard deviation) and the females averaged 1,175 ± 248g sd. The mean carapace length for male terrapins was 133 ± 9 mm sd and for female terrapins was 184 ± 13 mm sd, while carapace width averaged 104 ± 6 mm sd for males and 144 ± 9 mm sd for females. All but one male terrapins could not be aged because of obscured annular growth rings. The one male that was aged was five years old. The two females were ages six and seven years. Both were palpated for eggs but neither was found to be gravid.

Most of the terrapins caught had extremely worn shells. Six of the eight terrapins had chipped shells and circular blemishes. One female had extra segments on both her carapace and plastron. Three terrapins were caught with chips on their marginal scutes which resembled old notches. These notches were noted as part of the terrapin's ID code. Two captured terrapins had flesh wounds inflicted prior to capture. The seven-year-old female had a cleft in her chin, and one male had a circular gash on his right hind leg. We were surprised to find a six-year-old female terrapin with no species-specific gray markings on her skin, and observed a completely white terrapin basking on the rocks at the North Sandbar location.

Table 1. Descriptions of Terrapins Captured in Piermont Marsh from June 6 to August 24, 1997.

Date	Location	Terrapin ID Code	Carapace (mm)	Plastron (mm)	Weight (grams)	Sex	Age (years)
8-Jun	S. Sandbar	C I/J M/N	124 x 97	102 x 63	275	male	CND
9-Jun	N. Sandbar	KM	131 x 101	109 x 67	400	male	CND
20-Jun	N. Sandbar	A I/J	136 x 101	420 x 67	420	male	CND
22-Jun	N. Sandbar	A M/N	131 x 102	112 x 66	350	male	CND
22-Jun	N. Sandbar	LM	175 x 137	161 x 92	1000	female	6
12-Jul	N. Sandbar	CJ	149 x 113	124 x 71	475	male	CND
27-Jul	S. Sandbar	J/K O	193 x 150	172 x 95	1350	female	7
24-Aug	S. Sandbar	BW	128 x 109	113 x 65	375	male	5

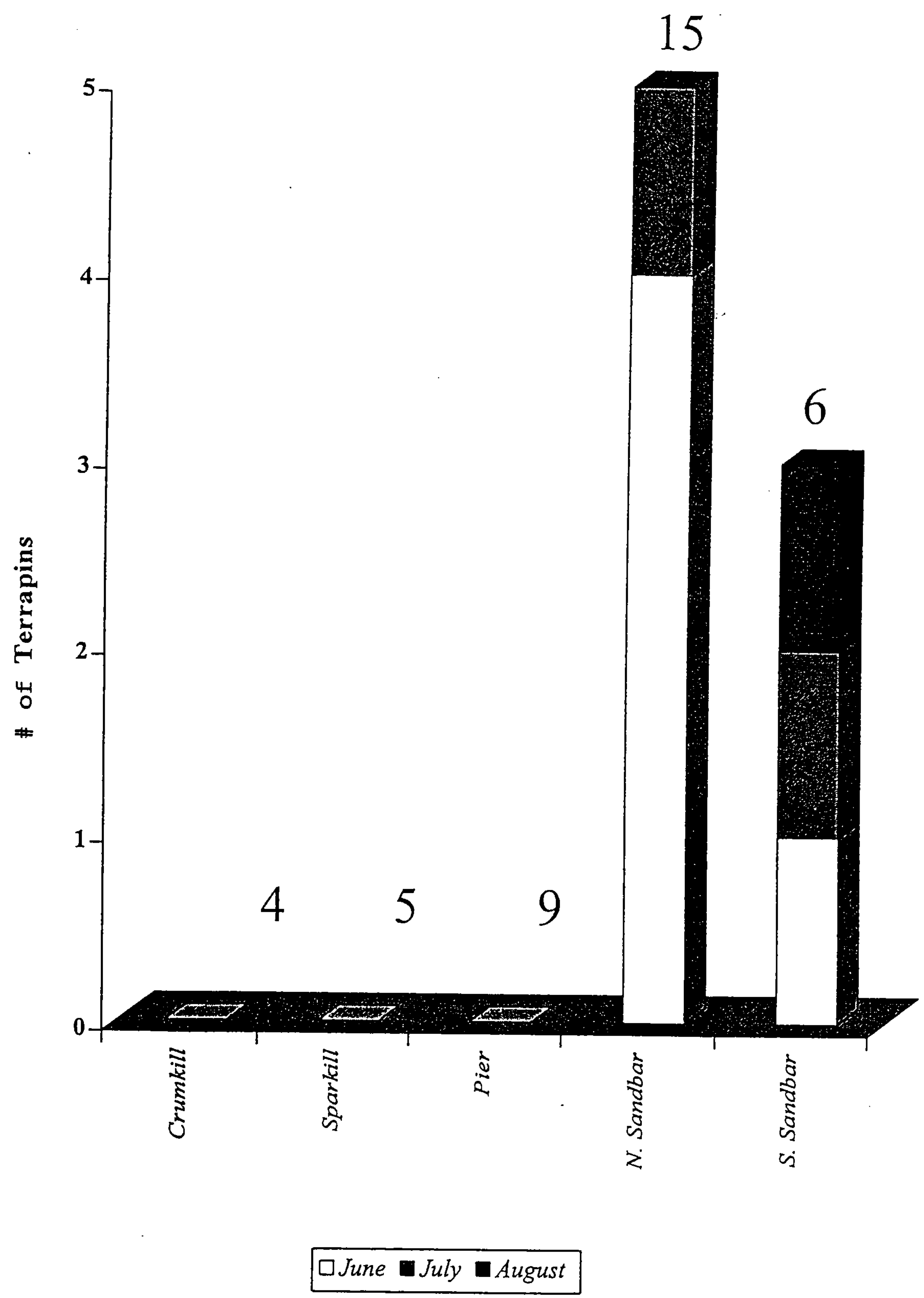
CND = Could Not be Determined

The small sample size precludes any definitive statements about terrapin activity. Half of the terrapins, however, were caught within seventy-five minutes of high tide, suggesting that terrapins may be foraging at this time. Terrapins were caught during both inclement and fair weather over a broad range of temperatures. The first diamondback was captured June 8, a partly cloudy day (70° F); two weeks later two terrapins were caught during a thunderstorm (95° F). Relative to temperature and tidal patterns, the seasonal pattern of terrapin captures was most pronounced, with five turtles caught in June, two in July and one caught on the last trapping day in August.

No terrapins were captured in Piermont Marsh (Figure 3). Despite nine trapping efforts in the marsh, trammel nets and hoop nets set up in Sparkill and Crumkill Creeks yielded no diamondback terrapins. Furthermore, no terrapins were spotted swimming in the creeks. Nine trapping efforts were also made at the Pier where up to six diamondback terrapins were spotted swimming and basking at one time. No terrapins were captured in either the crab pots or the trammel nets set up at this location. All terrapins surveyed were trapped off of the sandy spits just south of the pier. In fact, most of the terrapins spotted were seen basking and swimming near the North Sandbar station. Fifteen trapping efforts were completed in the North Sandbar location and five terrapins were caught, yielding a trapping efficiency of 33%. Despite observing only one terrapin swimming in the South Sandbar area, three terrapins were captured using only six trammel nets resulting in a trapping efficiency of 50%.

Investigations of potential nesting sites showed that Piermont Marsh has few suitable habitats for terrapin nesting i.e., open sandy uplands above the high tide level. Nesting suitability models indicate that an ideal nesting site should have between 25% and 75% canopy cover, grass cover between 5% and 25%, and a mean slope less then 25° (Palmer and Cordes 1988). The upland areas at the base of Tallman Mountain were rocky, highly vegetated and steep. Shrubs, vines and trees covered the land, and wild rice and *Phragmites australis* covered the marsh leading up to the banks. North and South Sandbar, however, had less vegetation. The soil was open and sandy, generally free from vegetation. However, during high tides both sites were almost completely submerged. *Phragmites australis* fringed both sand pits, possibly restricting terrapin access to more suitable uplands beyond the beaches.

Figure 3. Terrapin Trapping Effort in Piermont Marsh from June 6 to August 24, 1997. (Numbers refer to traps set)



By-catch

Crustaceans, chelicerates, reptiles, and fish were also captured in the study (Table 2). Generally, terrapin captures coincided with low by-catch captures. Since none of the by-catch was marked, it is not known whether the animals caught were initial captures or recaptures. A total of 105 blue crabs (*Callinectes sapidus*) were trapped during the study, along with 2 horseshoe crabs (*Limulus polyphemus*). In addition to diamondback terrapins, two other species of turtles were found inhabiting Piermont Marsh. Snapping turtles (*Chelydra s. serpentina*) were caught four times, and one softshell turtle (*Trionyx* spp.) was also captured. Several varieties of fish were removed from the nets. Species identification was confirmed by Robert Schmidt (Simons Rock College). Catfish (*Ictalurus catus*) were caught most often with a total of 37. Other species of fish included 8 carp (*Cyprinus carpio*), 1 flounder (*Paralichthys dentalus*), 1 goldfish (*Carassius auratus*), 9 gizzard shad (*Dorosoma cepedianum*), 16 white perch (*Morone americana*) and 4 striped bass (*Morone saxatilis*).

Capture of some species was distinctly seasonal (Figure 4). For example, all carp and 75% of perch were caught in June, whereas all shad were captured in August. By-catch also showed distinct spatial distributions. Almost 75% of the blue crabs were trapped around the area of the Pier including North and South Sandbar. However, 75% of the trapping effort was also at the Pier and Sandbar areas (Figure 3) indicating that the distribution of crabs was continuous throughout the study area. Gizzard shad and striped bass were only caught in the Sandbar locations. Although only a quarter of the trapping effort was in the marsh, two-thirds of all catfish were caught in marsh creeks. Other species occurred in all sampling locations or were too rare to discern a pattern.

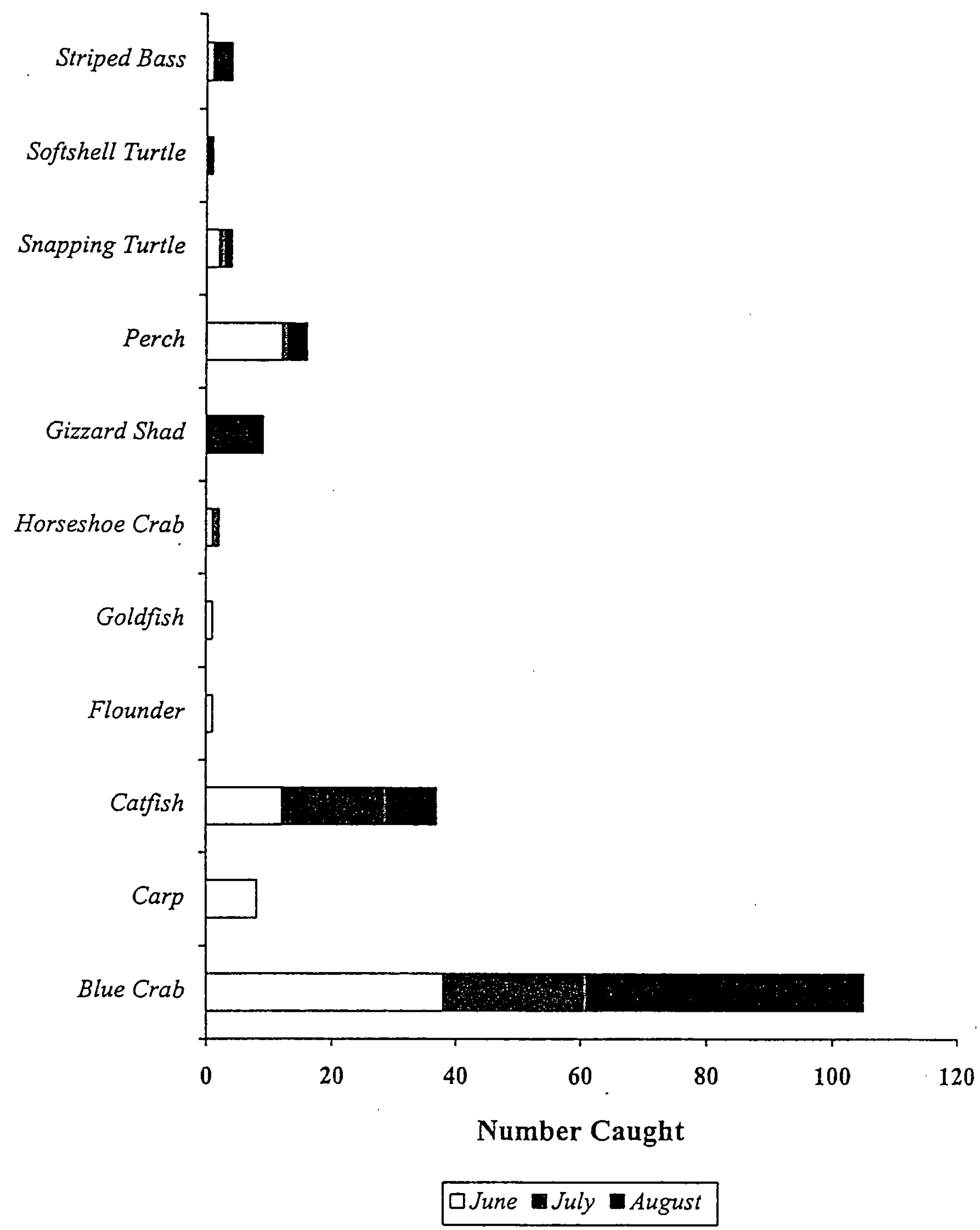
Table 2. By-catch and Terrapins Captured in Piermont Marsh from June 6 to August 24, 1997.

Trapping Period	Date	Location	Method of Capture	Terrapin Capture	By-catch
1	6-Jun	Crumkill	50 ft. net		3 catfish
2	7-Jun	Sparkill	50 ft. net		2 blue crabs; 1 perch
3	8-Jun	S. Sandbar	75 ft. net	male, 275g, 124mm x 97mm	1 catfish
4	8-Jun	N. Sandbar	50 ft. net		1 carp; 1 perch
5	9-Jun	S. Sandbar	75 ft. net		1 carp; 1 catfish
6	9-Jun	N. Sandbar	50 ft. net	male, 400g, 131mm x 101mm	1 striped bass
7	20-Jun	N. Sandbar	75 ft. net; 1 hoop net		3 carp; 1 perch
8	20-Jun	N. Sandbar	50 ft. net	male, 420g, 136mm x 101mm	1 blue crab
9	21-Jun	Sparkill	50 ft. net		2 perch; 1 catfish; 1 snapping turtle; 1 horseshoe crab; 3 blue crabs; 1 carp
10	22-Jun	N. Sandbar	75 ft. net	male, 350g, 131mm x 102mm; female, 1kg, 175mm x 137mm	2 blue crabs; 1 flounder
11	27-Jun	Crumkill	50 ft. net; 1 hoop net		5 catfish; 1 perch; 7 blue crabs
12	28-Jun	N. Sandbar	50 ft. net; 1 hoop net		2 perch; 5 blue crabs
13	28-Jun	N. Sandbar	75 ft. net		1 perch; 4 blue crabs
14	29-Jun	Sparkill	50 ft. net		2 perch; 1 carp 4 blue crabs; 1 snapping turtle
15	29-Jun	Sparkill	75 ft. net		1 carp; 1 catfish; 1 perch; 1 goldfish; 10 blue crabs
16	11-Jul	Pier	Hand net		
17	12-Jul	Pier	Hand nets; 2 crab pots		
18	12-Jul	N. Sandbar	50 ft. net; 1 crab pot	male, 475g 149mm x 113mm	3 blue crabs

Table 2. By-catch and Terrapins Captured in Piermont Marsh from June 6 to August 24, 1997. (continued)

Trapping Period	Date	Location	Method of Capture	Terrapin Capture	By-catch
19	13-Jul	Pier	75 ft. net		3 catfish; 3 blue crabs
20	13-Jul	Pier	50 ft. net		2 blue crabs
21	25-Jul	N. Sandbar	75 ft. net		1 perch; 3 blue crabs; 1 horseshoe crab
22	25-Jul	N. Sandbar	50 ft. net		7 blue crabs
23	26-Jul	Crumkill	50 ft. net		6 catfish; 1 blue crab
24	26-Jul	Crumkill	75 ft. net		7 catfish; 1 blue crab
25	27-Jul	S. Sandbar	75 ft. net	female, 1.35 kg, 193mm x 150mm	1 catfish; 2 blue crabs
26	27-Jul	N. Sandbar	50 ft. net; 1 hoop net		1 snapping turtle; 1 blue crab
27	28-Jul	Pier	50 ft. net; 2 hand nets		
28	1-Aug	Sparkill	50 ft. net		2 perch; 2 catfish; 1 snapping turtle; 3 blue crabs
29	1-Aug	S. Sandbar	75 ft. net		5 blue crabs
30	2-Aug	Pier	50 ft. net		1 blue crab
31	2-Aug	Pier	75 ft. net		4 catfish; 3 blue crabs
32	2-Aug	Pier	50 ft. net		4 blue crabs; 1 perch
33	2-Aug	Pier	75 ft. net		1 blue crab
34	11-Aug	N. Sandbar	50 ft. net		7 blue crabs; 1striped bass; 3 gizzard shad;
35	11-Aug	N. Sandbar	75 ft. net		6 blue crabs; 1 striped bass; 1 gizzard shad;
36	24-Aug	N. Sandbar	75 ft. net		
37	24-Aug	S. Sandbar	50 ft. net	male, 375g, 128mm x 109mm	
38	24-Aug	N. Sandbar	75 ft. net		4 gizzard shad; 1 striped bass; 11 blue crabs; 1 catfish
39	24-Aug	S. Sandbar	50 ft. net		1 gizzard shad; 3 blue crabs; 1 catfish; 1 softshell turtle

Figure 4. Total By-catch Captured in Piermont Marsh from June 6 to August 24, 1997.



DISCUSSION

Terrapins

The low numbers of terrapin caught in this study (eight) are indicative of a small population; the low numbers of turtles marked and the absence of recaptures precludes the use of any statistically reliable estimates of population size. Small populations of terrapin are common in northern latitudes. Unlike the expansive barrier island marshes of New Jersey and further south, the brackish estuarine environments of New York and Connecticut are generally small and isolated from each other and do not support large populations (Victoria 1994; Roger Wood, Stockton State College, pers. comm.).

In addition to small population size, one potential reason for the low trapping efficiency of the trammel nets was the location of nets in the marsh complex. Setting up nets in the open waters of the Hudson (near the Pier and Sandbar sites) may have allowed terrapins to avoid the nets. The trapping efficiency of the nets is higher when they are set in tidal creeks such as Crumkill and Sparkill. As a test, two trammel nets were set up in Crumkill Creek during a rising tide, one at the mouth and one as far upstream as possible. Six catfish were caught in the net at the mouth. After being released, the same six catfish were caught an hour later in the net upstream. We also set up trammel nets in a tidal creek in Milford, Connecticut, where terrapins had been observed swimming. Within two hours we had captured six diamondback terrapins.

Trammel nets were set at the Pier and Sandbar sites because nets set in Crumkill and Sparkill Creeks did not capture any terrapins. Terrapins typically forage in tidal marsh creeks. In this study, however, terrapins were neither seen nor captured in marsh creeks. Rather, all terrapin captures and sightings occurred near the Sandbar area. This suggests that the terrapins are finding a greater abundance of the crustaceans, mollusks and other invertebrates that they consume (Carr 1952; Ernst and Barbour 1972; Spagnoli and Margonoff 1975) in the Sandbar locations. Terrapins might also be using other locations for foraging such as the Pier, where the largest number of terrapins were observed basking and swimming, and could utilize the Sandbar area as a nesting site.

Terrapin nesting sites in areas subject to tidal influence are constructed in flat sand substrates above the levels of normal high tides, with shrub canopy ranging between 25% to 75% (Palmer and Cordes 1988). Although North and South Sandbar are not ideal nesting sites due to their low elevation and granular, muddy soil, the sites historically were prime nesting habitats (A. Ciganek, private herpetologist, pers. comm.). Terrapins usually nested in the fine silty dredge that the Town of Piermont deposited at South Sandbar. During the past few years, the Town has not dredged and as a result South Sandbar has subsided and become overgrown with *Phragmites australis*. Despite having deteriorated as a nesting site, terrapins may still be returning to South Sandbar to nest because of nest site philopatry (Roosenberg 1994).

A terrapin's choice of nesting site is a major determinant of sex ratios. In this study adult males outnumbered females three to one. Although the current sample size was small, sex ratios which depart from one to one are not uncommon in terrapin populations, owing to environmental sex determination (Jeyasuria et al. 1994; Roosenberg and Place 1994). Environmental sex determination is such that terrapins must nest on sandy uplands with a restricted range of thermal conditions to ensure appropriate sex ratios. Nests placed in cooler microhabitats generally produce an abundance of male hatchlings. The potential nesting habitats investigated in this study

were low elevation, sandy spits oriented toward the east. Although east facing beaches are exposed to direct morning sunlight, the angle of incoming solar radiation does not warm the sand as much as on beaches facing south. Nesting areas close to mean high tide are also generally cooler. Terrapin nesting in the Sandbar locations could have produced the sex ratios that were observed.

Terrapins are most active during the nesting season. The exact duration of the nesting season in Piermont in unknown. However, up to twenty terrapins have been observed swimming in the South Sandbar area in late May in previous years, and it is possible that terrapin nesting begins at that time (C. Nieder, HRNERR, pers. comm.). In May 1997, terrapins were not observed during preliminary surveys in and around the marsh complex. Colder temperatures this year may have delayed the terrapin nesting season (B. Hergreuth, Paradise Boat Rentals, NY, pers. comm.). In New Jersey, oviposition in terrapins has been reported from June 9 to July 23 (Burger and Montevecchi 1975; Burger 1977), and in Massachusetts, from June 10 to July 20 (Lazell and Auger 1981). Seven terrapins in the current study were caught between June 8 and July 27. One female was caught June 22 and the other was captured on July 27. Neither was found to be gravid, however, indicating that they had already deposited their eggs for the season.

Daily terrapin activities tend to increase during the nesting season. Nesting is typically observed in the daytime during high tides (Palmer and Cordes 1988) and most terrapins in Piermont were captured near high tide. Daily terrapin activity is determined for the most part by tidal variations. The diamondback terrapins in Piermont exhibited typical terrapin activity. Swimming activity, and therefore trapping frequency, was strongly associated with high tide while inactivity or basking activity on the Pier was observed at lower tides (Muehlbauer 1987). Terrapins may swim more during high tides because of increased food availability. At high tides, more snails are available and marsh-dwelling crabs are more active with the rising tides (Teal 1985; Tucker et al. 1995). Terrapins bask at low tides because more choice upland areas and rocky intertidal areas around the pier become exposed.

The average weight of the male terrapins captured in this study, 382 g, was well within the typical range of terrapin weights, 350 g to 400 g (P. Warny, private herpetologist, pers. comm.). In a study on the foraging ecology of the diamondback terrapin in South Carolina, the average length of male terrapins was 12 mm smaller than the terrapins in this study; likewise, females were larger in Piermont relative to South Carolina (Tucker et al. 1995). This difference indicates that resources are allocated sooner to reproduction in the southern populations and thus the turtles are smaller upon reaching maturation. However, average carapace lengths for the males captured in this study were also higher than the average range of lengths measured in a study conducted in Connecticut (Wood 1992). Piermont's population of terrapins may be reaching sexual maturity at a later time in their development than other northern populations due to environmental stresses such as decreased food quality.

Age could not be determined for five male terrapins because of worn shells. This phenomenon is typical of most terrapin studies. Over half of the 2,800 terrapins captured in a study on the Patuxent River could not be aged (Roosenberg 1990). Sloughing of scutes over time removes the annuli on the shell. As a result, individuals greater than ten years cannot be aged by examining the scutes. Because male terrapins do not increase

significantly in size after reaching sexual maturation, their ages can not be determined from size. The five terrapins almost certainly were older individuals whose scutes were worn with time.

The shell and skin features observed in this study are consistent with the characteristic markings seen on terrapins in other studies. Worn spirals, chips and extra segmentation are common. Terrapins often scrape their shells on river bottoms. Nicks and extra segmentation are caused by propellers and animal bites. Skin color also varies from terrapin to terrapin. A completely black skinned female was captured and a white skinned terrapin was observed in this study; terrapin studies in Connecticut indicate that "skin color can be pure white, cream, dusky, gray, or black, marked with black stripes, splotches, freckles or a combination of all three" (Wood 1992).

<u>By-catch</u>

A significant portion of this study was spent handling a variety of species other than diamondback terrapins. Two species of particular note were the horseshoe crab and softshell turtle. Two horseshoe crabs were captured during this study, one at the end of June, the other at the end of July. Horseshoe crabs are usually found in ocean waters, but they have been known to migrate into rivers as salt wedges from the ocean proceed up stream. However, horseshoe crabs are seldom observed in locations as far north as Piermont Marsh (T. Lake, SUNY-New Paltz, pers. comm.). Both chelicerates were caught when salinity was low during June and July, relative to August. Stranger still was the unexpected capture of a softshell turtle. Softshell turtles have a home range that extends from Florida up to the Great Lakes and Lake Champlain. Softshells are not typically found in the Hudson River. This particular softshell may have migrated down from Lake Champlain or been released by someone, as softshell turtles are frequently sold as pets and as food.

Besides the terrapin, several species of animal observed in this study are of management concern. The thousand-acre marsh still supports a wide variety of estuarine species. For example, estuarine birds such as herons, mallards and marsh wrens utilize the marsh extensively for feeding and/or nesting. Likewise, the presence of blue crabs, catfish, perch, gizzard shad and carp is an indicator that Piermont Marsh is still a viable resource for recreational fishing and commercial trapping. As a habitat for several species of commercial, recreational and environmental concern, Piermont Marsh has great management potential.

Recommendations

Based on the results of this study and observations from others, the population of terrapins inhabiting Piermont Marsh is small. Small populations are particularly vulnerable to even the smallest change in their environment (Roosenberg 1990). In terrapins, recruitment is low, replacement rates are unknown, and the generation time is long. It is unlikely that terrapin populations can adapt to rapidly changing environmental pressures. There are several environmental pressures in Piermont which threaten the viability of the terrapin population.

The decreasing quality of the nesting sites in Piermont Marsh is particularly detrimental to maintaining healthy populations. North and South Sandbar, the nesting habitat of the terrapins, has been subject to significant disturbance in the past few decades

decades (A. Ciganek, private herpetologist, pers. comm.). North and South Sandbar are located right along a road with car and foot traffic. The town has stopped dredging a small creek near the pier which provided fine silty soil as a nesting site for gravid turtles in the South Sandbar area. In addition, the coverage of marsh by *Phragmites australis* has doubled in the past thirty years (Winograd and Kiviat 1997), choking off potential nesting areas and creating a hazard for turtles searching for upland areas to lay their eggs. Furthermore, development along the edge of the marsh has claimed more potential nesting habitat. Construction crews have limited access to sandy uplands by erecting chain link fences around their sites. Despite the deterioration of the North and South Sandbar sites, terrapins continue to use these habitats, often to their disadvantage, due to nest site philopatry.

Healthy terrapin populations are also threatened by human predation. Crab pots, fishing nets and fishing lines increase terrapin mortality. I observed several crab traps and fishing nets submerged for over eight hours around the pier. Terrapins caught in these devices suffer from hypoxic stress and eventually die. Juvenile and male terrapins are more frequently caught in crab traps; adult females are too large to fit in these traps. However, fishing nets and lines do not discriminate between organisms. Terrapins of both sexes and all sizes become entangled in nets or hooked on broken fishing lines. Terrapins are also threatened by raccoon predation on small terrapins, hatchlings and eggs. As nesting sites deteriorate, nesting densities increase, allowing raccoons to increase predation rates on these concentrated food sources (Roosenberg 1990).

Specific recommendations can be made to protect the diamondback terrapin of Piermont Marsh. Nesting habitat must be protected and isolated from human disturbance. Maintaining a sandy shore is integral to providing terrapins with suitable nesting habitat. This can be done in a variety of ways. A few truck loads of sand could be deposited in the Sandbar areas and *Phragmites australis* could be aggressively controlled through physical mowing and/or removal. A more cost-effective alternative would be to have the construction company or the Town of Piermont dredge the small creek near the sandbar. The dredge spoils could be piled on the North and South Sandbar area to increase the sites' elevation, and dumped on some of the *Phragmites australis* that surround the sites so to increase the overall area of the nesting habitat. Dredge spoils should be piled on this area each year or as needed, after hatchlings emerge from their nests in the late fall. Furthermore, dredging the creek will increase tidal flushing, opening up more area for access by Hudson River estuarine species.

The most effective way of preventing terrapin drowning is to require crab trappers and fishermen to check their pots and nets periodically, every three to four hours, and remove any terrapins that get captured. Another solution is for crab trappers to use "turtle excluder devices," or TEDs, developed by Dr. Roger C. Wood at the Stone Harbor Wetlands Institute, N.J. (Campbell 1997). Crab pots can be designed so that portions remain above water to give turtles access to air, or pots can be set in shallow water. Lastly, educational programs can be implemented to educate local high school students on the significance of the wetlands and the diamondback terrapin and the need to protect these valuable natural resources.

ACKNOWLEDGMENTS

We gratefully acknowledge the support of the Tibor T. Polgar Fellowship Program of the Hudson River Foundation for Science and Environmental Research and the New York State Department of Environmental Conservation. Special thanks to Connie Wood who provided the trammel nets and to Jose M. Simoes and Bela for field assistance. Thanks to Peter R. Warny Jr., Chuck Nieder, Drew Ciganek, Bill Hergreuth, and Marsha Meyer for helpful discussions and logistical support.

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The Relationship Between Fecundity of an Alewife *(Alosa pseudoharengus)* Spawning Population and Egg Productivity in Quassaic Creek, a Hudson River Tributary (HRM 60) in Orange County, New York

A Final Report of the 1997 Tibor T. Polgar Fellowship Program

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ABSTRACT

This research grew out of our 1996 Polgar study at Quassaic Creek. That effort investigated the various components of the Quassaic fishery: anadromous, potamodromous, catadromous, and resident species. An unexpected finding of the 1996 study was the strong spawning run of alewives *(Alosa pseudoharengus)*, far exceeding previous estimates of adult alewives for Quassaic Creek.

We isolated the alewife component of the 1996 Quassaic study, repeated the sampling, and compared the two years of data. This comparison allowed us a higher level of confidence that the unexpected number of alewives in 1996 were not anomalous. In order to better understand the significance of the alewife fishery in Quassaic, we investigated the relationship between alewife fecundity (input) and egg and larval productivity (output).

To estimate total eggs being spawned (input), we created a length-fecundity association for all female alewives. Gill nets were used to collect gonads from 52 alewives. They were measured (TL) and their eggs counted. The resulting length-fecundity association (275.1 mm-72,000 eggs) allowed us to estimate average fecundity for all spawning females in Quassaic Creek. Once we estimated the number of females in the spawning run (2248), we could then estimate the total number of eggs being spawned (162 million).

We collected, identified, and counted eggs and larvae being exported from Quassaic Creek (output) using drift nets. The total number of eggs being exported was estimated at 38 million eggs, or 23% of the total spawned, a 77% mortality rate.

The spawning reach of Quassaic Creek is relatively short (<0.9 km). Drift net collections were taken ~0.24 km from the Hudson leaving ~0.7 km of possible alewife spawning reach. This short distance from spawning location to collection location, as well as the shallow and narrow characteristics of Quassaic Creek, may account for the high survival rate. Eggs and larvae that have to travel longer and through broader and deeper reaches to a collection location would seem to be more susceptible to predation and other mortality factors.

The 1997 alewife spawning run was estimated to be 80% (4496) of the 1996 spawning run (5600). The difference is not unreasonable and could be the result of a dry spring (1997) as opposed to one of high flow (1996). Total egg and larval transport from Quassaic in 1997 was estimated to be 3.8×10^7, an order of magnitude higher than a 1988 estimate of 9.4×10^6. It is reasonable to assume that the 1996 egg and larval transport was equal or larger.

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INTRODUCTION

The term "River Herring" includes two species of anadromous clupeids that are difficult to distinguish- alewife (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*). River herring management is soon to become a focus item for the Atlantic States Marine Fisheries Commission (ASMFC). New York State will be required to comply with ASMFC guidelines, among which are to have an understanding of various life history parameters such as spawning range and habitat requirements. Other than anecdotal observations, there is little information available on the use of Hudson River tributaries by anadromous herrings. Such information as which species spawns in which tributary is poorly known. Tributary productivity of either species is similarly unknown.

With this in mind, we had two main purposes for this study: Repeat our 1996 sampling of Quassaic Creek to compare the size of the 1997 alewife spawning run to our estimate for 1996, and compare our 1997 estimate of the alewife spawning run to estimates of the magnitude of egg and larval drift.

In 1996 we demonstrated that alewives were, in fact, spawning very successfully in Quassaic Creek. However, what was the magnitude of Quassaic alewife egg and larval transport into the tidal Hudson? What was the relationship between number of spawning adults and production of eggs and larvae? Previous biological assessments of Quassaic Creek (Schmidt 1985, 1987) implied that productivity should be low. To our knowledge, these kinds of data have never been collected from a Hudson River tributary.

METHODS

Study area—Quassaic Creek is located at approximately river mile (RM) 60, which is very near, or at, the average summer upstream limit of the Hudson River "salt front" (~1-3 ppt salinity) in Newburgh, New York (Fig. 1). It is 3.2 km north of Moodna Creek, and directly across the river from Fishkill Creek, the two closest major Hudson River tributaries.

The lower portion of the watershed (Fig. 1) is highly urbanized; modifications include stream channel alterations and degraded water quality (Stevens *et al.* 1994), including effluent from a combined sewer overflow on the north bank under the River Road bridge. Two barriers to upstream movement of fishes were identified by Schmidt and Cooper (1995), a partial barrier located about 0.7 km upstream of the mouth of Quassaic Creek and an eroding dam about 1.1 km upstream of the mouth. This study concentrated on that portion of Quassaic Creek downstream of the dam (Figs. 1 and 2). Sampling was done at two stations within this area, the entrance of the creek (confluence with the Hudson) and the observed spawning reach at and above the range of tide.

This study required the capture and analysis of both spawning adult alewives and subsequent eggs and larvae from those not captured. The methods varied for each of these efforts.

Adults were captured in gill nets at Station 1, located at the southeast channel at Quassaic's confluence with the Hudson (Fig. 1 & 2). Eggs and larvae were captured in drift nets at Station 4, Quassaic's main channel at the head of tide (Fig. 2).

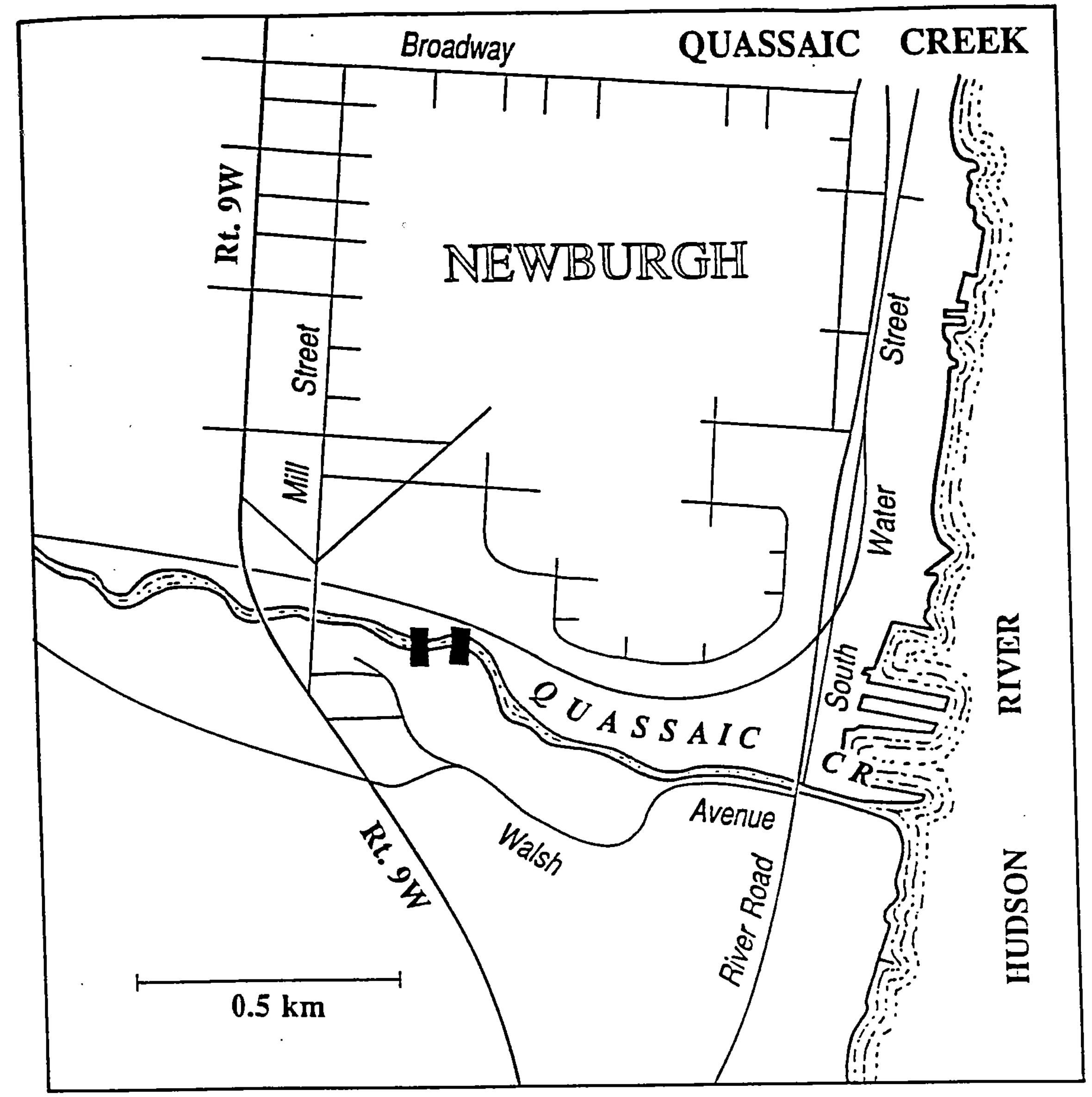

Figure 1. Mouth of Quassaic Creek, Newburgh, New York (from Schmidt and Cooper 1995). The two black bars are barriers to upstream movement of fishes.

Procedures-

Adults: Our study required that we estimate number of eggs being spawned (input) the number of eggs and larvae being exported (output) and, thus, mortality. For this we

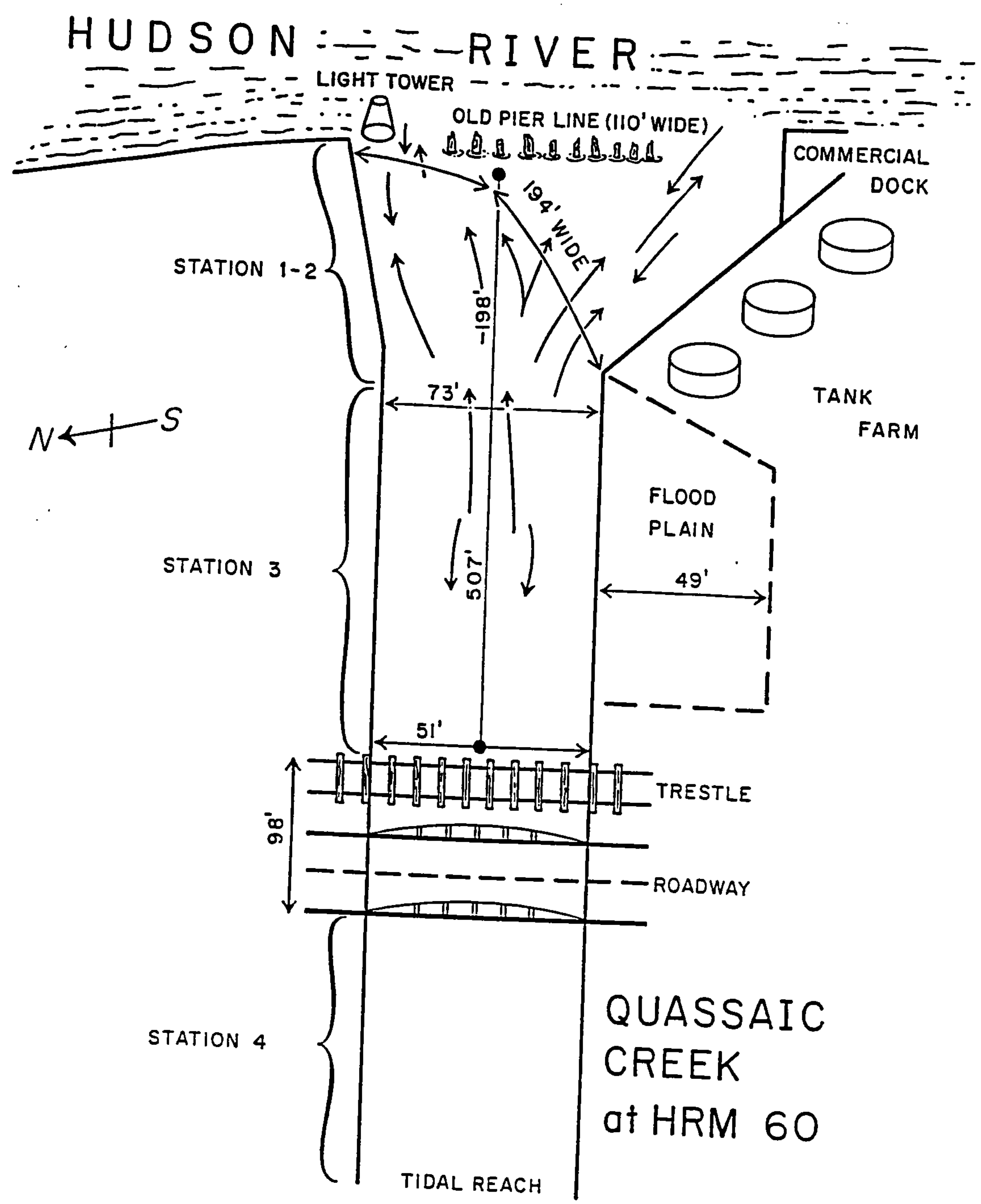

Figure 2. Diagram of the mouth of Quassaic Creek showing sampling locations.

had to capture gravid females with gill nets as they entered Quassaic from the Hudson. This sampling was conducted between March 23 and June 17, 1997.

Monofilament gill nets of two different sizes (15.5 m X 1.8 m X 6.4 cm stretch mesh; 15.5 m X 1.8 m X 3.2 cm stretch mesh) were used in a "standard set" at Station 1 (Fig. 2). This consisted of three 15.5 m gill nets (x 6.4, 3.2, 6.4 cm) set next to each other radiating from the shoreline approximately 3-5 m apart (Fig. 3). The inside net was used to determine direction of fish passage. Standard sets were made approximately every 2 days, generally during a late-afternoon or early evening ebb tide. The nets were checked periodically during the night, and then removed the following morning on the next ebb tide. These sets took advantage of night flood tides to measure immigration into Quassaic. Each fish captured was identified, measured (total length), gender determined if possible, and then released if alive. Alewives did not survive capture and, in addition to the previous data, all were weighed to the nearest gram.

The magnitude of the alewife spawning run was estimated from the numbers collected. We assumed that the gill nets (Fig. 3) collected all the individuals entering Quassaic from the south and, since our nets covered half the creek, we assumed that we intercepted half of the individuals immigrating on any given night. We estimated the relative magnitude of immigration during daytime flood tides by dividing average catch per gill net (CPUE) during the day by average CPUE at night (0.71, Lake and Schmidt 1997) and multiplying that percentage by our estimated nighttime run. We

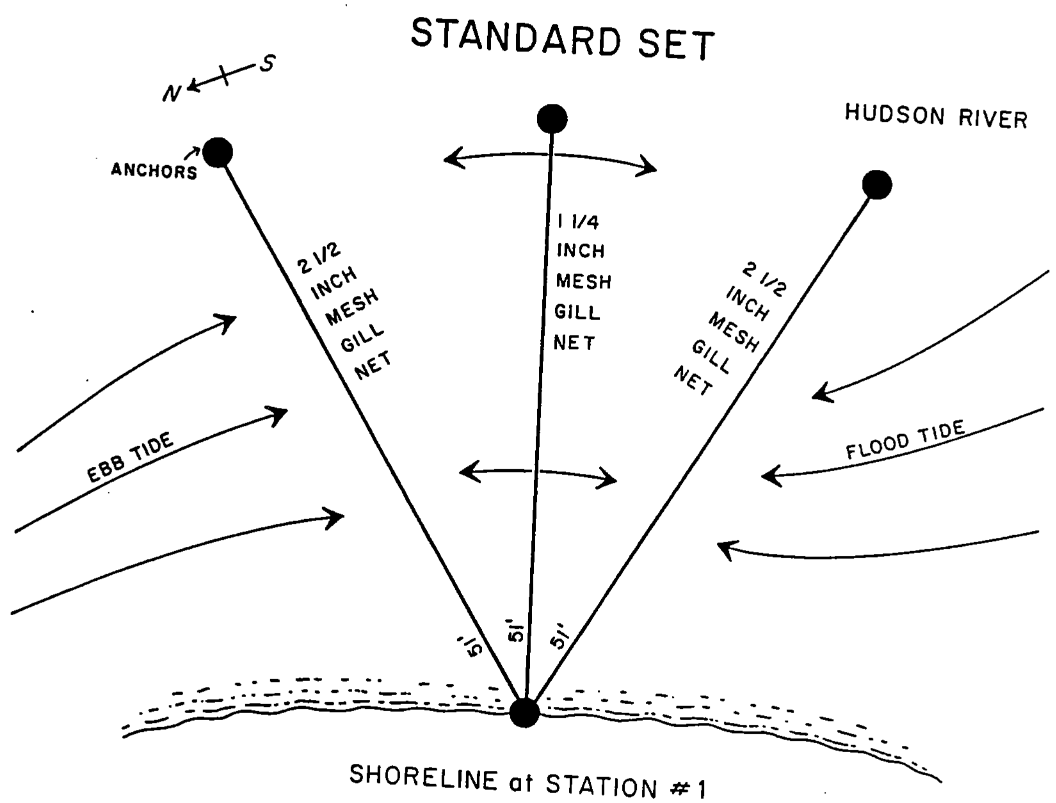

Figure 3. Diagram of a "standard set" of gill nets at the mouth of Quassaic Creek.

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assumed that runs were similar in magnitude on subsequent nights that we did not sample. These calculations gave us what we think is a minimum estimate of the total run.

Fecundity: In the laboratory, ovaries were removed from arbitrarily chosen individuals, within one hour of capture. The ovaries were weighed, labeled, preserved in zip-lock freezer bags in 50% isopropanol, and refrigerated. During subsequent examination, we eliminated those individuals that had spawned or partially spawned. For all the

unspawned fish, we dissected away as much extraneous tissue as possible and then weighed the ovaries. We then removed three small subsamples from ovaries of each fish, weighed them (nearest 0.001 g), and counted eggs in each subsample. There were two sizes of eggs present in the ovaries. We only counted the larger eggs assuming those were the ones that would have been spawned close to the time of capture. The average number of eggs per 0.001 g of ovary was then multiplied by the preserved weight of the entire gonad to derive the estimate of total egg number per fish.

A regression between fecundity and fish length was calculated. The total number of eggs produced by the alewife run was estimated by multiplying the population estimate by the gender ratio (= number of females), calculating the average body length of a female alewife in this run, deriving the fecundity of an average size alewife from the regression, and finally multiplying by the estimated number of females.

Egg and larval drift: We used three standard rectangular drift nets (0.135 m^2, opening; 303 μm mesh). The nets were deployed nearshore, midstream, and then midway between those points, facing upstream against the flow. Sampling periods were chosen, as near as possible, to occur during an ebb tide at dusk or after dark. Twenty-hour samples in Stockport Creek (located at RM 121- Schmidt *et al.* 1994) showed that alewife eggs drift at the same rate all day and all night but that yolk sacs drift mostly at dusk.

The drift nets were fished for 20 minutes, removed and the contents collected and preserved in 10% formalin. While the nets were fishing, we measured water temperature (hand held thermometer), velocity of water in each net (Swoffer current meter), and a depth and water velocity transect over the width of the entire creek which was used to estimate stream discharge.

In the laboratory, eggs and larvae were sorted from the samples, identified, and counted. Knowing the total number of eggs and larvae in the samples, we used the flow data (volume through each net), and calculated the number of alewife eggs and larvae per cubic meter. Knowing the flow of Quassaic in cubic meters per second (which we measured), we calculated the number of alewife eggs and larvae coming out of Quassaic per second. We then multiplied the number of alewife eggs and larvae per second by the number of seconds until the next drift net sample—which might be several days. This assumes that drift remains the same until the next sample. So few yolk sac larvae were collected, that we did not distinguish between their drifting behavior and that of the eggs for purposes of calculating magnitude of the drift.

RESULTS

We collected 415 adult alewives entering Quassaic Creek with precisely half of the individuals being females. This is slightly fewer than the 531 we collected in similar sampling in 1996 (Lake and Schmidt 1997). Males appeared before females and the run had two peak periods, one in late April and one in mid-May (Fig. 4). A similar bimodal pattern was seen in Quassaic in 1996 (Lake and Schmidt 1997) and in Stockport Creek (Schmidt and Stillman 1994). Other potamodromous and incidental species were collected and they have been added to our species list for Quassaic Creek

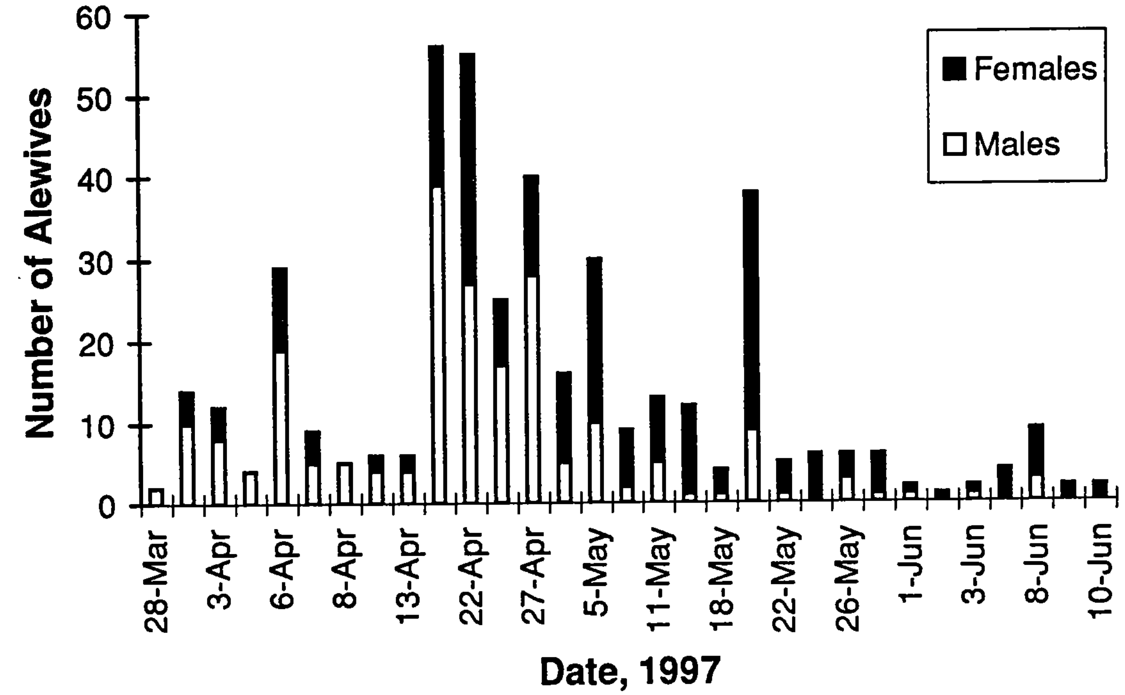

Figure 4. Number of adult alewives immigrating into Quassaic Creek, Newburgh, New York in 1997.

(Appendix Table 1). One major difference between this year and our 1996 collections is the total lack of spottail shiners (*Notropis hudsonius*) in Quassaic Creek this year. We have no explanation for this observation.

From our gillnet sampling, we estimated that there were 4496 total alewives entering Quassaic during the sampling period. This is about 1000 fewer alewives than we estimated in Quassaic in 1996. Of the total number, 2248 were females (~50:50 gender ratio).

The average total length (TL) of all female alewives captured was 275.1 mm. Females ranged from 232-318 mm TL, probably containing several age classes. Males were slightly smaller ranging from 232-302 mm TL.

Ovaries were removed from 55 alewives spanning the run from April 17-June 9, 1997. Three of these alewives were subsequently found to be spent or partially spent, leaving 52 ovaries for analysis. Fresh ovary weight was related to fish weight (correlation coefficient = 0.64) but there was a high variance in the data (Fig. 5). The ovary weight as a fraction of the total fish weight generally declined as the season progressed (Fig. 6) even though average size (TL) of females remained constant.

Fecundity estimates ranged from 15,000-135,000 eggs per female (Fig. 7). The calculated regression of egg number on TL was:

Egg # = -90,098 + 588.1(TL mm)

There was a lot of scatter in these data (Fig. 6) and the correlation coefficient for the regression was only 0.45.

Using the average size female alewife (275.1 mm TL), the average fecundity was 71,688 eggs per female. Given that our estimate of the females entering Quassaic Creek was 2248, multiplying gives us an estimate of alewife egg production at 1.6 X 10^8 eggs for the season.

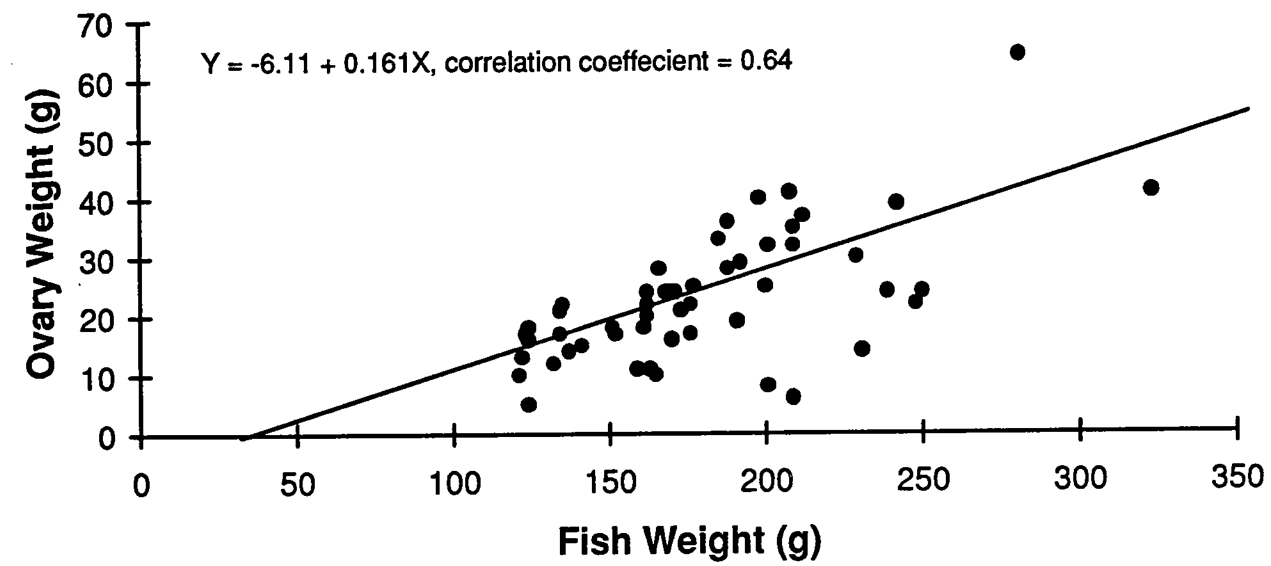

Figure 5. Scatterplot of fresh ovary weight relationship to alewife weight from Quassaic Creek, Newburgh, New York in 1997.

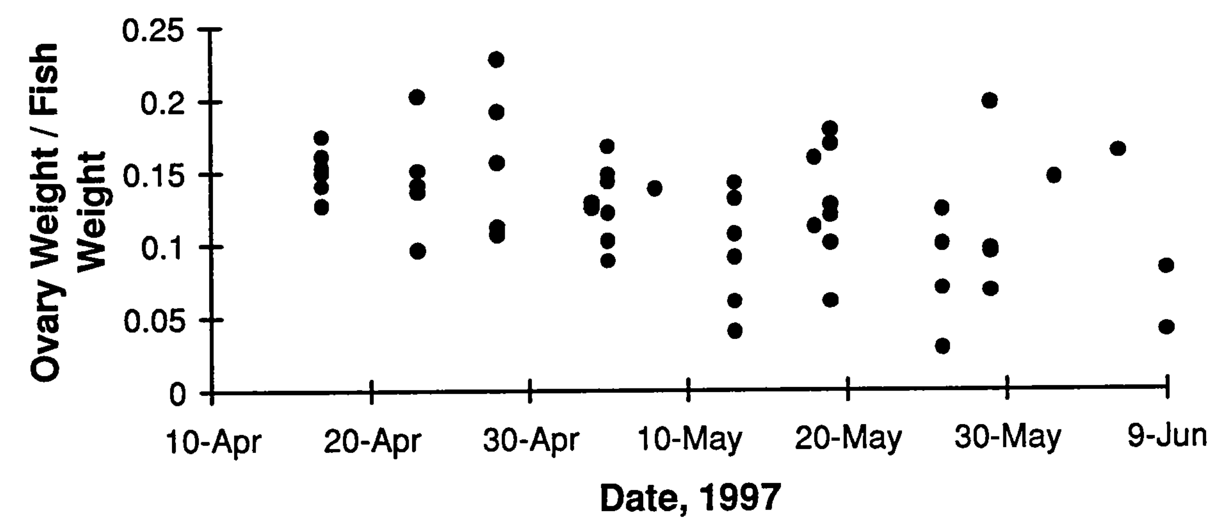

Figure 6. Ovary weight compared to total fish weight in alewives from Quassaic Creek, Newburgh, New York in 1997.

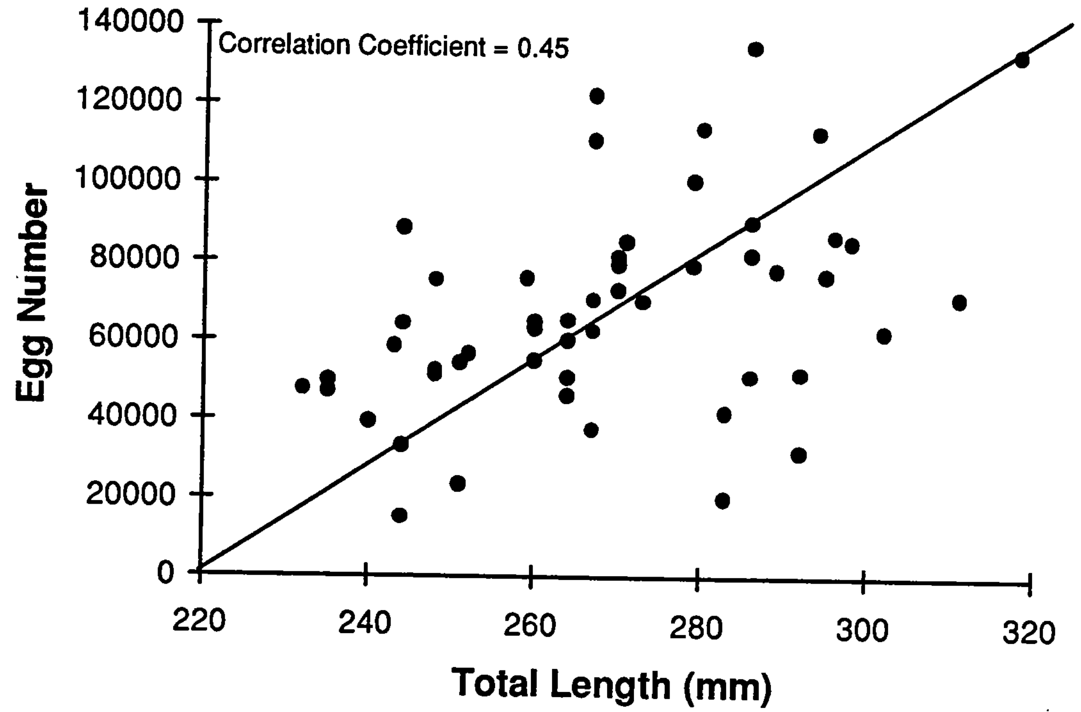

Figure 7. Fecundity of alewives in Quassaic Creek, Newburgh, New York in 1997.

Seven species of fishes were collected in the drift net samples (Table 1). These are the same species collected in drift in Quassaic Creek in 1988 (Schmidt and Limburg 1989) with the addition of yellow perch larvae (*Perca flavescens*) in 1997. Almost 85% of the eggs and larvae collected were alewives, which is typical of Hudson River tributaries in the spring (Schmidt and Limburg 1989).

The total number of alewives estimated from the drift (eggs and larvae) was 3.8 X 10^7. Although we know that alewife eggs and yolk sac larvae (the only stages seen in this study) have different diurnal drift patterns (Schmidt *et al.* 1994), we calculated the drift as if all the alewives caught were in the egg stage. Alewife yolk

Table 1. Early life stages of fishes collected in the drift from Quassaic Creek, Newburgh, New York, in 1997. Numbers are the totals from three replicate samples on each date. Unidentified eggs are probably cyprinids. Ap = *Alosa pseudoharengus*, Eo = *Etheostoma olmstedi*, Ma = *Morone americana*, Nh = *Notropis hudsonius*, Cc = *Catostomus commersoni*, Ui = unidentified, and Pf = *Perca flavescens*.

Date		Ap	Eo	Ma	Nh	Cc	Ui	Pf
Apr 23		27				2	2	
May 2		189		3	1		1	
May 7		52		1		4	3	
May 19		46	3	3		4	3	8
May 23		169	16	13	12	5		
May 26		380	8	32	12		4	
May 31		511	14	2	22	1		
Jun 7	32	6	8	7				
Jun 8	25	9	9	7				
Jun 10		30	26	1	8			
Total		1461	82	70	69	16	13	8

sac larvae were only 9.1% of the total catch. In 1988, we calculated that 9.5 X 10^6 alewife eggs were produced in Quassaic, 25% of those estimated in 1997.

The estimated number of alewife early life stages in the drift was 23% of the total number of eggs potentially released into Quassaic in 1997. Our calculations do assume that all females that entered Quassaic spawned all their ripe eggs in Quassaic. However, our estimate of female numbers is probably conservative since we did assume we caught all the females from half of the creek mouth (Lake and Schmidt 1997). Regardless, our estimates indicate a 78%
mortality between the time alewives spawned and the capture of eggs and larvae in the drift. Part of this mortality is probably due to egg predation by other fishes in the

spawning areas and, perhaps, by invertebrates. We have often observed fishes like white perch (*Morone americana*) and spottail shiners (*Notropis hudsonius*) mixed in with spawning alewives and we suspect they were consuming alewife eggs. The initially adhesive nature of the eggs and absence of parental care may make them especially vulnerable to benthic-feeding predators.

DISCUSSION

Our estimates of fecundity differ considerably from published estimates (Kissel 1974; citations in Carlander 1969). Most previous estimates were based on total egg count which ignored the presence of eggs of different sizes. We feel that estimating only the eggs ready to be spawned gave us a more accurate picture of the alewife run in Quassaic Creek because of the physiography of the creek and of Hudson River tributaries in general.

The spawning areas accessible to alewives in Quassaic Creek are within 0.7 km of the tidal creek mouth (Fig. 1). Quassaic Creek is generally shallow and provides little shelter for alewives during the day. Although we have observed alewives in Quassaic Creek in the daytime, we have never seen the numbers of fishes that should be present given our estimates of the magnitude of the run. We interpret these observations as an indication that the adults spend very little time in the creek and are present primarily at night.

Most observations of anadromous alewives (e.g. Kissel 1974) have been made on spawning runs into lakes or ponds where adults have a long residence time (at least

several weeks). The assumption in these situations is that all eggs in an ovary will be spawned in the lentic part of the system, in which case a total count of eggs in the ovaries is the reasonable estimate of egg deposition.

In Quassaic Creek, the proposed short residence time would dictate that only those eggs ready to be spawned would be deposited. In this scenario alewives would be considered iteroparous, maturing a second set of eggs that would be spawned later in the season.

There is some evidence in our data that supports iteroparity. Alewives spawning in Quassaic Creek later in the season had smaller ovaries than those of similar sizes spawning earlier (Fig. 6). If these alewives spawning later in the season are spawning for the second time in the season, there are fewer eggs in the second batch of eggs spawned. Our subjective observations from counting egg subsamples were that the smaller (undeveloped) eggs were less abundant than the larger ones.

CONCLUSIONS

Our observations on the alewife run in Quassaic Creek are the first in the Hudson River estuary that included population estimates, fecundity estimates, and an estimate of egg and larval mortality. Quassaic Creek is typical of Hudson River tributaries in its size, lack of ponded areas for alewife spawning, and short distances from tidal water in which alewives can spawn. There are also reasons why Quassaic Creek may not be typical of Hudson River tributaries, many of which are correlated with the urban nature of the environment immediately around the creek mouth. We propose the hypotheses that alewives in Hudson River tributaries have a very short residence time on the spawning grounds and that they are iteroparous within a single spawning season.

RECOMMENDATIONS

Studies like this one need to be repeated in other Hudson River tributaries. Our hypothesis, stated above, needs to be vigorously assaulted. It would be very interesting to estimate the magnitude of alewife egg consumption on the spawning grounds and identify what organisms (vertebrate and invertebrate) may be consuming the eggs while they are adhesive.

ACKNOWLEDGEMENTS

We thank and express our sincere appreciation to Kathleen Schmidt for drawing some of the figures and to Christopher and Phyllis Lake for helping with sampling in Quassaic Creek. We also thank the Hudson River Foundation and the Hudson River National Estuarine Research Reserve for their continued support and confidence in our efforts.

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Appendix Table 1. Fishes collected by station in Quassaic Creek, 1996-1997.

Fish	Station 1	Station 2	Station 3	Station 4	Station 5
American eel, *Anguilla rostrata*	♦	♦	♦	♦	
blueback herring, *Alosa aestivalis*	♦				
alewife, *Alosa pseudoharengus*	♦	♦	♦	♦	
American shad, *Alosa sapidissima*	♦	♦			
gizzard shad, *Dorosoma cepedianum*	♦				
bay anchovy, *Anchoa mitchilli*		♦			
goldfish, *Carassius auratus*	♦				
common carp, *Cyprinus carpio*	♦	♦	♦		
golden shiner, *Notemigonus crysoleucas*	♦	♦			
spottail shiner, *Notropis hudsonius*	♦		♦	♦	
fallfish, *Semotilus corporalis*	♦	♦	♦	♦	
white sucker, *Catostomus commersoni*	♦	♦	♦	♦	♦
white catfish, *Ameiurus catus*	♦				
yellow bullhead, *Ameiurus natalis*	♦				
brown bullhead, *Ameiurus nebulosus*	♦	♦			
channel catfish, *Ictalurus punctatus*		♦			
redfin pickerel, *Esox americanus americanus*				♦	
chain pickerel, *Esox niger*	♦	♦	♦		
brown trout, *Salmo trutta*	♦				
brook trout, *Salvelinus fontinalis*	♦				
eastern banded killifish, *Fundulus diaphanus diaphanus*	♦	♦	♦		
mummichog, *Fundulus heteroclitus*		♦			
white perch, *Morone americana*	♦	♦	♦	♦	
striped bass, *Morone saxatilis*	♦	♦	♦	♦	
rock bass, *Ambloplites rupestris*	♦				
redbreast sunfish, *Lepomis auritus*	♦		♦	♦	
pumpkinseed, *Lepomis gibbosus*	♦	♦	♦	♦	
bluegill, *Lepomis macrochirus*	♦	♦	♦	♦	♦
smallmouth bass, *Micropterus dolomieu*		♦		♦	
largemouth bass, *Micropterus salmoides*	♦	♦	♦	♦	
black crappie, *Pomoxis nigromaculatus*	♦				
tessellated darter, *Etheostoma olmstedi*	♦	♦	♦	♦	
yellow perch, *Perca flavescens*	♦	♦	♦	♦	
bluefish, *Pomatomus saltatrix*		♦			
hogchoker, *Trinectes maculatus*		♦			

Taxa:

Families	14
Genera	25
Species	35

INVESTIGATIONS INTO CADMIUM RESISTANCE IN *FUNDULUS* FROM A METALS CONTAMINATED SITE

A Final Report of the Tibor T. Polgar Fellowship Program

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Samson, J.C. and J.S. Weis. 1998. Investigations into cadmium resistance in *Fundulus* from a metals contaminated site. Section III: 24 pp. *In* J.R. Waldman, W.C. Nieder (eds.), Final Reports of the Tibor T. Polgar Fellowship Program, 1997. Hudson River Foundation.

ABSTRACT

Battery production in Foundry Cove (FC) on the Hudson River, NY, resulted in severe cadmium (Cd) pollution (< 39,500 μg/g in sediments). Superfund "clean up" dredging reduced sediment concentrations to ~80μg/g, still considered high. The Cd in FC is bioavailable, and levels would be expected to produce biological effects. Increased Cd resistance was reported in FC *Limnodrilus* worms compared to a clean site, South Cove (SC). Other organisms in FC might also adapt through increased resistance. We studied killifish larvae, *Fundulus*, to ascertain whether FC larvae are more Cd-tolerant than SC larvae and whether there are differences in larval behavior between controls from the two populations which might reflect Cd impacts. Data on acute (LC_{50}) and chronic (behavioral) effects revealed no distinct differences in sensitivity to Cd. Larval *Fundulus* had equivalent 96hr LC_{50} of ~80μg/L Cd. Exposure to 0, 25, or 50 μg/L Cd over 14 days caused no differences in spontaneous activity in larvae of either population. Prey capture ability of SC (but not FC) fish did decrease in the highest concentration of Cd, but we were unable to repeat the experiment. The lack of overall resistance in FC larvae may be due to: (1) current levels of Cd may be too low to induce resistance in *Fundulus* (data indicate tolerance to high levels), (2) resistance may not develop in larval stages of this species, or (3) the endpoints tested may not have been sensitive to population differences. Perhaps other endpoints or life history stages might have demonstrated enhanced resistance.

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INTRODUCTION

Foundry Cove, located near the town of Cold Spring, NY, on the east side of the Hudson River, was the site of intense cadmium-nickel battery production from 1953 through 1979 (Fig. 1). Wastewater discharge from these operations resulted in the most severe cadmium (Cd) pollution ever reported, up to 39,500 µg/g in sediments in some areas of the cove (Moore and Ramamoorthy 1984; Knutson et al. 1987). Levels of nickel (Ni) and cobalt (Co) were also high, up to 21,100 µg/g and 700 µg/g respectively, in the most polluted locations. Foundry Cove was the site of a massive dredging operation overseen by Sevensons Environmental Services from 1994 to 1995, which resulted in a reduction of sediment Cd concentrations to around 80µg/g (still considered significantly high levels of cadmium).

Cadmium toxicity increases with decreases in salinity and Foundry Cove is generally fresh water with salinities occasionally reaching 2-3‰ (Knutson et al. 1987). Eisler (1971) reported a range from 0.32 to 55.0 mg/L Cd was lethal to various marine invertebrate and vertebrate species (LC_{50} values at 20°C and 20‰ salinity). Other studies indicate significant behavioral effects at Cd concentrations in the µg/L range (Henry and Atchinson 1978; Mirkes et al. 1978; Sullivan et al. 1983; Hutcheson et al. 1985; Brown and Andrake 1992; Bryan et al. 1995). These data suggest that Cd concentrations in Foundry Cove are at or above the levels that are harmful to most aquatic organisms. It has been previously shown that the Cd in the cove is bioavailable to the resident organisms (Klerks 1987; Hazen and Kneip 1980; Hazen 1981). But macrobenthic species

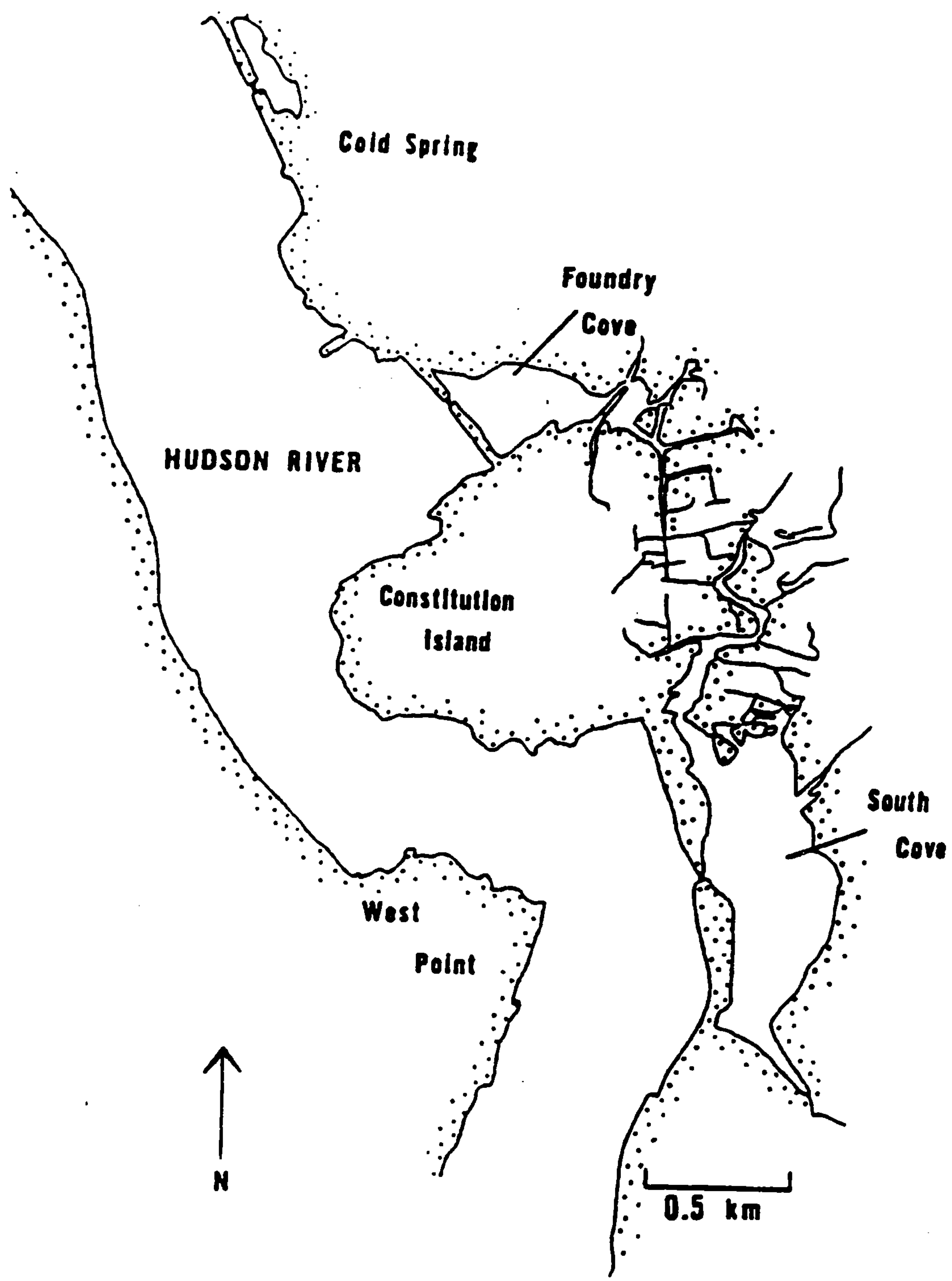

Figure 1. Location of Foundry Cove and South Cove, NY (Knutson et al. 1987).

composition studies comparing Foundry Cove to a nearby control site in South Cove (on the Hudson River, approximately 2 km from Foundry Cove) found no significant differences in density or diversity between the sites (Klerks and Levinton 1993). Foundry Cove is also home to many other organisms including several fish species such as *Fundulus heteroclitus* and *F. diaphanus*. Could these organisms be adapting to their surroundings through increased resistance to the heavy metals contaminating their environment?

Klerks and Levinton (1989) showed Foundry Cove populations of the oligochaete, *Limnodrilus hoffmeisteri*, developed resistance to the combination of Cd, Ni and Co found in the sediment when compared to the South Cove population. Resistance has also been reported in populations from other heavy metal contaminated sites, including lead and copper resistance in several populations of the isopod, *Asellus meridianus* (Brown 1976), zinc resistance in the polychaete, *Nereis diversicolor* (Bryan and Hummerston 1973), and methylmercury resistance in the killifish, *Fundulus heteroclitus* (Weis et al. 1981; Zhou et al. 1996). Such evidence supports the concept of organisms adapting to pollution through developing resistance.

With the continued use and creation of chemical substances for industry and agriculture, it has become increasingly important to examine the ecological effects these substances have on the environment. Foundry Cove provides an opportunity to study an ecosystem that has established itself despite high levels of heavy metal contamination in the habitat. In combination with the findings of Klerks and Levinton (1989), determining the mechanism for adaptation of a vertebrate species in Foundry Cove could provide some answers to the question of how the ecosystem maintains itself under such adverse conditions. The killifish, *Fundulus heteroclitus*, appears to be a good candidate for such research because of its prevalence in estuaries all along the Atlantic coast, including highly polluted sites such as Foundry Cove. Several populations of killifish within the Hudson / Raritan estuary have developed resistance to other contaminants such as methylmercury and PCB's, suggesting similar mechanisms may be responsible for their prevalence in Foundry Cove (Weis et al. 1981; Zhou et al. 1996). This research set out to address the following questions:

1. Are embryos from Foundry Cove more tolerant to Cd than embryos from South Cove (the control site)?
2. Are larvae from Foundry Cove more tolerant to Cd than larvae from South Cove?
3. Are there differences in fertilization rates, embryonic development and larval behavior between the controls from the two populations, which might indicate impact of Cd contamination in Foundry Cove?

The proposed method of egg collection and fertilization (stripping males and females and combining eggs and sperm in a small amount of water), has been used by many investigators over many years with *Fundulus* from many areas. However, for fish from SC and FC, all embryos thus produced were unable to procede through development beyond early cleavage. This failure to produce viable embryos made it necessary to revise the original objectives. The research instead focused on the questions of larval resistance as stated in objectives 2 and 3. This issue is further discussed in the Materials and Methods section.

Larval resistance was determined by comparing Cd concentrations that induced acute (LC_{50}) and sublethal behavioral toxicity in the two populations after larval exposure. Because behavior has been shown to be a sensitive indicator of metal toxicity in several fish species(Henry and Atchison 1991), we compared prey capture and spontaneous swimming activity in the larvae after Cd exposure.

MATERIALS AND METHODS

It was originally proposed that embryos would be collected by strip spawning adult killifish from the two different sites. Collected embryos would be used either immediately, for embryonic exposure, or maintained in the lab until hatching and used for larval exposures. Although this method has been highly successful with other killifish populations, adult killifish from both the Foundry Cove and South Cove population failed to provide viable embryos. This method was attempted for three consecutive spawning cycles without success. To avoid missing the short spawning period of the killifish (late May/early June through mid/late July) egg collection was replaced by field collection of hatched larvae in late June. It should be noted that there was a significant number of newly hatched larvae available in both Foundry Cove and South Cove. The questions of egg viability was beyond the scope of this summer research project but presented an interesting problem that should be addressed in the future.

Field collection of larvae presented a second issue of distinguishing between the two different species of killifish present at both sites, namely *F. heteroclitus* and *F. diaphanus*. As adults, the two species are easily distinguished, but larval identification requires microscopic examination which causes stress to the fragile larvae, resulting in unacceptably high mortality. This prevented determination of species prior to exposure but larvae were examined after test termination or mortality and the majority were *F. heteroclitus*. Due to the lack of *a priori* species separation, *Fundulus* spp. will be used to refer to both species.

Fundulus spp. larvae (8-12mm TL) were collected from both Foundry Cove and South Cove using dip nets. Larvae were collected from small water pockets left on the mudflats during low tide and transported back to the lab where they were allowed to acclimate for at least one week in filtered water (5 ppt salinity) before being used for larval exposures.

LARVAL LC_{50} EXPERIMENTS

Acute toxicity tests were conducted to determine the relative sensitivity of the two populations of *Fundulus* to Cd. An LC_{50} was determined after 96 hours of exposure. Larval exposure began after a week of lab acclimation using exposure concentrations of 25, 50, 100 or 250 μg/L Cd as $CdCl_2$ in glass finger bowls containing 150ml of test solution. Four replicate dishes, each containing 5 larvae, were used for each concentration and the control. Mortality was recorded every 24 hours and all test solutions were renewed every 48 hours. Acute tests were terminated after 96 hours of exposure. Probit Analysis was used to calculate the LC values using software provided by the Ecological Monitoring Research Division of the U.S. Environmental Protection Agency (EPA 1994).

SUBLETHAL EFFECTS ON LARVAE

Larvae used for prey capture and spontaneous swimming activity experiments were exposed to two different sublethal concentrations of Cd after a one week lab acclimation period. Cd concentrations used were 25 and 50μg/L Cd, based on results of

acute toxicity tests. Four replicate dishes, each containing five larvae, were used for each concentration and the control, for both populations. All larvae from each exposure group were tested for all experiments. After testing, larvae were returned to exposure dishes.

PREY CAPTURE EXPERIMENTS: Prey capture ability for Cd-dosed and control larvae from the two populations was compared after both 7 and 14 days of exposure. Trials involved placing individual larvae in a small finger bowl containing 50 ml water and 50 newly-hatched *Artemia* nauplii. The sides of the finger bowl were covered with white tape to minimize distraction to the larvae during testing. Parameters included number of prey caught in 1 and 5 minutes for each larva. Larvae were fed *Artemia* daily after the day's trials were complete. The experiment was repeated for the South Cove population, but due to the late change in collection methods, no larvae of comparable size could be collected from Foundry Cove to run a second trial. Statistical procedures included ANOVA and Tukey's pairwise comparisons of means ($p \leq 0.05$).

PREDATOR AVOIDANCE EXPERIMENTS: Larvae from both populations were to be tested for predator avoidance after 14 days of exposure, using their natural predator, adult *Fundulus heteroclitus*. Several attempts were made to run this experiment using a variety of designs, but in all cases the predators would not consistently pursue the larvae. Due to the lack of performance from the predator we could not get a reliable result for predator avoidance. To provide more insight into the dynamics of Cd and the two *Fundulus* populations, experiments were conducted to assess spontaneous swimming activity between the different exposure groups and populations. This experiment was designed to reveal differences in activity which might be correlated with Cd exposure or population.

SPONTANEOUS SWIMMING ACTIVITY EXPERIMENTS: Swimming activity for Cd-dosed and control larvae from the two populations was compared after both 3 and 10 days of exposure. Trials involved placing individual larvae in a finger bowl containing 100 ml water. The finger bowl was place over a pie-shaped grid divided into 8 equal slices and the sides of the bowl were again covered with white tape. Larvae were allowed to acclimate for one minute after which the number of lines crossed in 30 seconds was recorded. The pie-shaped design was chosen because of the larval tendency to swim only along the outside edge of the finger bowl. The experiment was added towards the end of the sampling period and therefore could only be run once using larvae from both populations. Statistical procedures included ANOVA and Tukey's pairwise comparisons of means ($p \leq 0.05$).

RESULTS

LARVAL LC_{50} EXPERIMENTS

Larval *Fundulus* spp. from both populations were equally sensitive to Cd at acute concentrations (Table 1). Probit Analysis revealed that a concentration of ~80µg/L was lethal to 50% of the test larvae in 96 hours regardless of population ($p \leq 0.05$).

Table 1. 96 hour LC_{50} data for cadmium exposure of larval *Fundulus* spp. (8-12mm TL).

POPULATION	ENDPOINT	CONCENTRATION	95% Confidence Limits	
			Lower	Upper
SOUTH COVE	96hr. LC50	81µg/L Cd	33	74
FOUNDRY COVE	96 hr. LC50	83 µg/L Cd	61	117

SUBLETHAL BEHAVIORAL EFFECTS

PREY CAPTURE EXPERIMENTS: The results of the prey capture experiments indicated that most larvae could capture all *Artemia* within 5 minutes, making this parameter a poor indication of ability. Therefore only the 1 minute data will be presented as they were more appropriate for analysis.

Comparisons were made between the different exposure groups and the controls, and the two different exposure durations. The prey capture ability of larvae from the Foundry Cove population was not significantly affected by exposure to Cd at either 25 or 50 µg/L, even with an increase in exposure duration from 7 to 14 days (Fig. 2). Pairwise comparison of the means after one-way ANOVA indicated no significant differences between or within groups at a critical value of 0.05 (7 day: $f = 0.37$; $p = 0.6946$; 14 day: $f = 1.05$; $p = 0.3618$) .

The highest concentration, 50 µg/L Cd, did produce a significant decrease in the prey capture ability of larvae from the South Cove population after 7 days of exposure ($f = 6.62$; $p = 0.0023$) (Fig. 2). The difference was maintained, but did not increase, with continued exposure for an additional 7 days ($f = 5.38$; $p = 0.0069$)(Fig. 2). Prey capture ability was not affected by exposure duration, as there were no differences between 7 and 14 day exposures. Analyses of statistical significance were as previously described for the Foundry Cove population.

Comparisons between the control groups of the two populations indicated both had comparable prey capture ability, suggesting no baseline differences between the two populations.

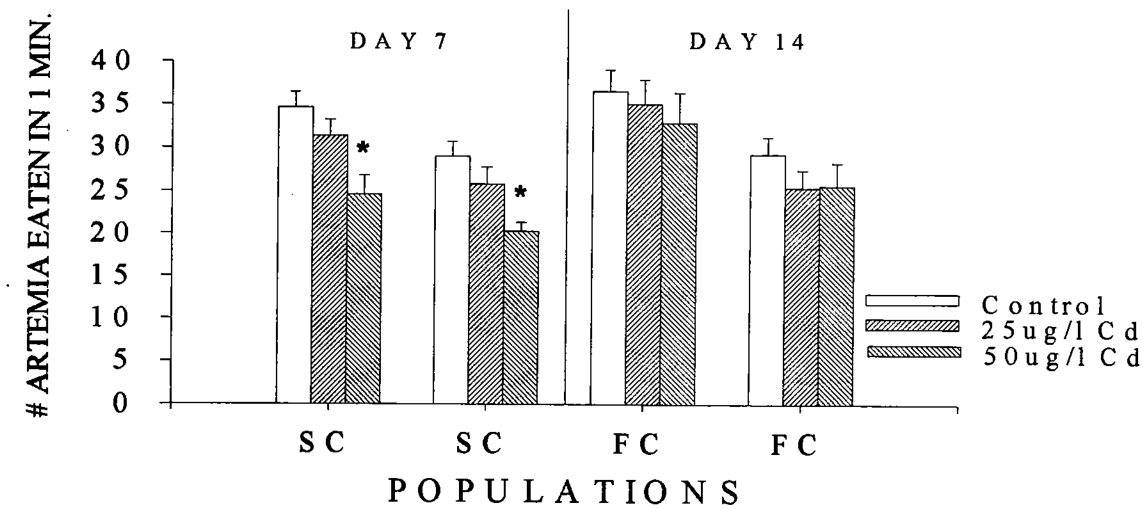

Figure 2. Prey Capture Ability of South Cove (SC) and Foundry Cove (FC) larvae exposed to various concentrations of Cd. Larvae were exposed to concentrations of 0, 25 or 50 μg/L Cd for 7 or 14 days. SC larvae exposed to 50μg/L Cd showed a significant decrease in prey capture ability after 7 day ($p = 0.0023$) and 14 day ($p = 0.0069$) exposures. SC(Day 7): 0 (n=34); 25μg/L (n=33); 50μg/L (n=24). SC(Day 14): 0 (n=31); 25μg/L (n=25); 50μg/L (n=15). FC(Day 7) 0 (n=13); 25μg/L (n=14); 50μg/L (n=14). FC(Day 14): 0 (n=12); 25μg/L (n=13); 50μg/L (n=11).

SPONTANEOUS SWIMMING ACTIVITY EXPERIMENTS: There were no differences in swimming activity of Cd-exposed larvae in either population nor were they affected by increased exposure duration from 3 to 10 days (Fig. 3). All larvae were active regardless of exposure to the toxicant. (Significance at 0.05 level, SC: Day 3; $f = 0.12$, $p = 0.8833$. SC Day 10; $f = 1.43$, $p = 0.2529$. FC: Day 3; $f = 0.42$, $p = 0.6626$. FC Day 10; $f = 1.14$, $p = 0.3327$)

The control groups from both populations showed equal levels of activity indicating no baseline difference in activity between the two populations. Significance was set at the 0.05 level using analyses previously described.

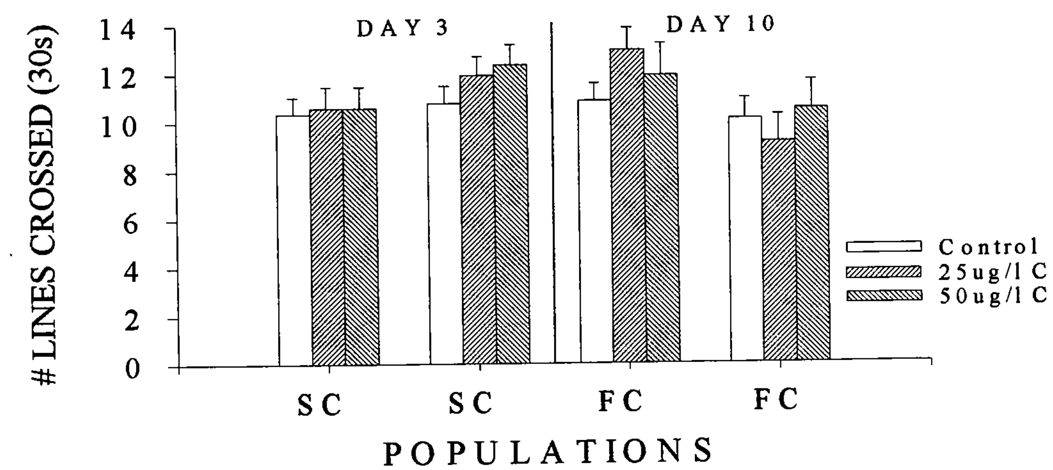

Figure 3. Spontaneous Swimming Activity of South Cove (SC) and Foundry Cove (FC) larvae exposed to various concentrations of Cd. Larvae were exposed to concentrations of 0, 25 or 50 μg/L Cd for 3 or 10 days. SC(Day 3): 0 (n=20); 25μg/L (n=20); 50μg/L (n=19). SC(Day 10): 0 (n=16); 25μg/L (n=15); 50μg/L (n=10). FC(Day 3) 0 (n=19); 25μg/L (n=19); 50μg/L (n=14). FC(Day 10): 0 (n=13); 25μg/L (n=13); 50μg/L (n=11).

DISCUSSION

The described experiments were conducted to ascertain whether the population of *Fundulus* spp. in Foundry Cove had developed tolerance to Cd at the sensitive life stage of larval development. We focused on both acute (LC_{50}) and chronic (behavioral) responses of larvae to ascertain to what degree, if any, tolerance was developed.

Foundry Cove waters are basically fresh (0-2 ppt salinity), which has been shown to significantly increase the toxicity of cadmium to aquatic organisms compared with more saline environments (Robert and His 1985; Gill and Epple 1992; Sastry and Shukla 1994; Lin and Dunson 1993). Both the Foundry Cove and South Cove populations of *Fundulus* showed lethal responses at equal concentration of Cd (LC_{50} = ~80 μg/L) indicating a lack of enhanced resistance to acute levels of cadmium in the Foundry Cove fish (Table 1).

Compared with other freshwater species, *Fundulus* is relatively insensitive to Cd (Table 2). *Fundulus heteroclitus* tested in marine salinities were even less sensitive to Cd, with a 96 hour LC_{50} of 12 mg/L (Middaugh and Dean 1977).

Table 2. LC_{50} values for some freshwater fish species exposed to acute concentrations of cadmium.

SPECIES	STAGE OF DEVELOPMENT	LC_{50}	CITATION
Salmo salar	Alevin	0.47 µg/L	Rombough and Garside 1982
Oreochromis mossambicus	7 day larvae	29 µg/L	Hwang et al. 1995
Danio rerio	Larvae	30 µg/L	Dave 1985
Pimephales promelas	Larvae	80 µg/L	Birge et al. 1985

Cadmium concentrations of 80 µg/L in the water column are not likely to be present in environmental systems, and is below the levels found in Foundry Cove waters before the clean-up. The baseline resistance of *Fundulus* spp. to Cd may be high enough to eliminate the need for evolved resistance in the Foundry Cove population.

Swimming activity experiments also failed to reveal enhanced resistance in the Foundry Cove population. Larvae from either population exposed to 25 or 50 µg/L maintained control levels of spontaneous swimming activity regardless of the duration of exposure (Fig. 3). A comparison of controls indicated no differences between the two populations in baseline activity levels.

Swimming activity has been shown to be a sensitive indicator of Cd exposure in other species. The bluegill, *Lepomis macrochirus* displayed a biphasic effect of Cd with increased swimming activity at low levels and decreased activity at higher levels

(Ellgaard et al. 1978). Experiments involving invertebrates reported a decrease in swimming activity with exposure to Cd in mud crab larvae, *Eurypanopeus depressus* (Mirkes et al. 1978), grass shrimp, *Palaemonetes pugio* (Hutcheson et al. 1985) and fiddler crab larvae, *Uca pugilator* (Vernberg et al. 1974).

Only the tests for prey capture ability with exposure to Cd revealed a difference in response between the two populations. Prey capture ability of larvae collected from Foundry Cove was not affected by Cd exposure regardless of exposure duration, while South Cove larvae showed decreased prey capture when exposed to 50 µg/L Cd for 7 or 14 days (Fig. 2). The degree of effect was not greater at 14 days than 7 days. Again a comparison of controls revealed no baseline differences between the two populations, suggesting that the Cd had a more pronounced affect on the South Cove population than on larvae from Foundry Cove.

To imply that these results represent an increased resistance in the Foundry Cove population may be premature as only one trial was run with larvae from this population and increasing the sample size might eliminate the difference between the two populations. Conversely, differences in prey capture ability may imply true differences in sensitivity to Cd between the two populations and suggest that additional parameters be investigated to determine the relevance of this observation. These parameters could include physiological effects (such as respiration, metallothionein induction or metabolism), bioaccumulation rates, or growth rates. Embryonic exposures are still needed to determine Cd sensitivity in the two populations but an alternate method of egg collection will have to be developed.

Recent work by Klerks et al. (1997) also reported a lack of resistance in a fish (darter gobie, *Gobionellus boleosoma*) population from a polluted site, which supports the idea that enhanced resistance may not be the only mechanism of survival in polluted systems. Other findings on the lack of developed resistance may not be reported due to the difficulty of producing strong conclusions when the null hypothesis is accepted. Thus, the overall lack of enhanced resistance in the Foundry Cove population of larval *Fundulus* spp., may be explained by at least three factors.

1. Levels of Cd may be too low to induce resistance in *Fundulus* spp. as they are a relatively robust species that can tolerate high levels of Cd without significant lethal or sublethal effects.
2. The larval stage of *Fundulus* spp. may not develop resistance to Cd. It has been previously noted (Weis and Weis, 1989) that metal-tolerance may be present only at certain life history stages, and Zhou et al. (1996) reported only the embryos and not the larvae of *Fundulus heterclitus* showed resistance to methylmercury, implying larvae may not be the most sensitive indicators of induced Cd resistance.
3. The parameters tested may not have been sensitive to differences between the two populations; tests using other parameters may reveal stronger evidence for enhanced resistance in the Foundry Cove population.

These factors indicate a need for future research to provide a more complete investigation into *Fundulus* resistance in Foundry Cove. The next step is to conduct embryonic and adult exposures to Cd, to reveal any lifestage-specific resistance and/or sensitivity to Cd. To allow data comparisons to be made, the methods of exposure and testing should be similar to those employed for this project. It is important to note that

before any embryonic research could be done, preliminary work would be necessary to investigate the problem of egg viability that was reported in the introduction of this report.

ACKNOWLEDGEMENTS

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THE DEVELOPMENT OF A NEW APPROACH TO EVALUATE ENVIRONMENTALLY INDUCED GENETIC DAMAGE IN HUDSON RIVER BIOTA

A Final Report of the Tibor T. Polgar Fellowship Program

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ABSTRACT

The Hudson River has one of the highest levels of polycyclic aromatic hydrocarbon (PAHs) contamination levels of any estuary in the United States (7,100-34,000 ng PAHs/g dry weight). These PAHs are believed to cause damage to bottom dwelling organisms. The Atlantic tomcod, *Microgadus tomcod*, was used as a sentinel species of environmental quality to test the extent of DNA damage caused by PAHs. DNA damage was quantified in juvenile, one-year-old, and two-year-old age classes of Hudson River tomcod using a new extra-long PCR-based technique. DNA from all three age groups of Hudson River fish was amplified and compared. It was hypothesized that the older age classes of fish would have increased levels of DNA damage due to longer exposure to Hudson River sediments. Results suggest that there was a lower yield of amplification product in one-year-old fish compared to juvenile tomcod, possibly indicating a bioaccumulation of DNA damage over time. Two-year-old Hudson fish had higher levels of amplification product than expected, greater than the one-year-olds, and only slightly less than the juveniles. DNA from two-year-old tomcod from the Margaree, a pristine Canadian river, was also amplified and compared to the Hudson two-year-olds. The Margaree samples appeared to have higher yields of extra-long-PCR product compared to the Hudson samples. These results offer promise for further use of this PCR-based technique to quantitatively and reproducibly assess overall DNA damage in Hudson River biota.

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INTRODUCTION

The Hudson River estuary is polluted with a variety of both halogenated aromatic hydrocarbons (e.g., PCBs and dioxins) and polycyclic aromatic hydrocarbons (PAHs) (O'Connor et al. 1982). The organic contaminants found in estuaries generally have low water solubility and thus accumulate in the sediment. Hudson River sediments have one of the highest levels of PAHs (7,100-34,000 ng PAHs/g dry weight) of any estuary in the United States (NOAA Technical Memorandum 1987). PAHs are formed by the incomplete combustion of fossil fuels and the action of internal combustion engines. They enter the water systems through runoff from roadways, atmospheric fallout and precipitation, as well as through petroleum spillage and seepage (Neff 1985; Baek et al. 1991).

Once in the cell, PAHs are metabolized to highly mutagenic and carcinogenic forms. Previous studies have shown that metabolites of benzo[a]pyrene (a PAH commonly found in Hudson River sediments) rapidly and preferentially accumulate in mitochondria (Ballinger et al. 1996; Backer and Wernstein, 1980; Allen and Coombs, 1980). Once in the mitochondria, PAH metabolites adduct with DNA and cause mutations. DNA adducts interfere with the organelle's ability to make critical enzymes needed for cellular metabolism.

An organism which has considerable contact with the PAH-bound sediment is the Atlantic tomcod (*Microgadus tomcod*). The tomcod is an anadromous, bottom dwelling fish species of the northeast coast of North America whose distribution extends from Labrador to Virginia (Bigelow and Schroeder 1953). The Hudson River supports the tomcod's southern most spawning location. Therefore, the fish may be thermally stressed during the warmer summer months (Dew and Hecht 1976; Grabe 1978). Tomcod also have extremely high hepatic lipid levels. Elevated hepatic lipid levels increase the bioaccumulation of lipophilic organic contaminants in the Hudson River tomcod's liver (Wirgin et al. 1994). Tomcod are confined to estuaries and undergo annual winter spawning migrations. Since Atlantic tomcod are benthic, they are exposed to sediment-bound lipophilic environmental agents throughout the lower Hudson River estuary by direct dermal contact and their benthic diet.

The age structure of Hudson River tomcod is different from Canadian tomcod. The Hudson River tomcod population is truncated, with few two-year-old fish and hardly any older fish. Canadian fish, on the other hand, attain an age of 3-7 years. The Hudson tomcod population also has a history of a high prevalence of hepatocellular carcinomas. Previous studies have indicated that the prevalence for carcinomas exceeds 50% in one-year-old tomcod and is as high as 90% in two-year-old fish (Dey et al. 1993). A large percentage of Hudson River tomcod also exhibit a high frequency of DNA mutations, perhaps promoting formation of liver tumors. An elevated level of hepatic DNA adducts, caused by PAHs, was also found in the Hudson population (Wirgin et al. 1994). Therefore, they are an excellent sentinel species of environmental quality (Klauda et al.1988).

For all these reasons, it is expected that Hudson tomcod populations should have a greater extent of DNA damage compared with Canadian populations, which are not subjected to large quantities of sediment-bound lipophilic environmental agents. Therefore, the Atlantic tomcod is an excellent species to test a new PCR-based approach to quantitatively and reproducibly assess overall DNA damage in animal cells. The extra

long PCR (XL-PCR) technique can amplify a 16 Kb fragment of DNA, in contrast to regular PCR techniques which amplify 0.1 to 5 Kb fragments. The technique is based on the assumption that the DNA polymerase used in the PCR will stop when it encounters damaged DNA, such as a DNA adduct caused by PAHs. Therefore, increased DNA damage will result in decreased yields of PCR products. The longer the length of DNA amplified, the more likely PAH-induced damage to DNA will be encountered, and the more likely the yield in PCR products between damaged and undamaged DNA will differ.

This PCR-based approach was used in a study which evaluated the levels of mitochondrial DNA (mtDNA) and nuclear DNA (nDNA) damage in lung cells from smokers and non-smokers (Ballinger et al. 1996). Ballinger's results did find that smokers exhibited approximately six-fold higher levels of damage than did non-smokers. This is an extremely high induction for a human biomarker study and exemplifies the potential sensitivity of this approach to assessing DNA damage. In addition, this study found that mtDNA was far more susceptible to damage than nDNA. This is possibly due to the less efficient DNA repair process of mtDNA compared to nDNA. Or it could be due to the fact that PAHs, which are also found in smoke, accumulate preferentially in mitochondria (Ballinger et al. 1996; Backer and Wernstein, 1980; Allen and Coombs, 1980).

For several reasons, we hypothesize that this technique should find an even greater level of DNA damage in Hudson River tomcod compared with human smokers. First, lung alveolar macrophages are replaced approximately every 30 days, whereas liver cells of a tomcod are not replaced, and thus, should show accumulated DNA damage over time. Secondly, the levels of PAHs bound in the sediment which tomcod are continually exposed to are much greater than that found in smoke. Therefore, Hudson River tomcod should exhibit a much greater level of DNA damage than the human smokers did.

METHODS

Samples Collected

A total of 41 specimens of Atlantic tomcod were collected from three different river systems, 18 from the Hudson, 12 from the Miramichi, 6 from the St. Lawrence, and 5 from the Margaree (Figure 1). The Hudson River tomcod were composed of three age groups: six juveniles (< 6 months), six one-year-old fish, and six two-year-old fish. The twelve tomcod from the Miramichi were composed of six two-year-olds and six one-year-old fish. All of the St. Lawrence and Margaree fish were two years of age. The fish's ages were estimated by their total lengths.

Tomcod DNA was extracted from frozen liver tissue using the ammonium hydroxide triton X-100 protocol and standard phenol chloroform extractions (Downs and Wilfinger 1983). The DNA was then precipitated in ethanol and high molecular weight DNA was spooled on a glass pipette and transferred to another tube. The DNA was then resuspended with TE Buffer (Sambrook et al. 1989). All samples produced high molecular weight DNA with the exception of the St. Lawrence River fish. These liver samples were freezer burned. As a substitute, DNA previously extracted from the St. Lawrence fish was used.

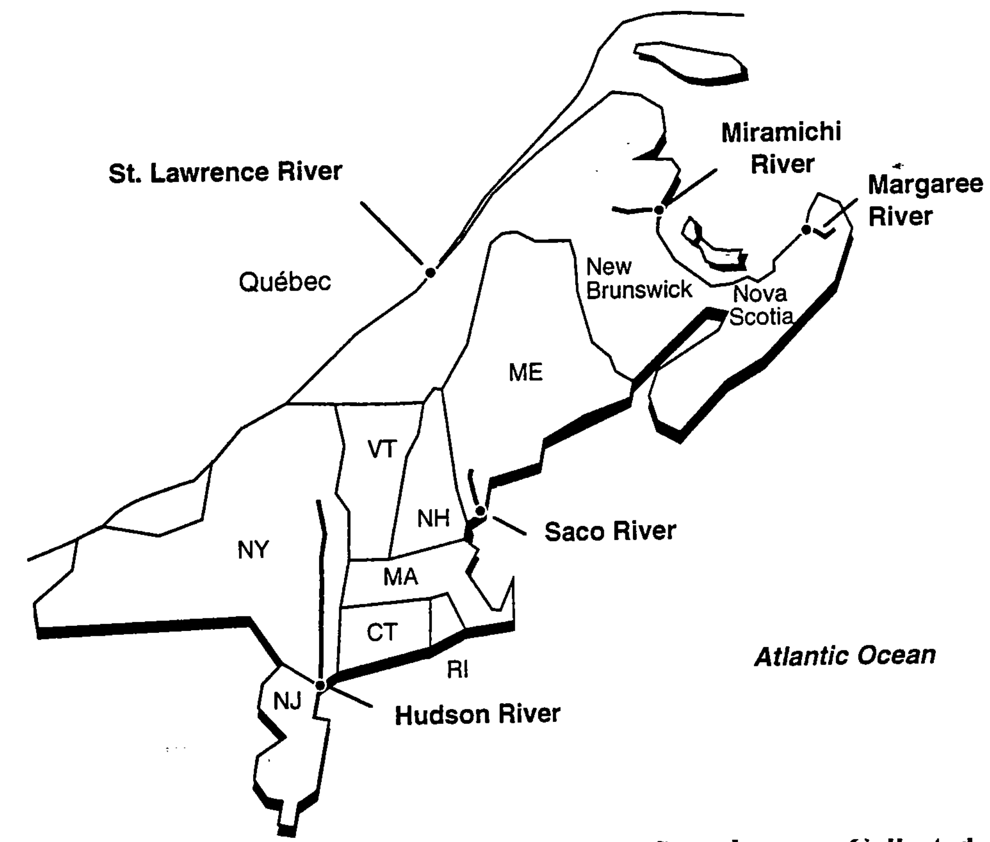

Figure 1: Map of Rivers from which Samples were Collected

Development of Atlantic tomcod-specific PCR primers

Originally, Atlantic tomcod-specific PCR primers were designed from published DNA sequence data of the Atlantic tomcod control region (Woo-Jai Lee et al. 1995). Two regular PCR primers, TCCRD and TCCRA, and two XL-PCR primers, TCCR 84-60 and TCCR 641-664, were ordered from Gibco-BRL. The position of the primers is shown in Figure 2.

No product was initially obtained with the original XL-PCR primers. An additional set of XL-PCR primers was developed by sequencing the mtDNA control region and the 12S ribosomal DNA (rDNA) gene of an Atlantic tomcod from the Hudson River. The PCR product was generated with TCCA and a universal 12S rDNA primer and run on a low melting point agarose gel. The band of amplified DNA was cut out and both ends were directly sequenced using TCCA and the 12S rDNA primers (Kretz and O'Brien 1993). From the sequence data obtained, two new XL-PCR primers were ordered, TC12SXL and TCCYTBXLNEW. (Table 1)

Table 1: Primer Sequences

Primer Name	Primer Sequence	Source
TCCRD	5' GTCCATCCTAATATCTTCAGTA 3'	1
TCCRA	5' TCCACCTCTAACTCCCAAAGC 3'	1
TCCR 84-60	5' ATATCTAGGACATCTGTACATGGTA 3'	1
TCCR 641-664	5' TACTCCTCCTCGATGAGTTCCTAA 3'	1
TC12SXL	5' CCCTAAGACCTCTGATTCCACGAAAGCCAT 3'	2
TCCYTBXLNEW	5' TACGTCACGGCAGATGTGTACGACAGACGA 3'	2

1. Woo Jai et al.
2. Zimmermann et al. in prep

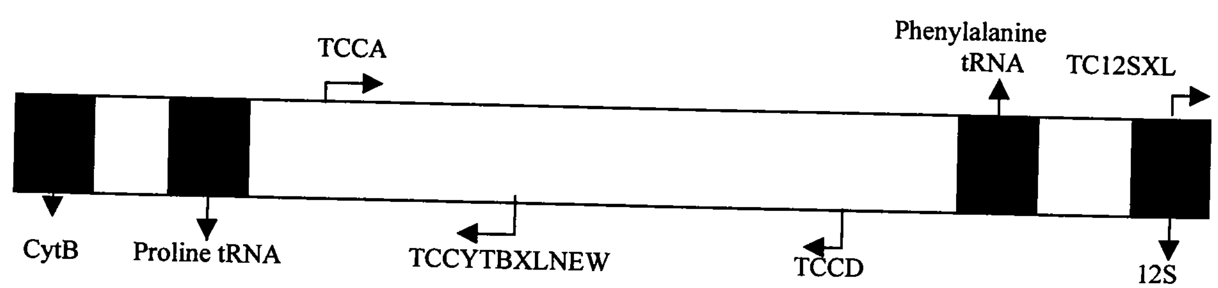

Figure 2: Map of Atlantic Tomcod mtDNA Control Region.

Normalization of mtDNA copy number from all tomcod DNA samples

The DNA concentrations of all samples were normalized prior to performing the PCR reactions. For each sample, DNA concentration was read using a spectrophotometer at 260 nm. This reading gave a general idea of the total DNA concentration, which could

include nDNA, mtDNA, and high and low molecular weight DNA. Next, three micrograms of total DNA from each sample was run on low percent gel (0.7%) to verify the concentration of high molecular weight DNA. This gel was then Southern blotted to a nylon membrane and hybridized to a ^{32}P-labeled mtDNA probe as previously described (Wahl et al. 1979). The membrane was then washed and exposed to x-ray film.

A slot blot analysis was then performed on the DNA samples to quantify the total amount of mtDNA in each sample. Six micrograms of DNA were filtered on to a nylon membrane using the manufacturer's protocol (Schleicher & Schuell). The membrane was hybridized to a mtDNA probe and exposed to x-ray film. The integrated optical densities of the visualized fragments were quantified using a Millipore-Bioimage densitometer and the DNA concentrations of each sample were adjusted accordingly. The slot blot procedure was repeated two more times as described in order to confirm that the mtDNA concentrations of all the samples were equivalent.

DNA sample quality test for PCR (Q-PCR)

QPCR primers TCCRA and TCCRD were used to amplify an approximate 1,000 base pair fragment of the mtDNA control region. Amplification occurred in 25 µl volumes containing 2.5 µl of 10x buffer (Gibco), 0.5 µl of each dNTP, 1.0 µl of each QPCR primer, 0.3 µl of Taq polymerase (Gibco), 100 ng of template DNA, and ddH_2O to volume. Amplification parameters were as follows: 94 C for 5 min, 35 cycles of denaturing at 94 C for 1 min, annealing at 58 C for 1 min, and extension at 72 C for 1 min, followed by a final 7-min extension at 72 C.

After amplification, the products were electrophoresed in an ethidium bromide stained agarose gel (0.8%) and the PCR fragments were visualized on an UV transilluminator.

Long Template PCR – XLPCR and quantification of the products

XL-PCR primers, TC12SXL and TCCYTBXLNEW, were used to amplify an approximate 15 kbp fragment of the mtDNA genome in tomcod. Amplification occurred in 50 µl volumes containing 15.0 µl Buffer (Perkin Elmer), 4.0 µl dNTPs, 1.0 µl of each XL-PCR primer, 1.0 µl of enzyme (Perkin Elmer), 2.2 µl of Mg, 100 ng of template DNA, and ddH_2O to volume. Amplification parameters were as follows: 94 C for 30 sec, hot start at 80 C for 4 min, 94 C for 1 min, 26 cycles of denaturing at 94 C for 20 sec, and annealing and elongation at 70 C for 12 min, followed by a final 10-min extension for 10 minutes.

The amplification products were electrophoresed in an agarose gel (0.7%) stained with ethidium bromide and visualized on an UV transilluminator. The intensity of the stained bands was quantified using the Millipore Bioimage densitometer.

RESULTS

Determination of High Molecular Weight DNA

Southern blot analysis of the gel confirmed the presence of high molecular weight mtDNA in all samples. The DNA hybridized to a tomcod mtDNA probe, confirming the DNA's mitochondrial origin. Extracted DNA from all tomcod samples ran above the 23.1 Kb molecular weight marker indicating its quality. (Figure 3)

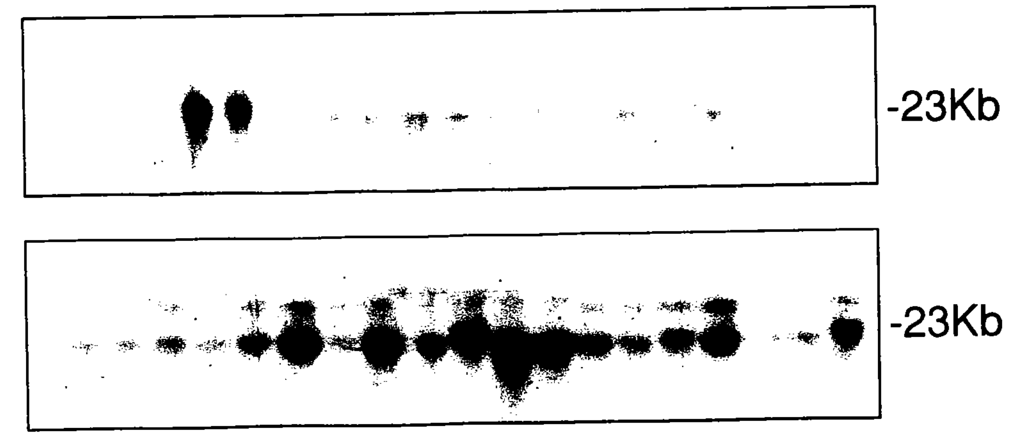

Figure 3: Southern blot of high molecular weight mtDNA : Ethidium bromide stained agarose gel (0.7%) southern blotted to a mtDNA probe confirming the high molecular weight of the DNA (>30 Kb).

Normalizing DNA Concentrations

The high molecular weight DNA was filtered on to the slot blot membrane and hybridized to the tomcod mtDNA probe. The integrated optical densities (IOD) of the visualized fragments were quantified using the Millipore-Bioimage densitometer. The DNA concentrations were adjusted and this procedure was repeated two more times in an effort to normalize all DNA samples. After the third slot blot, DNA concentrations appeared equivalent, but IODs ranged from 2.854 to 1.650. The two-year-old Hudson fish tended to have higher concentrations of mtDNA compared to the juveniles and one-year-olds. (Figure 4)

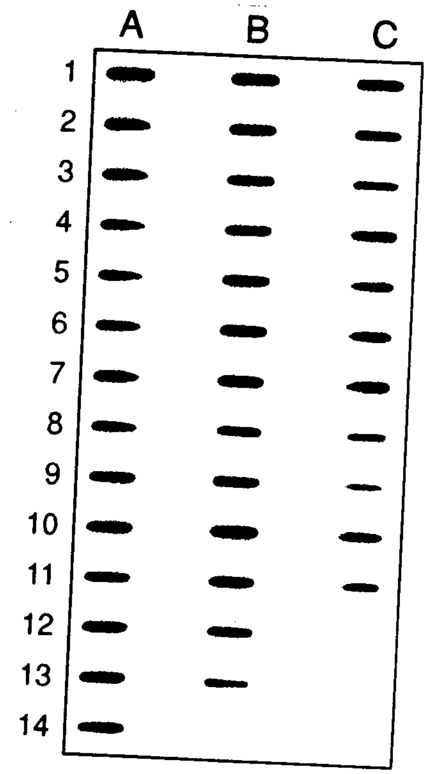

Figure 4: Third Slot Blot Analysis: Slot blot of dilutions used in the PCR reactions. The Hudson River juveniles samples included B10-12&C1,C3,C4; Hudson River 1-yr.-olds samples included A1,A4,A5,A8,A11,B9; Hudson River 2-yr.-olds samples included A2,A3,A6,A7,A12,A13; Miramichi River fish were A9,A10,A14, B1-8,B13; and St. Lawrence River fish were C2, C5-10

QPCR

All samples were amplified using PCR according to the QPCR analysis. The visualized fragments also appeared to be equivalent in size, therefore leading us to believe the mtDNA concentrations in each sample were close to equivalent. (Figure 5)

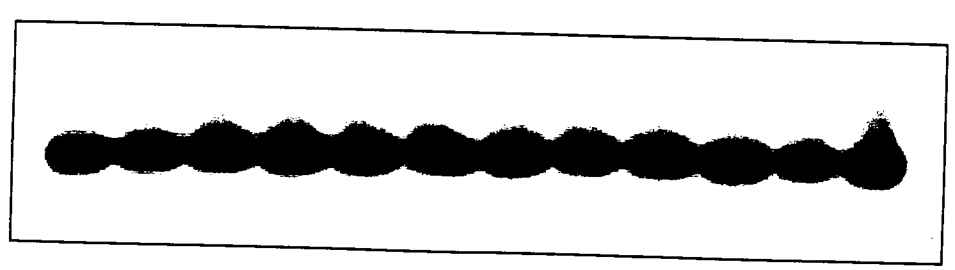

Figure 5: QPCR Ethidium Bromide Stained Gel: One of three QPCR gels illustrating the visualized 1000 bp products.

XL-PCR

Due to time constraints and initial difficulty in getting the XL-PCR technique to work, only Hudson River samples were amplified and quantified. A difference in the yield of XL-PCR product was observed among the three age groups of Hudson River tomcod. (Figure 6). The average IOD for juveniles was greater than that of the one-year-old samples. The two-year-old samples had a greater yield than expected. Their average IOD was greater than the one-year-old fish and equivalent to the juvenile group. (Table 2).

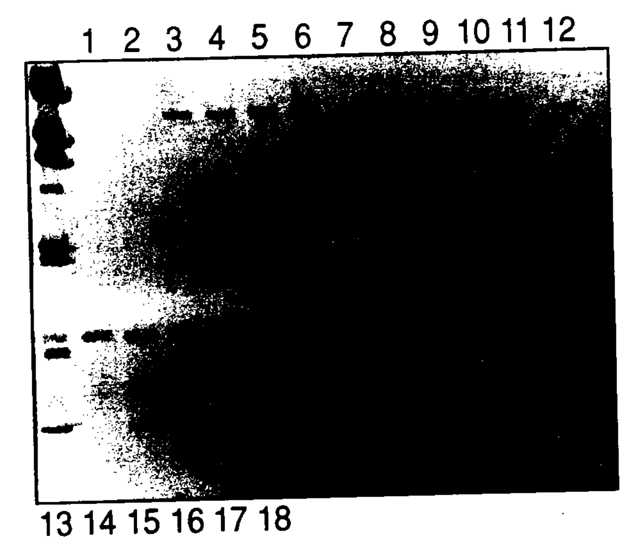

Figure 6: XL-PCR Ethidium Bromide Stained Gel: Ethidium bromide stained agarose gel (0.7%) containing XL-PCR products of three different age classes of Hudson River tomcod. Numbers 1-6 are juvenile Hudson fish, 7-12 are one-year-old Hudson fish, and 13-18 are two-year-old Hudson fish.

Table 2: Quantification of XL-PCR Products (IOD readings)

Juvenile Hudson Fish	One-Year-Old Hudson Fish	Two-Year–Old Hudson Fish
0.186 (3)	0.118 (7)	0.219 (13)
0.199 (4)	0.113 (8)	0.196 (15)
0.225 (5)	0.111 (9)	0.127 (16)
0.138 (6)	0.166 (10)	0.181 (18)
	0.138 (11)	
	0.111 (12)	
Avg.=0.187	**Avg.= 0.126**	**Avg.=0.181**

DISCUSSION

Results suggest that the XL-PCR technique shows promise in assessing DNA damage in animal cells. Amplification products were obtained for all tomcod DNA samples using the Q-PCR technique, indicating that there were no contaminants in any tomcod DNA sample that would inhibit amplification. In addition, all tomcod DNA samples, regardless of their geographic origin, had equivalent yields of the Q-PCR product. Thus, the results of the X-LPCR should indicate the extent of DNA damage present in the original sample.

Differences in the yield of XL-PCR products were observed among the three age classes of Hudson River tomcod. As expected, the average IOD of the juvenile age class was greater than that of the one-year old group. This general trend of less yield in the older fish was hypothesized to be the result of a lengthy exposure time to PAHs in Hudson River sediments. However, two-year-old Hudson River tomcod had high yields of XL-PCR products. There are a number of possible factors why two-year old Hudson River fish did not exhibit the level of DNA damage hypothesized. First, there were only a small number of two-year old fish examined in this study. It is possible that only

tomcod which avoid or are somehow adapted to high levels of PAHs are able to survive to the age of two. Secondly, there is a great deal of inter-individual variability in how Hudson River tomcod react to organic pollutants. This is evidenced in Hudson River tomcod's inducibility of the cytochrome P450 gene (CYP1A1). Upon exposure to an organic pollutant, the CYP1A1 gene is expressed. The enzyme encoded by this gene is responsible for detoxifying the pollutant. Previous studies have shown that individual Hudson River tomcod have different levels of expression of this gene, probably reflecting genetic variability in the population (Courtenay, et. al. 1994) Therefore, it is possible that the small number of two-year-olds that survive may be better able to cope with high levels of Hudson River PAHs. Finally, the average concentration of initial template DNA used in the XL-PCR reaction was greater in two-year-old fish than the other age groups. This would lead to an overestimate of the final XL-PCR product, because of the greater number of mtDNA copies in two-year-old samples.

Technical difficulty in getting the XL-PCR technique to work used up a great deal of the research time allotted for this study. There was considerable difficulty in getting the technique to work consistently. To improve the study, a better normalization of the DNA concentrations is necessary. The initial template DNA concentrations were not close enough to allow for an accurate interpretation of the results. Further, the sample size must also be increased for both the Hudson and Margaree Rivers.

DNA from four Margaree River fish was also amplified and compared to the Hudson River samples. The Margaree samples did appear to have higher yields of XL-PCR products but were not formally added to this study because the concentration of their initial template DNA was not normalized to that of the Hudson River fish. The concentration of the template DNA from the Margaree fish was an order of magnitude less than the Hudson River fish (Zimmermann in prep.). This suggests that if the DNA's were normalized, the Margaree samples would have much higher yields of XL-PCR products in comparison to Hudson River tomcod. Overall, these results suggest that the XL-PCR technique could be useful in assessing DNA damage in Hudson River biota if further refinements are made.

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LAND USE, SOIL EROSION, AND SEDIMENT DELIVERY IN TWO HUDSON RIVER VALLEY WATERSHEDS

A Final Report of the Tibor T. Polgar Fellowship Program

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ABSTRACT

Soil erosion and sediment delivery were estimated from 1683 to 1997 for the Stony Creek (Tivoli North Bay) and Saw Kill (Tivoli South Bay) watersheds. It was hypothesized that Stony Creek, originally named White Clay Kill, conveyed larger quantities of sediment to North Bay and contributed to the development of a raised cattail marsh. By contrast, we hypothesized that South Bay received less sediment and remained a shallow embayment with floating and littoral aquatic plants. Eight historical time periods were defined for relatively distinct and consistent agricultural land uses. For each time period, the proportion of the watersheds used for agriculture was estimated from a variety of sources. A GIS-based decision rule used proximity to roads, the Hudson River, and slope gradient (a proxy for soil texture, fertility, and suitability for agriculture) to distribute the settled areas across the landscape. Standard methods were used to estimate soil erosion rates; a digital terrain model was used to estimate sediment delivery. Although agricultural land use was more extensive in the Stony Creek watershed (up to 91%), cumulative sediment delivery to North Bay (129,000 Mg) was about one-half of the predicted loading to South Bay (258,500 Mg). This suggests tidal exchange with the Hudson River and differing trap efficiencies, not watershed characteristics and land use, have been the dominant influence on the current form and function of the Tivoli Bays.

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INTRODUCTION

Tivoli North Bay and Tivoli South Bay, centered at river mile 100 along the Hudson River, provide a novel opportunity to evaluate an unplanned natural experiment in wetland creation. These two bays have very different present forms, despite being geographically contiguous and connected to watersheds of similar size. Tivoli North Bay, once an open embayment, has developed into a raised cattail marsh. Tivoli South Bay remains an open embayment with littoral vegetation such as spatterdock and arrowhead along with a seasonal growth of European water chestnut (Fraser and Barten 1995).

There is no definitive work on how the bays reached their present condition. While there are a number of factors that may have contributed to the differences between the bays, we focused on historical patterns of settlement and agricultural land use in their watersheds. Our principal hypothesis was that the differential mass of accumulated sediment in the Tivoli Bays was caused, in part, by differing temporal and spatial patterns of land use and subsequent rates of soil erosion in the Stony Creek and Saw Kill watersheds. Since the two watersheds have equivalent areas and climate, direct comparison of their development characteristics was possible.

To test our hypothesis we quantified the changes in land use from 1683 to 1997 in the watersheds to reconstruct how these temporal changes interacted with the relatively static physiographic characteristics (e.g., terrain features, soils, etc.) of the watersheds. The quantification of the changing land use variable allowed us to estimate soil erosion in the watersheds and sediment deposition to the bays. Our study focuses on agricultural land uses, which accounted for up to 91% of land use during the study period, and does not consider industrial, manufacturing or other small-scale land uses.

SITE DESCRIPTION

The study site (Figure 1) encompasses Tivoli North Bay and the Stony Creek watershed (5,569 hectares) and Tivoli South Bay and the Saw Kill watershed (6,882 hectares). The Tivoli Bays are located in Dutchess and Columbia Counties, New York, and are part of the Hudson River National Estuarine Research Reserve. Cruger Island, a

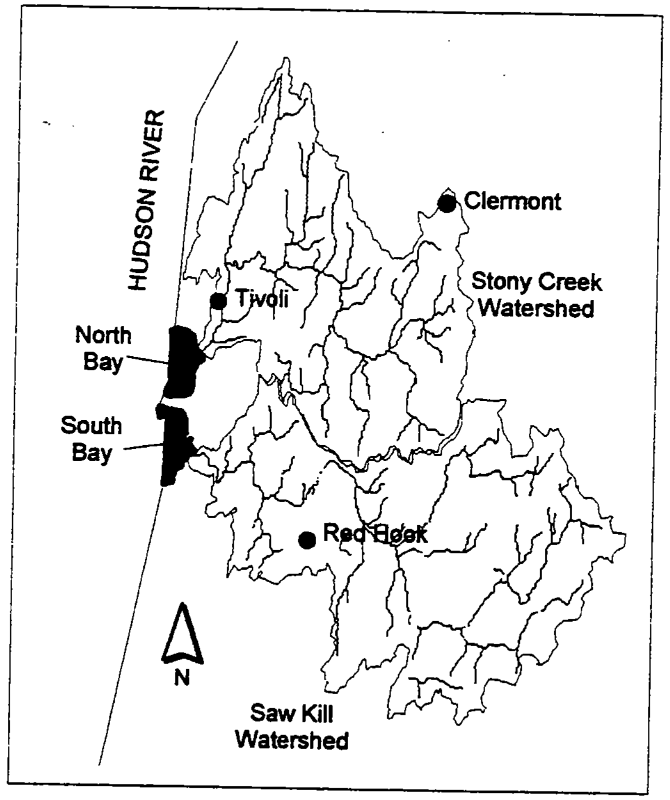


FIGURE 1: Location map for Tivoli Bays and the Stony Creek and Saw Kill watersheds, Hudson River Valley, New York.

peninsula, limits tidal exchange between the bays. Both bays are bordered to the west by a railroad causeway constructed in 1851. Tidal exchange with the Hudson River occurs through five bridge openings (Carey and Waines 1986).

The majority of the watershed system (73%) lies within the Town of Red Hook, Dutchess County. The Saw Kill watershed lies entirely within Dutchess County, with 74.2% in the Town of Red Hook and 25.8% in the Town of Milan. The Stony Creek watershed lies in both Dutchess and Columbia Counties with 70.8% in the Town of Red Hook and 29.2% in the Town of Clermont.

The Stony Creek and Saw Kill flow through glacial till and glacial Lake Albany clays and on to Normanskill Formation shales and sandstones (Carey and Waines 1986). Soils in the Tivoli Bays watersheds are quite varied, representing some 40 different soil types ranging across all textural classes. Yet, approximately 75% of the soils are silt loams derived from glacial till. These may be shallow (0.8 meters to bedrock) or moderately deep (2.3 meters to bedrock), with a relatively well-drained surface layer underlain by a poorly-drained layer (Reichheld and Barten 1992). Climate in the mid-

Hudson River Valley is influenced by continental polar and maritime air masses. Mean January and July air temperatures are -4 °C, and 23 °C, respectively. Annual precipitation ranges from 900 to 1,100 mm and is relatively uniform in distribution throughout the year.

METHODS

Historical data were collected to describe and quantify temporal changes in land use in the Stony Creek and Saw Kill watersheds. A review of regional and local history revealed distinct time periods during which land use patterns and agricultural practices were relatively constant. Based on this information, we subdivided our analysis into eight time periods. For each period we determined total area settled and proportions of different land uses (e.g., row crop, pasture, woodlot, etc.). Primary data were gathered from three sources: (1) historical references and interviews, (2) map interpretation, and (3) analysis of census data. Because available data and information varied for many time periods, so did our methods for estimating the total area of settled land. However, our methods were consistent between the watersheds for each time period.

We used the estimates of settled land to create GIS layers that depict the settlement patterns for each time period. The spatial distribution of settled areas was predicted with a decision rule using historical patterns of access to the Hudson River and roads, as well as terrain features. We calculated annual soil erosion for each watershed with the Modified Universal Soil Loss Equation (MUSLE) (Brooks et al. 1997) and sediment delivery to the bays using the Spatially Explicit Delivery Model (SEDMOD) developed by Fraser and others (1996).

RESULTS AND DISCUSSION

Land Use History and Time Periods

As noted earlier, eight time periods emerge as descriptors of land use history in this part of the Hudson River Valley (adapted from Danhoff 1969; Ellis 1946; Hasbrouck 1909; Hedrick 1933; Kim 1978; McDermott 1986; Secor 1939; Zimmerman 1988). They vary in duration from 30 to 70 years and encompass the dramatic changes in the landscape since European settlement began in 1683 (Table 1). Within each period the nature of agricultural land use and crop types remained relatively constant. Therefore, predictions of soil erosion and sediment delivery as functions of crop type and settlement pattern are derived from best estimates of watershed characteristics for each period. The salient details are discussed below.

TABLE 1: Historical time periods and land use in the Tivoli Bays watersheds, Hudson River Valley, New York.

before 1683	pre-European Settlement
1683 - 1720	Land Patent Period
1720 - 1750	Pioneer Settlement Period
1750 - 1820	Grain Period
1820 - 1860	Transition Period
1860 - 1910	Dairy and Manufacturing Period
1910 - 1950	Population Growth Period
1950 to present	Modern Era

Before 1683: pre-European Settlement

Prior to 1683, Mahican Indians lived on the eastern side of the Hudson River in the vicinity of what is now Dutchess County in small, permanent villages (Jeanneney and Jeanneney 1983; Secor 1939). Land between settlements was not inhabited and only small areas were cleared for crops (Secor 1939). The Dutch began to settle in the Hudson River Valley in the early 1600s, but did not colonize Dutchess County until later in the century (Jeanneney and Jeanneney 1983).

Several sources confirm that Native American settlement in the northeastern U.S. was extensive, and that forest clearing for agriculture and understory burning for hunting were significant (Thompson and Smith 1970; Day 1953). However, most archeological evidence indicates that the location of villages and agricultural practices were typically limited to floodplains (Whitney 1994). Significant settlements along floodplains in the region would have been limited to the Roeliff Jansen Kill to the north and Esopus Creek on the west side of the Hudson River (C. Lindner, Resident Assistant Professor of

Archeology, Bard College, pers. comm.). The floodplain areas of the Saw Kill and Stony Creek are thought to be too small and dispersed to have been cleared for Native American agriculture. Our assumption of complete forest cover is consistent with similar land use studies (Davis 1976; Howarth et al. 1991) for pre-European settlement.

1683-1720: Land Patent Period

European colonial settlement of the lands around the Stony Creek and Saw Kill watersheds began in the late 1680s. In 1683, the Province of New York was divided into counties and land patents were granted to "men of influence" to promote settlement (Hasbrouck 1909). Most of the land in the Stony Creek and Saw Kill watersheds (73%) was granted in 1688 to Colonel Peter Schuyler, henceforth known as Schuyler's Patent (Hasbrouck 1909). The remaining 27% of the watersheds not in the original Schulyer Patent corresponds to the portions of the watersheds that occupy the present day Towns of Milan and Clermont (Hasbrouck 1909). The Milan portion of the Saw Kill was part of the Little Nine Partners Patent and the Clermont portion of the Stony Creek watershed was part of Livingston Manor.

Little settlement occurred in the Stony Creek and Saw Kill watersheds until 1720. Schuyler's Patent was held as an investment and then was sold to other interests in 1704 and 1719. Settlement on the Little Nine Partners Patent was sparse through 1737 (McDermott 1986) and began on the Livingston Patent property in Clermont in 1715 with the arrival of a group of German Palatines (Hedrich 1933). Population and infrastructure data confirm this lack of settlement. In 1703, only 10 to 12 families lived in all of Dutchess County (W. McDermott, Local Historian, pers. comm.). By 1714, this number had grown to 49 families with only nine families living in what was known as the North Ward; a composite of Schuyler's Patent, Little Nine Partners Patent, and Rhinebeck Patent (Figure 2) (McDermott 1986). Except for the Post Road, no other roadways or mills were established in this area until 1720 (Hasbrouck 1909). This period of very limited settlement was represented in the GIS and subsequent calculations in a completely forested condition.

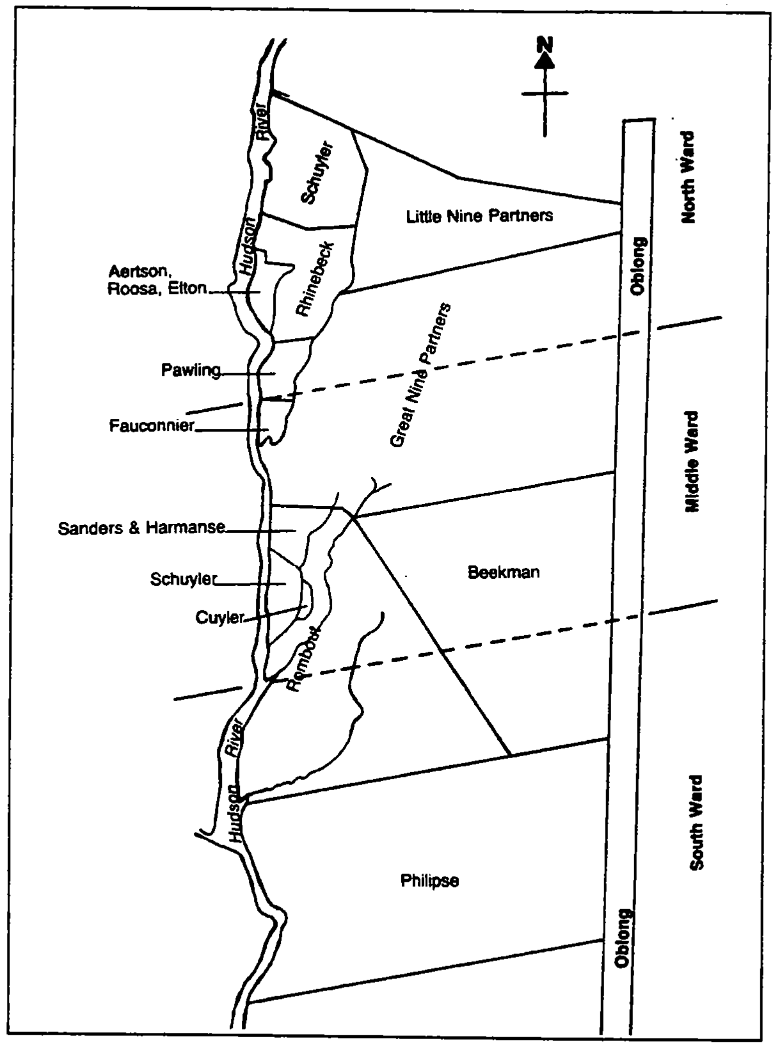


FIGURE 2: Map of land patents in Dutchess County, New York. Reprinted from McDermott (1986).

1720-1750: Pioneer Settlement Period

Clearing of forest land by pioneer settlers began in earnest around 1720 under the leasehold system. Owners of land patents actively recruited settlers who leased lands for farming (Hedrick 1933). Farms were nearly self-sufficient, and cash crops were rare (Secor 1939). Settlement rates during this period were slow. Population in the North Ward of Schuyler's Patent increased from 9 heads of household in 1714, to 121 in 1727, and 197 in 1737 (Hasbrouck 1909).

Land settlement increased moderately during the period without ever exceeding the degree of settlement of 1750 (McDermott 1986; Hasbrouck 1909). Unfortunately,

these data could not be converted into a meaningful estimate of area of settled land and, therefore, linear interpolation of more reliable estimates for adjacent time periods was used.

1750-1820: Grain Period

The year 1750 marks a turning point in land settlement patterns and population growth in Dutchess County (Secor 1939). The Little Nine Partners and Great Nine Partners Patents (Figure 2) in the middle and northeastern portions of the county were subdivided for sale. The end of the leasehold system in these areas sparked a rapid growth in settlement and associated population increases. The total population of Dutchess County was 1,727 in 1731, 14,148 in 1756, and 42,566 in 1790 (Hasbrouck 1909). Because the leasehold system continued in the Rhinebeck, Schuyler and Livingston Patents until 1840, the rate of population growth was less dramatic in the Stony Creek and Saw Kill watersheds (McDermott pers. comm.). Nevertheless, settlers continued to clear forest lands to grow grain. During the period of the Revolutionary War, Dutchess County was known for its wheat production and was referred to as "the breadbasket of the Northern Revolutionary Army" (Kim 1978). After the war, population increases in New York City sustained huge demands for wheat and Dutchess County farmers enjoyed prosperous times.

For this time period, we calculated the percentage of settled land by interpreting a 1797 survey map showing the roads, farms and mills in the Red Hook-Rhinebeck region (Figure 3). By transferring the watershed boundaries to this map, we were able to estimate the total number of farms in each watershed. The Thompson survey does not contain the Milan portion of the Saw Kill watershed nor the Clermont portion of the Stony Creek watershed. We estimated the number of farms in these areas with the farm density calculated from the Red Hook-Rhinebeck portion.

To estimate the total amount of settled land in the watersheds, we multiplied the number of farms by the typical farm size for this period. A review of historical literature reveals a wide variance in farm size in the Dutchess County region. Average farm sizes for different areas of the Hudson River Valley in the 1700s include: 218 acres for Schulyer's Tenants, 256 acres in the Beekman Patent (Kim 1978), 171 acres as the

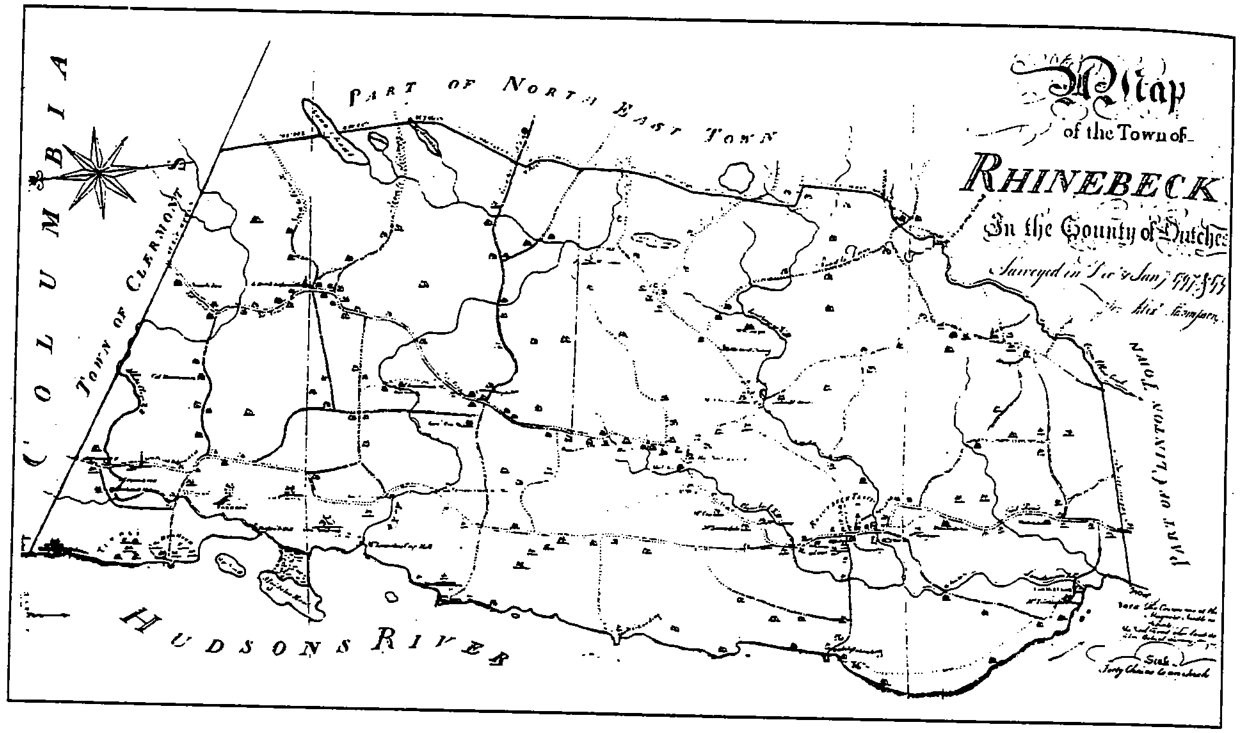


FIGURE 3: Survey map of Rhinebeck in 1797 (Thompson).

average leasehold for New York State, 128 acres for the Clermont estate, and 150 acres in the Red Hook region.

Preliminary results of William McDermott's (1986, 1997) ongoing research of farm conditions in the Red Hook-Rhinebeck region in the 1700s indicate that the median farm size during this period was 85 acres (McDermott pers. comm.). We elected to use 85 acres for our research with the view that a locally-derived estimate is preferable to general references pertaining to a larger region. It appears that the 85 acre median farm size is significantly smaller than other historical references because other research has calculated the mean farm size and included large landholdings that were probably not cleared and cultivated.

Several references establish that approximately 30% of the average farm during this period was maintained in forest to provide fuelwood for heating and cooking (Aldrich 1979; Goddard 1988; Kim 1978). Less than one percent of the average farm consisted of house and barn structures, home gardens, and small orchards (Kim 1978). The remaining area of the average farm (70%) was dedicated to wheat production (Kim

1978). Smaller quantities of corn, rye, and other grains also were grown for family use and livestock feed (McDermott pers. comm.). Thus, an average 85 acre farm of the period in the Stony Creek or Saw Kill watersheds probably retained about 25 acres of forest with the remaining 60 acres used for crop and livestock production (Figure 4).

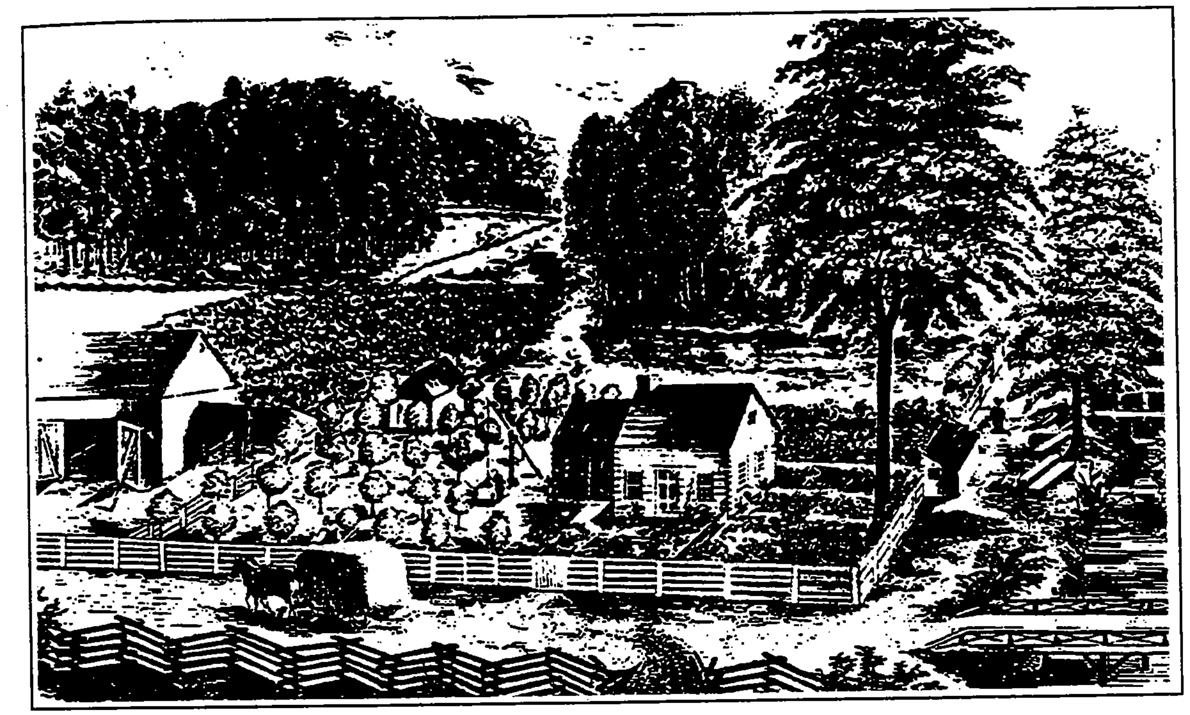


FIGURE 4: A New York farm in the late 1700s. Reprinted from Thompson (1977).

1820-1860: Transition Period

A transition in the agricultural practices of Hudson Valley farmers began in the years following the prosperous Grain Period. Several factors in the region combined to begin a gradual shift from wheat production and subsistence farming to dairy production and industrial expansion in the Hudson Valley (Danhoff 1969; Whitney 1994; Zimmerman 1988). The year 1820 marks the beginning of this transitional period.

The hilly, thin soils of eastern New York were quickly becoming depleted after decades of intensive wheat production (Jeanneney and Jeanneney 1983). Depletion of the soils was exacerbated by the infestation of black stem rust and the Hessian fly, both of which served to further deteriorate the quality of Hudson Valley wheat (Ellis 1946). With the opening of the Erie Canal in 1825, already struggling wheat farmers of eastern

New York were faced with ever increasing competition from western farmers. Wheat produced from the virgin, fertile soils of western New York and the Ohio Valley quickly upstaged the eastern wheat farmers and initiated the shift from wheat to dairy production.

Derivation of the amount of land settled during the time period 1820-1860 relied primarily on historical references. Macauley (1829) recorded the number of improved acres within each county in the State of New York in 1829. Improved land was interpreted to include all lands where forest cover had been removed. The fraction of the Stony Creek watershed in Columbia County was multiplied by the value of settled land for the county and summed with the similar product from the Dutchess County fraction of the watershed. The improved acreage in the Saw Kill watershed was calculated directly from Dutchess County data.

1860-1910: Dairy and Manufacturing Period

The completion of the railroad in 1851 allowed farmers to ship fresh milk to New York City. This solidified the importance of dairy production in the region and accelerated the transition from wheat production to dairying. Diverse farms that formerly maintained sheep and swine now added more cattle and cleared still more land for pasture (Jeanneney and Jeanneney 1983).

Increased demand for dairy pasturage led directly to increased rates of forest clearing. The development and commercialization of steamboats and locomotives also increased the demand for fuelwood, railroad cross-ties, and oak for shipbuilding. By the late 1800s, the clearing of land had peaked (Ellis 1946) and the landscape was a patchwork of small fields separated by stone walls and split-rail fences. The woodlot on the average farm had decreased in size from 30% of total farm area in the late 1700s, to approximately 12% of total farm area in 1875. The mean farm size in the Stony Creek and Saw Kill watersheds was approximately 115 acres (Hough 1877).

Detailed state census data exist for the years 1855, 1865, and 1875 and was organized by town, as well as by county. The state census data from these years is much more reliable than in previous years because it was conducted by appointees of the Secretary of State, as opposed to groups of people appointed by local town authorities.

This helped to minimize errors by standardizing the approach of census takers (Hough 1867).

The inclusion of town data in the census was particularly helpful for our study since it allowed the compilation of separate statistics for portions of the watersheds in the Towns of Milan, Red Hook and Clermont. By differentially weighting the state census statistics according to the amount of the watershed within each town, we were able to compare land use conditions in the Saw Kill watershed with those in the Stony Creek watershed and develop accurate estimates of both the percent of each watershed that was settled and the profile of land use on the average farm.

Our main reference point for the 1860-1910 time period was 1875 because it contained the most detailed agricultural statistics (Hough 1867). The 1875 census lists the total area of land contained in farms in each of the towns in the state. Total farm area was divided by the total number of acres of land in each town to derive the total percentage of settled land in each town for the year 1875. To arrive at the estimate of settled land in each watershed for the time period, the relative proportions of the watershed within each town were used to estimate weighted averages and the total settled area.

Following the calculation of settled land for each watershed in 1875, we turned to the categories of the census data that detailed the relative proportions of land use on the farms in each town to generate a profile of the average farm per watershed. In particular, we concentrated on the proportion of *improved* land (number of acres plowed, pasture, mowed for hay, or other) versus *unimproved* land, which includes areas reserved for woodlot and areas labeled as "other" (presumably including wetlands, rocky areas, and other "unusable" land). Table 2 summarizes the data that we compiled for Milan, Red Hook and Clermont. To estimate conditions on the average farm in the Stony Creek and Saw Kill watersheds from these statistics, we again used a weighted mean. For each watershed, the percentage of a particular land use (e.g., 18% for plowed land in Red Hook) was multiplied by the relative size of both towns in that watershed (e.g., 71% for Red Hook and 29% for Milan in the Saw Kill watershed). These products were summed to produce the overall percentage of that land use for each watershed.

TABLE 2: Agricultural Statistics for 1875 in the Towns of Red Hook, Milan, and Clermont, New York (New York State Census of 1875).

	Red Hook		Milan		Clermont	
	(acres)	(%)	(acres)	(%)	(acres)	(%)
Total Area in Farms (% of total watershed area)	20,607	87.7	22,805	82.1	11,255	97.7
Improved Land (% of total farm area)						
Area Plowed	3,733	18.1	5,006	21.9	2,900	25.8
Area in Pasture	3,131	15.2	4,415	19.4	1,413	12.6
Area Mown	8,611	41.8	5,306	23.3	5,054	44.9
Other	1,988	9.6	2,859	12.5	71	0.6
Unimproved Land (% of total farm area)						
Area in Woodlot	2,592	12.6	3,864	16.9	1,036	9.2
Other	552	2.7	1,355	6.0	781	6.9

1910-1950: Population Growth Period

After the turn of the century, the gradual decline of agriculture led to the abandonment of marginal land and subsequent regrowth of forests. Manufacturing and associated residential development increased and the population of Dutchess and Columbia Counties grew rapidly. For the time period 1910-1950, we quantified both the percentage and spatial distribution of settled lands in the watersheds. A land cover layer showing the actual areas of settled and forested lands was created from a 1938 USGS topographic quadrangle map. By convention, green areas on the map were interpreted to indicate tracts of remaining forest, while white areas were categorized as *settled* lands. This spatial information was digitized and then analyzed with the ArcView GIS package (ESRI 1996) at a 30 meter grid cell resolution.

1950 to present: Modern Era

The rural population of Dutchess and Columbia Counties continued to increase during the second half of the twentieth century as agricultural production declined.

Forest regrowth continued as more field and pastures were abandoned. Improved highway access brought more summer and suburban residents to the area.

Data for the Modern Era were developed with a combination of digital satellite imagery and 1:24,000 enlargements of 1995 National High Altitude Photography program (NHAP) color infrared aerial photographs. A land cover layer was developed with on-screen digitizing of the different land use categories using ArcView to display a 1995 Satellite Pour I'Observation de la Terre (SPOT) satellite image. The NHAP aerial photographs and field inspections were used to verify land cover classifications. Land cover was divided into five categories: forest, row-crop agriculture, pasture/mown areas, orchards, and development. The last four classes comprise the settled category. Roads, streams, and lakes were added to the land cover layer from the Tivoli Bays GIS database developed by Fraser and Barten (1995).

Summary of Land Settlement Over Time

Figure 5 depicts the shifting balance between forest and settled land in the Tivoli Bays watersheds. It illustrates two important trends. First, relevant to both watersheds, is the general pattern of land settlement from pre-European settlement to the present. Forests were cleared for agricultural purposes throughout the 18th and 19th centuries with the maximum amount of clearing in the late 1800s during the Dairy and Manufacturing Period (86% for the Saw Kill; 91% for the Stony Creek). The twentieth century marks the decline of agriculture and the natural regeneration of forests on abandoned farm lands. This pattern was typical of New York and New England (Foster 1992; Whitney 1994). Second, Figure 5 shows a larger proportion of the Stony Creek watershed was settled, at any given time, than the Saw Kill watershed.

GIS Modeling

Spatial Distribution of Settlement Patterns

Once the proportion of settled and forested land was estimated for each watershed and time period, GIS layers were created to spatially represent these changes. The distribution of settled lands in the watersheds was accomplished by creating an algorithm to mimic historical settlement patterns. Settlement appears to principally have followed

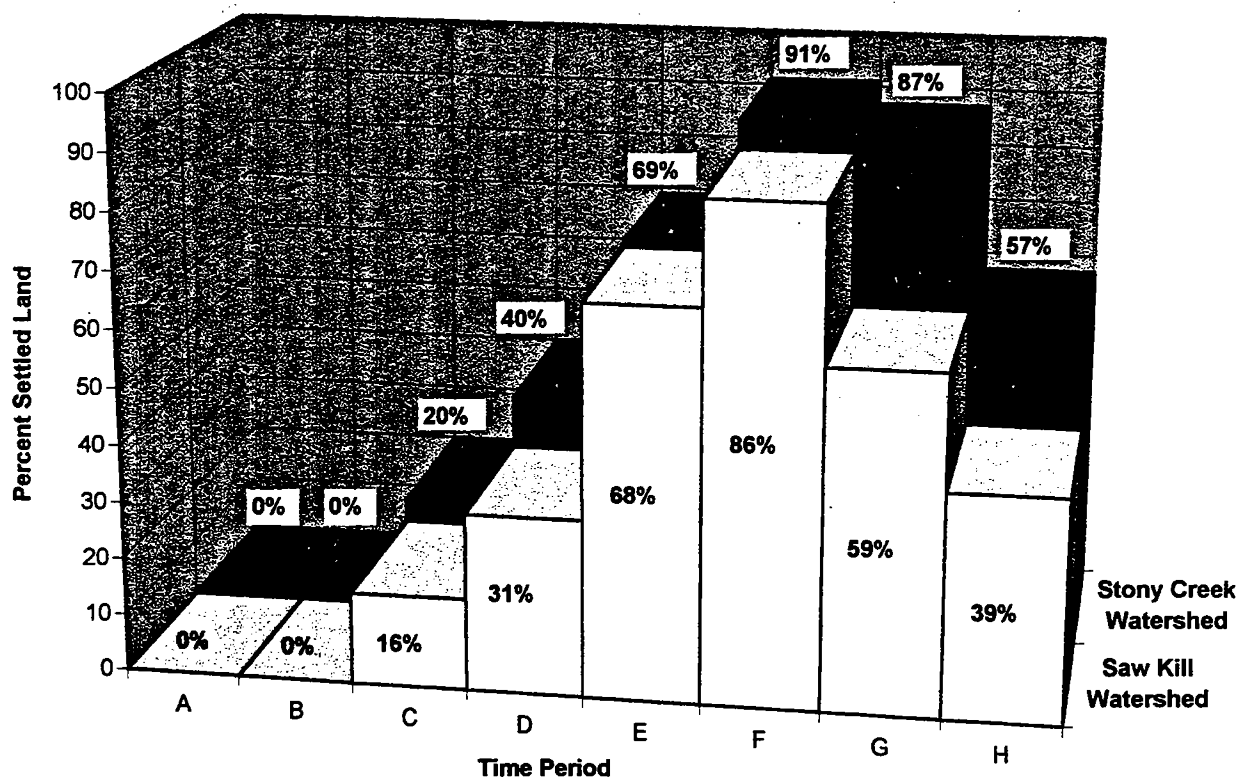


FIGURE 5: Percent of settled land during historical time periods for the Stony Creek and Saw Kill watersheds, Hudson River Valley, New York. Time periods: (A) Before 1683: pre-European Settlement; (B) 1683 - 1720: Land Patent Period; (C) 1720 - 1750: Pioneer Settlement Period; (D) 1750 - 1820: Grain Period; (E) 1820 - 1860: Transition Period; (F) 1860 - 1910: Dairy and Manufacturing Period; (G) 1910 - 1950: Population Growth Period; (H) 1950 to present: Modern Era.

existing road networks and to have moved progressively inland from the Hudson River. In addition, settlement was more likely to occur first on gentle slopes with deeper, fertile soils, with later development moving onto steeper slopes with shallow, stony soils. This settlement pattern was common throughout the northeast due to the direct correlation between slope gradient and desirable soil attributes for farming such as thickness, fertility, depth and water retention. Foster (1992) concluded that proximity to roads was the primary determinant of settlement patterns in his study of the Prospect Hill tract in the Harvard Forest in central Massachusetts. Although other factors such as market

conditions, land tenure, and demographic shifts also influenced settlement patterns, our decision rule used three parameters that can be consistently implemented with the GIS.

Distance from existing roads was calculated and valued so that regions closest to roads were assigned the highest values (most likely to be cleared and settled). Distance from the Hudson River was calculated next and assigned a range of similar values. The lowest values were assigned to the region immediately adjacent to the Hudson River because maps (Thompson 1797; Beers 1891) and other references indicated that this property was held by wealthy landowners and was not settled by individual farmers (R. Wiles, The Charles Ranlett Flint Professor of Economics, Bard College, pers. comm.). To the east of this relatively undeveloped region, a range of values were assigned decreasing progressively to the eastern boundary of the study area. Similarly, slope gradients ranging from level areas to steep hillsides were represented with a linear suitability scale from high to low, respectively.

Once these attributes were completed, an algorithm was developed to sum their overall influence on settlement patterns. The range of values derived for the distance from the Hudson River was assigned a base value of 1, while the value range for slope steepness was weighted by a factor of 2, and the value range for distance from existing roads, perhaps the most influential characteristic, was weighted by a factor of 5. The composite GIS layer representing likelihood of settlement was iteratively resampled, proceeding from the highest to the lowest value, until the appropriate total area of settled lands was reached (Figures 6 and 7).

Soil Erosion

The GIS layers for each period were used to solve the Modified Universal Soil Loss Equation (MSLE). MSLE extends the application of the Universal Soil Loss Equation to range and forest land. Empirically defined from field data, the MSLE equation is: $A = R\,K\,(LS)\,(VM)$; where A = predicted soil loss (tons/acre)/year; R = rainfall erosivity factor; K = soil erodibility factor; LS = slope length and steepness factor; and VM = vegetation management factor (Brooks et al. 1997).

The Tivoli Bays GIS database (Fraser and Barten 1995) includes four of the five parameters needed to calculate soil erosion with the MSLE equation: soil erodibility,

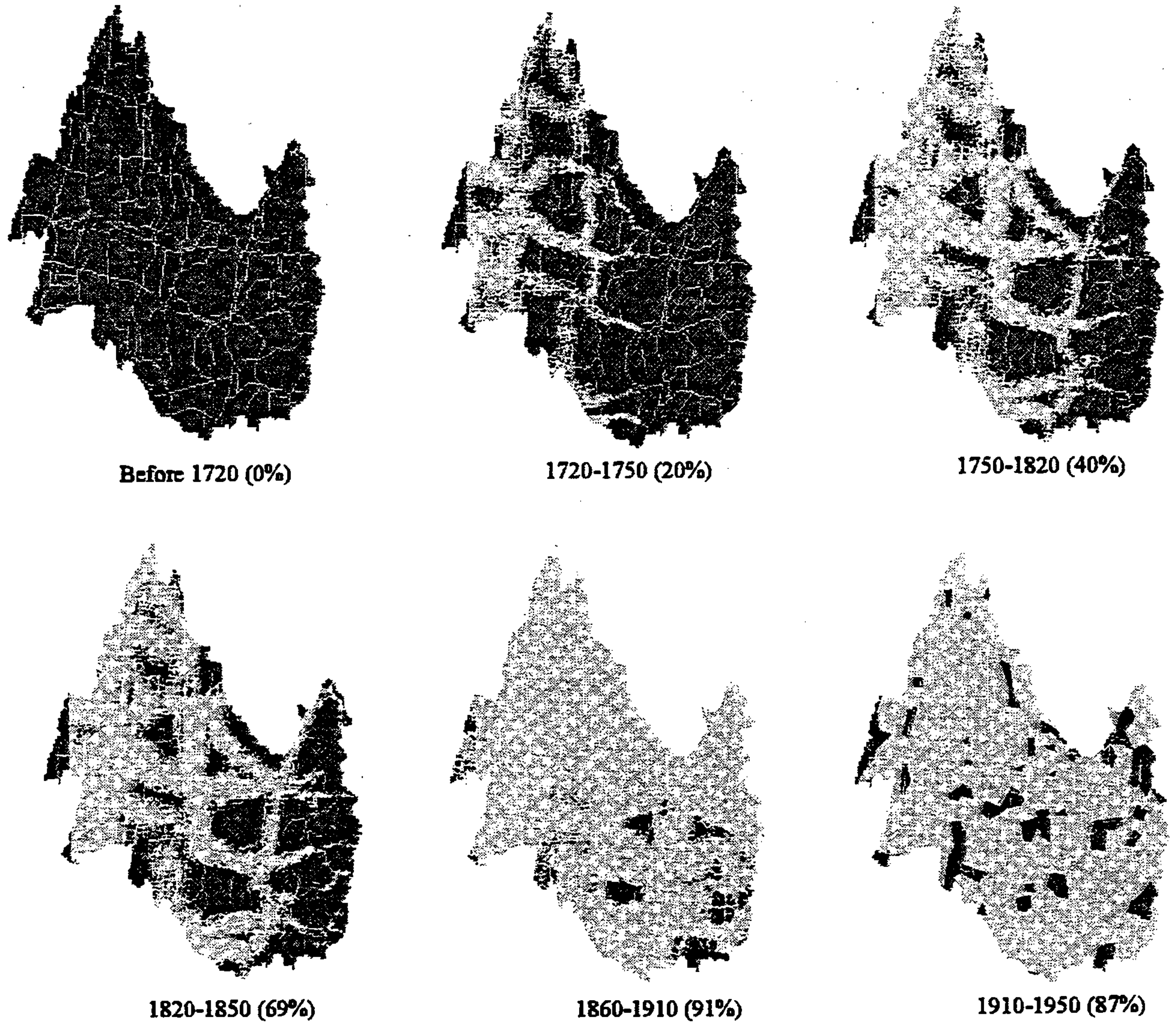
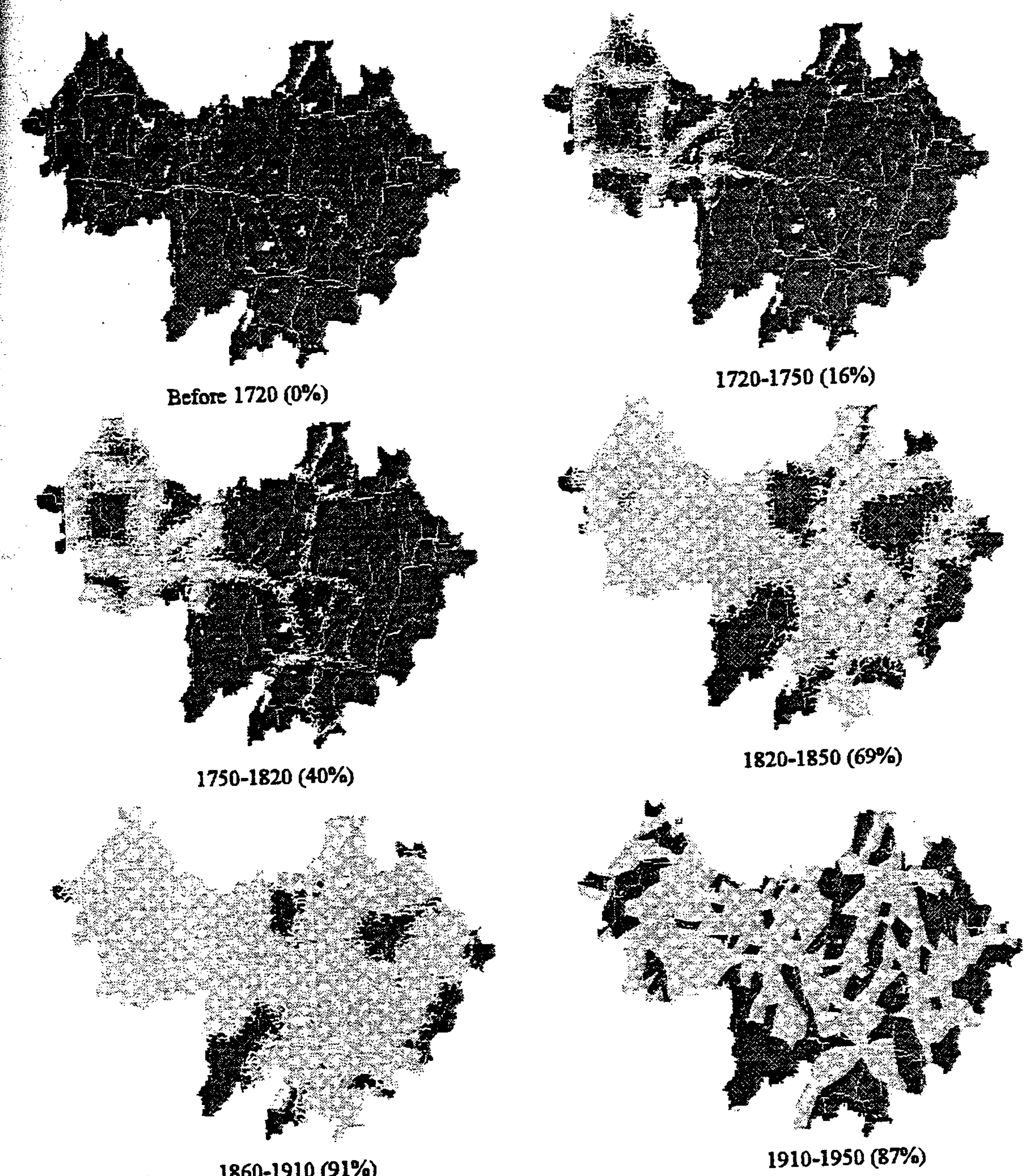


FIGURE 6: Predicted spatial and temporal distribution of settlement patterns in the Stony Creek watershed, Hudson River Valley, New York. Forested areas are represented with dark gray and settled areas with light gray. The (%'s) indicate percent settled land.



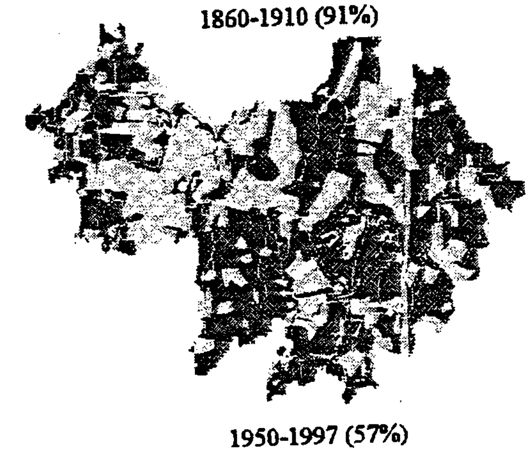


FIGURE 7: Predicted spatial and temporal distribution of settlement patterns in the Saw Kill watershed, Hudson River Valley, New York. Forested areas are represented with dark gray and settled areas with light gray. The (%'s) indicate percent settled land.

slope steepness, slope length, and rainfall erosivity. We used a constant R value because long-term meteorological data are not available before 1900. Although interannual variation in climate may have affected our predictions, the relative response of the watersheds is clear. For a detailed discussion of the MSLE parameters for the Stony Creek and Saw Kill watersheds see Reichheld and Barten (1992) and Fraser and Barten (1995).

The VM factor is the ratio of soil loss from land managed under specified conditions to the corresponding loss from bare soil. Hence, the values range from 0 for well protected, heavily vegetated land to 1 for bare soil. Table 3 lists the VM factors selected from USDA Soil Conservation Service (1975) tables for this study.

Settled lands in both the Stony Creek and Saw Kill watersheds for the period 1720-1820 were represented by a single VM factor. A value of 0.23 was selected based on historical references indicating that most of the cleared lands during this time were used for wheat production.

The inclusion of data by town in the 1875 State Census of New York allowed for the separate calculation of VM factors for settled lands in the watersheds in the time interval from 1820-1910. The VM factor used to represent the Transition Period and the Dairy and Manufacturing Period was based on the values in Tables 2 and 3. A weighted mean VM factor was calculated for the Stony Creek and Saw Kill watersheds. The 1875 census reported approximately half the plowed areas were used for corn and the remainder for oats, yielding a mean of 0.31 for tilled areas. The "Other" category in the *improved* lands section - farmhouse, kitchen garden, barn, outbuildings, and walkways - was represented with a single factor of 0.20. The "Other" category listed for *unimproved* lands - wetland areas, rock outcrops, and small ponds - was assigned a value of 0.

The average VM factor for settled areas calculated for the Population Growth Period of 1910-1950 was retrospectively estimated with the proportion of each land use characterized in the 1995 land cover-land use layer. Again, the percentages of different land use categories were determined for the Stony Creek and Saw Kill watersheds, multiplied by the appropriate VM factors, then summed to yield a composite VM factor for settled lands. The values of 0.34 for plowed lands and 0.10 for developed areas from

TABLE 3: A summary of Vegetation Management (VM) factors for soil erosion estimates in the Tivoli Bays watersheds, Hudson River Valley, New York.

Forested Land	0.002
Settled Land	
Improved	
Plowed Land	
1720-1820	0.23
1820-1910	0.31
1910-1997	0.34
Pasture Land	0.1
Mown Land	0.06
Orchards	0.003
Other	0.2
Unimproved	
Woodlot	0.002
Other	0

Reichheld and Barten's (1992) Saw Kill study were used for both watersheds. A value of 0.06 was used to represent pasture and mown agricultural areas. This value was derived by averaging the previously selected value for pasture (0.10) and mown (0.013) areas. This VM factor for open field areas dominated by perennial vegetation is the same as that used in Howarth et al. (1991) for pasture areas. Orchards and tree farms were assigned a value of 0.003 (Brooks et al. 1997).

For the Modern Era (1950 to present), the same VM factors were used as the 1910-1950 time period. These VM factors were applied directly to the land use categories created in the 1995 land use layer. Since the GIS layer for this time period includes the actual location of settled lands (pasture, crops, and developed areas), an average VM factor was not needed.

Annual soil erosion was multiplied by the number of years in each time period and summed to estimate cumulative soil erosion for each of the eight time periods. Annual soil erosion ranged from 100 to 4,400 Mg in the Stony Creek watershed and from

300 to 10,400 Mg in the Saw Kill watershed. Table 4 shows the annual and cumulative soil erosion.

Estimated annual soil erosion was consistently greater in the Saw Kill watershed. Furthermore, the two-fold difference in soil erosion was uniformly greater than the 1.2X difference in watershed area. This reflects cumulative differences in the interaction of land use with soil and terrain characteristics.

TABLE 4: A summary of soil erosion in the Tivoli Bays watersheds, Hudson River Valley, New York.

Watershed	Annual Soil Erosion (Mg/year)	Annual Soil Erosion per Unit Area (Mg/ha)	Duration (years)	Total Soil Erosion per Time Period (Mg)
Stony Creek				
1683-1720	100	0.02	37	3,700
1720-1750	500	0.09	30	15,000
1750-1820	1,700	0.31	70	119,000
1820-1860	2,200	0.40	40	88,000
1860-1910	4,200	0.75	50	210,000
1910-1950	4,400	0.79	40	176,000
1950-1997	2,000	0.36	47	94,700
Total	15,100			705,700
Saw Kill				
1683-1720	300	0.05	37	11,100
1720-1750	1,000	0.18	30	30,000
1750-1820	3,000	0.54	70	210,000
1820-1860	6,500	1.17	40	260,000
1860-1910	10,400	1.87	50	520,000
1910-1950	6,300	1.13	40	252,000
1950-1997	3,100	0.56	47	145,700
Total	30,600			1,428,800

Sediment Delivery

Only a portion of soil eroded in a watershed reaches the stream network and outlet. There are numerous opportunities for sediment deposition in small depressions, wetlands, densely vegetated riparian areas, behind small dams, etc. To account for storage effects most studies have relied on logarithmic functions to estimate sediment delivery ratio as a function of watershed area (ASCE 1975). However, as noted by Howarth and others (1991) in an earlier study of the Hudson River watershed, it would be preferable to use a method that represents the influence of site-specific watershed characteristics.

In a related project, we developed and tested a spatially explicit delivery model (SEDMOD) to predict the landscape-scale movement of nonpoint source pollutants via overland flow. The prototype model was tested with soil erosion-sediment delivery predictions on the 43 km^2 Little Beaver Kill watershed in the nearby Catskill Mountains (Fraser et al. 1996). An ongoing study is using the model to predict transport of fecal coliform bacteria from livestock areas to streams in a system of 12 sub-watersheds of the Saw Kill (Fraser and Barten 1995; Fraser et al. in press; Pinney and Barten 1997). In this project, we used SEDMOD to estimate sediment delivery to the Tivoli Bays from 1683 to present. The algorithm uses a digital terrain model to determine the flow-path from every grid cell to the nearest stream. Up to six parameters (flow-path gradient, shape [convex, planar, concave], surface hydraulic roughness, stream proximity, soil texture, and overland flow index) are used to derive a dimensionless delivery ratio (sediment delivered/soil eroded; range = 0 to 1) for each 30 meter grid cell. The soil erosion layer is multiplied by the result, a delivery ratio layer, to predict a net sediment delivery layer for the watershed. This operation was repeated for all eight time periods; results are summarized in Table 5 and Figure 8. As a consequence of their similar area and terrain characteristics, the Saw Kill and Stony Creek watersheds have a nearly identical total delivery ratio of 0.18. Hence, overall patterns of sediment delivery with respect to time parallel the trends described earlier for soil erosion.

TABLE 5: A summary of sediment deposition in the Tivoli Bays watersheds, Hudson River Valley, New York.

Watershed	Duration (years)	Annual Sediment Delivery (Mg/year)	Total Sediment Delivery per Time Period (Mg)
Stony Creek			
1683-1720	37	20	700
1720-1750	30	100	3,000
1750-1820	70	320	22,400
1820-1860	40	420	16,800
1860-1910	50	770	38,500
1910-1950	40	790	31,600
1950-1997	47	340	16,000
Total		2,760	129,000
Saw Kill			
1683-1720	37	60	2,200
1720-1750	30	180	5,400
1750-1820	70	540	37,800
1820-1860	40	1,210	48,400
1860-1910	50	1,920	96,000
1910-1950	40	1,070	42,800
1950-1997	47	550	25,900
Total		5,530	258,500

SUMMARY AND CONCLUSIONS

Our results lead us to reject the null hypothesis and raise a number of additional questions. Our primary hypothesis was that greater amounts of settlement over time in the Stony Creek watershed led to elevated levels of soil erosion and sediment delivery to Tivoli North Bay. Our historical research indicates that the Stony Creek watershed did, in fact, have higher percentages of settlement. However, this did not translate to larger amounts of soil erosion. It appears that physiographic characteristics of the watersheds that affect soil erosion (slope length, slope steepness and soil erodibility) interacted with

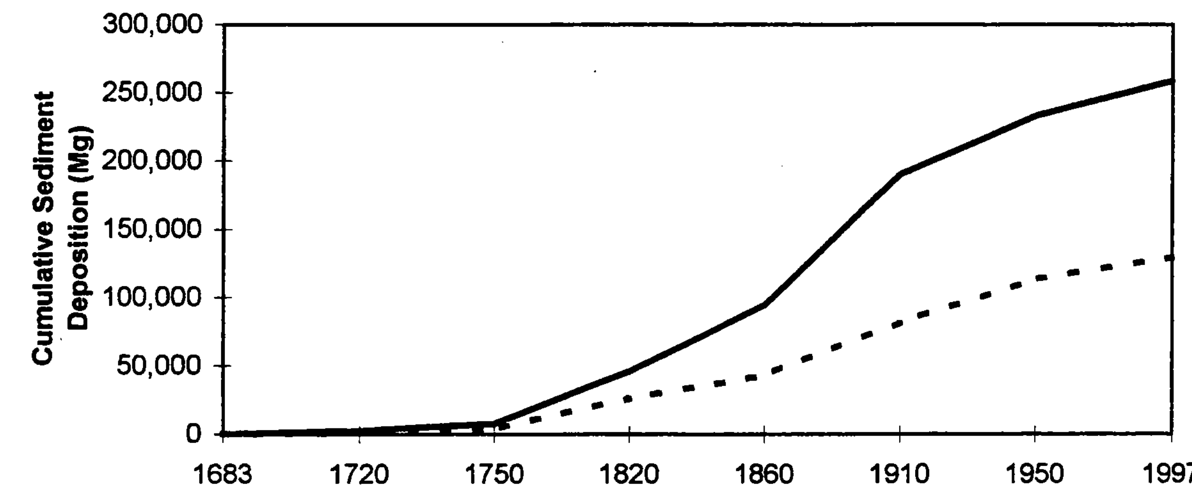


FIGURE 8: Estimated cumulative delivery to Tivoli South Bay (solid line) and Tivoli North Bay (dashed line) from 1683 to present, Hudson River Valley, New York.

the changing patterns of land use to generate greater rates of soil erosion in the Saw Kill watershed.

The greater rate of soil erosion in the Saw Kill watershed demonstrates that it is not necessarily the magnitude of a force that has the largest effect on a system, but often the location of the force. We predicted that the amount of clearing would be directly related to the amount of soil erosion in these watersheds. This theory has been widely documented in the literature (Davis 1976; Judson 1968; Meade 1969). Yet our research indicates that the location of forest clearing and settlement has an even greater influence on soil erosion than just an increase in open land. This underscores the importance of site-specific analysis and management of watersheds.

Many other factors also may have contributed to differences in the form of the bays. These include: (1) three acres of land reputedly subsided into Tivoli North Bay (Carey and Waines 1986); (2) large quantities of sawdust, crop residues and fine sediment may have been contributed by a sawmill, gristmill and brickyard that were operated on the banks of Tivoli North Bay; (3) small dams on the Saw Kill may have trapped sediment and reduced sediment delivery to Tivoli South Bay (Carey and Waines 1986); (4) the construction of the railroad in 1851 altered the tidal exchange with the river and may have caused less sediment to be deposited in Tivoli South Bay; and (5) the increased sediment trap efficiency of Tivoli North Bay as the marsh vegetation became established.

Our results shift the focus of sediment studies from differences in land use and watershed characteristics to other attributes of the ecosystem. They include, but are not limited to, (1) sediment routing along the Saw Kill and Stony Creek, (2) tidal exchange with the Hudson River, and (3) net sediment deposition in the Tivoli Bays. A combination of field, laboratory, and modeling research will be needed to further our understanding of the Tivoli Bays.

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CHARACTERIZATION OF DEMOGRAPHICS AND ATTITUDES OF FARMERS IN DUTCHESS COUNTY, NEW YORK

A Final Report of the 1997 Tibor T. Polgar Fellowship Program

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ABSTRACT

Agricultural watershed management programs based upon voluntary adoption of best management practices have met with limited or mixed success. Investigations of factors that influence the use of more environmentally sound practices are key to understanding problems, accomplishments, and future prospects. The heterogeneity of farmers, sites, and practices suggests a need to improve our understanding of this seemingly inherent variability. This will enhance the development of analytical tools to predict likely environmental consequences in relation to specific site characteristics, management practices, and farmer profiles. This study continued an investigation of background and attitudinal characteristics of farmers in the Saw Kill watershed in the Hudson River valley and expanded the sample to dairy farmers throughout Dutchess County, New York. It also contributed to continued development of a spatially distributed pollutant delivery model by reviewing livestock practices on field test sites. Dairy farmers tended to run larger, full-time operations – often on the family farm for several generations – while beef and sheep farms were more likely to be smaller, part-time enterprises. Similarly, dairy farmers were more likely to be making a profit from the farm in order to support their families. By contrast, beef or sheep farmers were not. Dairy farmers tended to be more at ease with the use of agricultural chemicals and more confident that voluntary initiatives would be sufficient to prevent environmental problems. Although some distinctions could be drawn between dairy farmers and beef, sheep or other (primarily crop) farmers, most of the observations supported earlier conclusions that farmers are characterized more by variability than consistency.

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INTRODUCTION

National attention drawn to recent fish kills in the Chesapeake Bay caused by *Pfiesteria piscicida* once again raises questions and accusations about the effects of farming on water quality. Meanwhile, ongoing pressure to secure minimum quality criteria for New York City's water is being addressed with a plan to promote voluntary adoption of Best Management Practices (BMPs) by farmers in upstate watersheds. Whether in regard to long-term goals or isolated incidents, questions are being raised by the general public about the ability of voluntary programs to reliably protect public interests (*Hartford Courant* 1997; *Poughkeepsie Journal* 1997). New York State has initiated a pilot study for a watershed-based management project called Agricultural Environmental Management. It is designed to work closely with *all* farmers in a given watershed to identify problematic sites and practices, then provide information and limited financial support to affect changes. Promotional materials for the program take pains to assure farmers that all participation is voluntary. Similar efforts in Wisconsin have yet to produce observable improvements in water quality (Wolf 1995).

The myriad combinations of farmer profiles, stock or crop types, and farm and watershed conditions yields an expansive range of problems and opportunities. Attempts to regulate these activities in order to meet water quality standards would, in theory, need to be restrictive enough to assure the most inappropriate practices on the most vulnerable sites are effectively controlled. Clearly, this approach would lead to excessive regulations for all other farms with less onerous pollution control problems – a politically and economically unpalatable situation. The alternative of promoting voluntary adoption of BMPs, even when they are carefully tailored to specific farms, does not eliminate the risk of failing to meet water quality goals.

The potential for success in these efforts can be enhanced by identifying the most vulnerable sites and the most threatening activities. Farms vary in their potential to contribute to water pollution (Fraser *et al.* forthcoming). Farmers vary in the management practices they use which, in turn, can alter the potential for contamination (Pease and Bosch 1994). Efforts to promote more appropriate practices have relied heavily on financial incentives or disincentives to guide farmers' choices. These choices are, however, affected by more than finances. Ownership patterns, use of hired labor versus family labor, and access to differentiated markets within which a farmer could be recognized for particular products or production methods (e.g., organic) are being examined to consider the influence of structural factors on the ability of farmers to use more environmentally friendly production practices (Lighthall 1995;Welsh and Lyson 1997). But even within a structural framework supportive of adopting BMPs, there are reasons to be concerned that variations among the farmers will prompt a variety of responses, some of which will not be sufficient to meet environmental quality goals (Pinney and Barten 1997).

Attitudes held by individual farmers are significant determinants on soil conservation practices (Lynne and Rola 1988; Pease and Bosch 1994). Appreciating the variation in attitudes held by farmers and anticipating how this affects their practices may be more important than technologies and management prescriptions.

OBJECTIVES

This study was undertaken to replicate and refine our pilot (1996) project to characterize livestock practices in the Saw Kill watershed in Dutchess County, New York (Pinney and Barten 1997). The first objective was to develop a more detailed and rigorous approach to measuring attitudes of farmers in regard to environmental issues. The second objective was to extend the effort beyond the Saw Kill watershed to the rest of Dutchess County in order to examine possible trends of regional interest. The third objective, as with the previous study, was to update livestock data used in testing model predictions of contamination of streams with fecal coliform bacteria (Fraser *et al.* forthcoming).

METHODS

A new questionnaire was developed based in part on the experience with the pilot project (Figure 1). Responses to open-ended questions used in the 1996 study provided the means for developing categories to accommodate responses within a closed-ended question amenable to coding and analysis. Most of the attention focused on measuring attitudes. Responses to last year's survey suggested several key subject areas. However, developing questions that yield reliable and consistent data and information requires careful pre-testing (Babbie 1973). Therefore, we used salient questions from peer-reviewed literature to measure general satisfaction with the environment and governmental affairs (Pelletier *et al.* 1996) and others focused on agricultural and environment issues (Halstead *et al.* 1990). These questions had already been used in the field, establishing their validity. For each topic addressed – use of agricultural chemicals,

FIGURE 1: Questionnaire for interviews with farmers in Dutchess County, NY.

Agricultural Survey - 1997 David Pinney
Dutchess County, N.Y. Yale University

Questionnaire #_______
Farm name or Owner: ____________________________
Location: ____________________________

Farm characteristics and management practices:

1) Farm acreage (owned and leased)
   - Total _________
   - cropland _________
   - hay _________
   - pasture _________
   - woodland _________
2) Are there streams or ponds on the farm? Yes or No
3) Livestock
   - Cattle
     - dairy _________
     - beef _________
   - Sheep _________
   - Horses _________
   - Others ____________ _________
   - ____________ _________
4) Livestock location (check one from each set)
   - ___ The animals are confined (barn or barnyard) most of the time
   - ___ The animals are confined at times and pastured at times
   - ___ The animals are pastured most of the time

   - ___ The animals stay in one pasture
   - ___ The animals rotate among several pastures
5) Livestock density
   - The most crowded pasture conditions would be ___animals on ___ acres
   - The least crowded pasture conditions would be ___animals on ___acres
6) Livestock feed (check all that apply)
   - ___ pasture
   - ___ hay
   - ___ grain
   - ___ supplements (minerals, steroids, hormones)
7) Water (pick one)
   - ___ stock tanks only
   - ___ ponds or streams
   - ___ either (depending on availability)
8) Manure (check those that apply)
   - ___ Scrape and spread (daily or frequently)
   - ___ Scrape and stockpile frequently, spread seasonally
   - ___ Collect and spread seasonally
   - ___ Leave on fields
9) Crops grown (check those that apply)
   - ___ hay
   - ___ field corn
   - ___ other grains
   - ___ sweet corn
   - ___ other vegetables

   - ___ apples, other large fruit
   - ___ small berries
   - ___ Christmas trees
10) Tillage (check those that apply)
   - ___ full tillage annually (moldboard)
   - ___ full tillage occasionally, reduced tillage in-between
   - ___ reduced tillage
   - ___ no till
   - ___ contour plowing
   - ___ fall plowing
11.) Materials used (check those that apply)
   - ___ fertilizer, chemical
   - ___ fertilizer, organic
   - ___ herbicide
   - ___ insecticides, chemical
   - ___ insecticides, organic

Operator Data:

12) Age ________
13) Gender ________
14) Family status
   - married ________
   - children ________
     - children involved with farm Yes or No
15) Farm profitability (check one)
   - ___ this farm shows a profit most years
   - ___ this farm shows a profit more years than not
   - ___ this farm has a profitable year occasionally
   - ___ this farm does not show a profit
16) Family finances (check one)
   - ___ Earnings from farming are the only financial support for me and my family
   - ___ Earnings from farming are the primary means of support
   - ___ Earnings from farming are secondary to other sources of income
   - ___ "I'm not in it for the money"
17) Education and experience
   - Highest level: ___ high school ___ college ___ graduate ___ no degree
   - Formal agricultural education: ___ none ___ vo-ag ___ college
   - Prior farm experience: ___ none ___ some ___ life-long
   - Ownership: ___ this farm purchased ___ years ago
     - ___ this has been my family's farm for ___ generations
18) Sources of information
   For each of the following, please indicate the extent to which each is a source of new ideas or technical information that you use in your activities. Choose among the following categories:

	Frequently	Occasionally	Rarely	Never
state agencies staff	_____	_____	_____	____
extension service staff	_____	_____	_____	____
sales people	_____	_____	_____	____
paid consultants	_____	_____	_____	____
other farmers	_____	_____	_____	____
educational programs	_____	_____	_____	____
farm magazines	_____	_____	_____	____
other publications	_____	_____	_____	____

19) To what extent have you done farm planning with state or federal agencies?
   - ___ I have completed a whole farm plan, including production and financial aspects
   - ___ I have worked on specific production or facilities issues with agents

___ I have not done planning work with agents, but might in the future
___ I am not interested in involving state or federal agents in my activities

20) Have you received government money to support production or facility expenses?
___ Yes
___ No, but it could be an important part of my interest and ability to improve my production or my facility
___ No, but I am not interested in accepting government money to support my operation

21) Using a scale of 1 to 5, with 1 indicating low priority and 5 indicating high priority, please evaluate the following issues
___ Supporting profitability in agriculture
___ Diversifying agriculture in the Hudson Valley
___ Attracting industry to the Hudson Valley
___ Controlling commercial or residential development in the Hudson Valley
___ Protecting water quality
___ Preventing soil erosion
___ Maintaining the viability of rural communities

22) For each of the following locations, please indicate how concerned you are that water quality may present problems for human health

	Level of Concern			
	Not at all	Somewhat	Very	Not sure
Nation as a whole	___	___	___	___
New York State	___	___	___	___
This county	___	___	___	___
My town	___	___	___	___
On my property	___	___	___	___

23) Please indicate the extent to which you agree or disagree with each of the following statements. The scale this time goes from -3 indicating no agreement at all, through 0 indicating neutrality or no opinion, to +3 indicating complete agreement.
___ Local environmental conditions are excellent
___ I am confident that agricultural chemicals, if used as directed, are not a threat to the environment.
___ In most ways, the quality of the government's environmental programs is very good.
___ Should water supplies become contaminated, I am confident scientists will develop ways to purify them.
___ So little agricultural chemicals enter the water, they could never pose a health problem.
___ The government policies developed to deal with the environmental situation are excellent.
___ Instead of worrying about the effects of agricultural chemicals, we should spend more time and effort in solving other problems of farming.
___ In most ways, the environmental conditions in my area are close to ideal.
___ For the most part, the programs developed by the government have addressed the most important environmental problems.
___ Animal agriculture accounts for more than half of any water quality problems.
___ In my opinion, the amount of attention given to the environment by the government has been satisfactory.
___ Crop-based farming accounts for more than half of any water quality problems.
___ Water quality is more of an issue for the future. Today, the threat from agricultural chemicals is quite small.
___ Pollution control requirements have gone too far. They have already cost more than they are worth.
___ So far, I am content with the state of the environment in my area.
___ Residential and commercial development accounts for over half of any water quality problems.
___ We must relax environmental standards in order to achieve economic growth.

___ We already have too much regulation of agricultural chemicals.
___ We cannot be too careful when it comes to putting new pesticides on the market.
___ I worry about the purity of drinking water in this area.
___ Protecting the environment is so important that the requirements cannot be too high and continuing improvements must be made regardless of costs.
___ We must accept slower economic growth in order to protect the environment.
___ Voluntary changes will provide sufficient response for any water quality problems. More regulation is not required.
___ If I could change some aspect of the environmental condition in my area, I would change almost nothing.

regulation of chemical use, satisfaction with the environment, satisfaction with governmental involvement with the environment, and sources of water degradation – three or four attitudinal questions were included. Questions were presented in a random order in the attitudinal section of the questionnaire so that a response to one question on a given topic would be made independently of responses to closely related questions.

Potential respondents were represented by last year's group as well as a sample drawn from other farmers in the county. All of last year's 26 respondents were contacted; 16 were available to be interviewed with the new questionnaire. Dutchess County Soil and Water Conservation District, Cooperative Extension Service and Farm Service Agency offices were contacted to obtain listings of farmers. Concerns about confidentiality limited access (without a freedom of information request) to a list of dairy farmers compiled by the Extension Service. All 40 people were contacted; interviews were completed with 32. Another four interviews were done with farmers suggested by earlier respondents bringing the total to 52.

RESULTS AND DISCUSSION

Characteristics of the farms

As documented in the initial survey, farms included from the Saw Kill watershed represent a wide variety of livestock and crop operations. In addition to the 32 dairy operations there are 9 beef and 5 sheep farms. The remaining 6 farms surveyed are involved primarily with crop production, though one has eight horses and another keeps two cows and a horse.

Given the requirements of managing a dairy herd of any size, all dairy farms are full-time operations focused on making a profit. The remaining farms include full-time and part-time operations, some of which have no expectation of making a profit. The dairy farms, as shown in Table 1, tend to be larger in area and have more animals. The largest has a herd of 500 animals on 1600 acres, while the smallest dairy has 50 animals contained on a rented facility consisting of a barn and associated barnyards on four acres of land. Of necessity, this farm is one of only three that keeps the animals confined in yards. Five of the others keep only the milking cows confined, while the calves, heifers, and dry cows are pastured. Among the livestock operations, most (31 out of 46) confine some of the stock for some part of the day (e.g., milking) or at some point in the year (e.g., winter). The livestock are in the pastures the balance of the time. Only 14 of the 46 operations rotate livestock among pastures.

Where the animals spend their time is important in relation to water quality because it affects where and when manure is deposited. Rotating stock among pastures and temporarily relieving grazing pressure will usually promote more vigorous vegetative growth. This helps reduce overland transport of manure and associated pollutants during

storms. However, it often leads to higher stocking densities and more manure in a given pasture when the animals are present. Manure deposited in confined areas has to be removed at some point and is ultimately spread on each farm's own hay, crop or pasture land. The majority of the dairy farmers scrape their barnyards and spread the manure daily (Table 1). Some scrape daily or every few days but stockpile the manure to spread just before plowing. Avoiding manure spreading on frozen soil and rapid incorporation by plowing can greatly reduce the amount of manure carried off-site by overland flow. On the other hand, allowing manure to build up in yards with impervious surfaces or uncontained storage near waterways can increase contamination rates.

TABLE 1: The type and average size of farms surveyed in Dutchess County, NY, including livestock practices pertaining to pasture use, manure handling, and water supply.

Type	#	Mean area	Mean herd	Pasture use[1]				Manure handling[2]				Water sources[3]		
		acres	size	a	b	c	d	a	b	c	d	a	b	c
dairy	32	462	160	8	22	7	10	23	10	1	0	13	6	20
beef	9	82	28	0	4	5	4	0	4	1	4	2	4	3
sheep	5	263	114	0	3	2	2	0	0	5	2	0	0	5
other	6	219	N/A	0	2	0	0	0	1	0	1	0	0	2
Total	52	363	149	8	31	14	16	23	15	7	7	15	10	30

[1] a - confined in barns or yards; b - confined or pastured; c - pastured only; d - rotated between pastures
[2] a - scrape and spread daily; b - scrape frequently, spread seasonally; c - collect and spread seasonally; d - leave on fields
[3] a - stock tanks only; b - ponds or streams only; c - either, depending on availability

The extent to which livestock are in direct contact with surface water also affects potential for bacterial contamination. Fifteen farms have some or all of their animals watered at stock tanks and kept away from streams and ponds (Table 1), while 40 farms allow some or all of their animals to have access to streams and ponds.

Virtually all farms are involved in some crop production (Table 2). The exceptions are the dairy farmer on the four rented acres who buys all of his feed and two sheep farmers who use their land only for pasture and do nothing to enhance forage. Most of the crops are grown to feed livestock but some of the livestock operations include crops (e.g., sweet corn) not related to livestock support. The non-livestock farms are focused exclusively on crops – vegetables or, in one case, Christmas trees.

TABLE 2: Crops grown by each type of farm, Dutchess County, NY.

Type	Hay	Field corn	Other grains	Sweet corn	Other vegs	Large fruit	Small fruit	Xmas trees
dairy	31	30	7	3	5	1	1	1
beef	9	3	2	0	0	0	0	0
sheep	3	0	0	0	0	0	0	0
other	3	2	1	2	3	3	0	1
Total	46	35	10	5	8	4	1	2

Tillage methods and chemical use

The potential for overland flow to carry soil and contaminants into surface waters can be affected by tillage methods. Thirty-seven of the 49 farmers raising crops use full moldboard plowing some or all of the time (Table 3). Some alternate with reduced tillage techniques while others use reduced till or no till techniques exclusively. *None* of these respondents contour plow. Two do some fall plowing, a technique that can leave soil exposed to erosion all winter.

TABLE 3: Crop practices by farm type, including plowing techniques and chemical use, Dutchess County, NY.

Type	Plowing Techniques						Chemical Usage				
	full till	full & reduce	reduce	no till	contour	fall	fert. chem	fert. organ	herbi-cide	insect. chem	insect. organ
dairy	17	10	6	7	0	2	31	0	31	2	0
beef	4	2	0	1	0	0	3	0	3	1	0
sheep	0	0	0	0	0	0	0	2	0	0	0
other	2	2	0	0	0	0	6	2	5	4	0
Total	23	14	6	8	0	2	40	4	39	7	0

Six of the nine beef farmers and three of the five sheep farmers add nothing to crops or pasture to promote growth (Table 3). Two sheep farmers use only manure to fertilize hay or pasture land. The large majority (77%) of the farmers use chemical fertilizers and herbicides. However, since hay and field corn rarely have significant insect problems, there is little use of insecticides among these operations.

Characteristics

While there is considerable variability among the survey respondents, the large block of dairy farmers represents less diversity than that represented across all types of farms. Given some of the capital and knowledge barriers to starting or sustaining a dairy operation, it is not surprising to find most of these farmers are members of farm families (Table 4). A larger proportion of other farmers have more post-secondary education. However, fewer have lifelong farming involvement or farm family backgrounds. Most farmers are men, except for sheep operations, where the principals are more likely to be women.

TABLE 4: Characteristics of the farmers, including mean age, gender, level of education, prior farm experience and land tenure, Dutchess County, NY.

Type	Age[1]	Gender		Education[2]				Experience			Land Tenure		
		M	F	<12	HS	BS	Grad	none[3]	some	life	rent	bought	family
dairy	52	31	1	2	10	10	1	2	3	27	5	5	22
beef	54	9	0	0	4	5	0	1	4	4	1	3	5
sheep	52	2	3	0	2	0	3	2	1	2	0	3	2
other	48	6	0	0	1	5	0	1	3	2	0	4	2
Total	52	48	4	2	26	20	4	6	11	35	6	15	31

[1] Mean age for each group and for all respondents.
[2] Categories indicate: did not complete high school, high school diploma, college diploma, graduate degree.
[3] No prior farm experience.

Questions were included to explore the role of farm profits. While a large proportion of dairy farmers indicated their operations were frequently profitable (Table 5), a similar number felt they were rarely coming out ahead. As an aside of interest, frustrations with the prospects of making a profit in dairy farming were the most frequent comments volunteered outside of the question and answer exchange. Almost all of the dairy farmers support themselves and their families exclusively or primarily from their farm.

Profits are not only less common among beef and sheep farmers, but also are less of a concern for each family's finances (Table 5). Sheep farmers, in particular, are not in the business for the money. In light of some large herd sizes (up to 600 animals), this is a somewhat surprising circumstance. On the other hand, crop farmers in the "other"

category rely on the enterprise to support their families. While their production activities may include hay, vegetables, fruit or Christmas trees, these farmers are more like the dairy farmers in devoting their full attention to agriculture.

TABLE 5: Financial circumstances of the farmers, Dutchess County, NY.

Type	Extent of profitability				Role in family finances			
	frequent	usually	some	none	only	primary	secondary	none
dairy	13	8	10	1	18	16	2	0
beef	0	2	1	6	1	1	4	3
sheep	0	0	2	3	0	0	1	4
other	4	1	1	0	1	3	2	0
Total	17	11	14	10	20	16	9	7

Another potential determinant of farm practices comes in the form of information farmers may gain from a variety of sources and apply to their operations. Dutchess County has offices and staff for the Soil and Water Conservation District, local agents from the Cooperative Extension Service operated through Cornell University (New York's land grant institution), and agents from the Farm Services Agency (federal). All are housed in one facility and interact through some programs. Other sources of information farmers identified in last year's survey include sales representatives from agricultural supply companies, paid consultants, other farmers, educational programs of government agencies or supply companies, and a variety of farm-oriented publications.

Table 6 summarizes the relative frequency of contact with these sources by farm type. Historically, dairy farmers have had close relations with their county agents. However, many noted that agents do not come around as much as they used to unless the farmer initiates the contact. Others, especially sheep and crop farmers, will contact county offices when they encounter a problem. They also interact with other farmers and subscribe to specialized publications.

TABLE 6: Mean frequency of contact with potential sources of information for 52 farmers in Dutchess County, NY.[1]

Type	County	Extension	Sales Reps	Consultant	Other Farmers	Education Programs	Publications
dairy	2.5	2.6	2.3	1.6	2.8	1.7	2.9
beef	2.0	2.0	1.8	1.0	2.3	1.7	2.6
sheep	2.2	2.8	1.8	1.2	3.2	1.8	3.6
other	2.7	3.0	2.2	1.7	2.7	2.0	2.8
Total	2.4	2.6	2.1	1.5	2.4	1.7	2.9

[1] based on a scale of: 4 = frequently, 3 = occasionally, 2 = seldom, 1 = never

Initiatives to modify farm practices are usually implemented as opportunities for farmers to voluntarily adopt changes, accompanied at times with government cost sharing. Farmers were asked about past or prospective involvement with specific or whole farm plans, cost sharing or other direct subsidies (Table 7). Dairy farmers spoke primarily of soil conservation plans required to qualify for various subsidies; some have done more comprehensive planning. However, more than 30% are not interested in receiving government money. Among the other farmers most have been or would consider involvement in some planning activities. Again, 30% are not interested in receiving government money.

TABLE 7: Farmers' involvement with government planning and subsidies, Dutchess County, NY.

Type	Planned with government agency				Received subsidy money		
	Farm plan	Specific plan	Not yet	Not interested	Yes	Not yet	Not interested
dairy	8	17	1	6	12	10	10
beef	1	1	4	3	1	4	4
sheep	0	5	0	0	3	0	2
other	1	4	1	0	3	2	1
Total	10	27	6	9	19	16	17

Attitudes

Because attitudes about farm and environmental issues may influence behavior, and hence, farm practices, a number of questions explored this domain. Each respondent was asked to indicate a priority ranking for seven issues (Table 8). The dairy and crop farmers, more focused and dependent on profits, tend to rank overall profitability as a higher priority issue than do beef or sheep farmers. The sheep farmers hold diversity in agriculture as a higher priority issue than other farmers. Beef farmers see attracting industry to the area as a higher priority issue. The concern noted by some who ranked this issue low – that industrial growth would increase pressure for land development – may not be captured by this question. Dairy farmers do not seem as concerned as others about controlling nearby commercial and residential development. Water quality and soil erosion are both viewed as high priority issues. Beef and sheep farmers are most concerned about water quality. Dairy and crop farmers are most concerned about soil erosion. For decades, government agencies have focused more on soil conservation and flood control, with water quality being a relatively recent direct concern. The dairy farmers, at least, have a long-term connection to this perspective. It could also be a reflection of profit-oriented farmers devoting more attention to soil as part of the farm's capital than to off-site water pollution effects. Finally, supporting the viability of rural communities appears as a medium priority issue for all except sheep farmers who rated this issue a high priority. The tone of the conversations around these questions indicate that dairy farmers focus more narrowly on economic issues directly affecting their profitability. Others give more consideration to broader issues and concerns.

Table 8: Priority rankings of issues associated with farming for 52 farmers in Dutchess County, NY.[1]

Type	Farm profits	Farming diversity	Attract industry	Control develop.	Water quality	Soil erosion	Rural viability
dairy	4.8	3.4	2.9	2.8	4.3	4.3	3.6
beef	4.6	3.3	3.4	4.0	4.6	3.9	3.8
sheep	4.4	4.8	2.2	4.2	5.0	4.0	4.8
other	4.8	3.7	2.3	3.8	4.3	4.3	4.0
Total	4.7	3.6	2.4	3.9	4.3	4.1	3.6

[1] based on a scale of: 5 = high priority to 1 = low priority

Using questions developed by Halstead and others (1990), respondents were asked to rate their level of concern for water quality degradation as a threat to human health at five spatial scales: for the nation, New York State, Dutchess County, town, and their farm. They found decreasing levels of concern at local scales were associated with less environmentally friendly farm practices. In Dutchess County, the dairy farmers evidence decreasing concern the closer the issue came to their farm (Figure 2). Beef farmers approximate this progression as well. Crop farmers come close to this

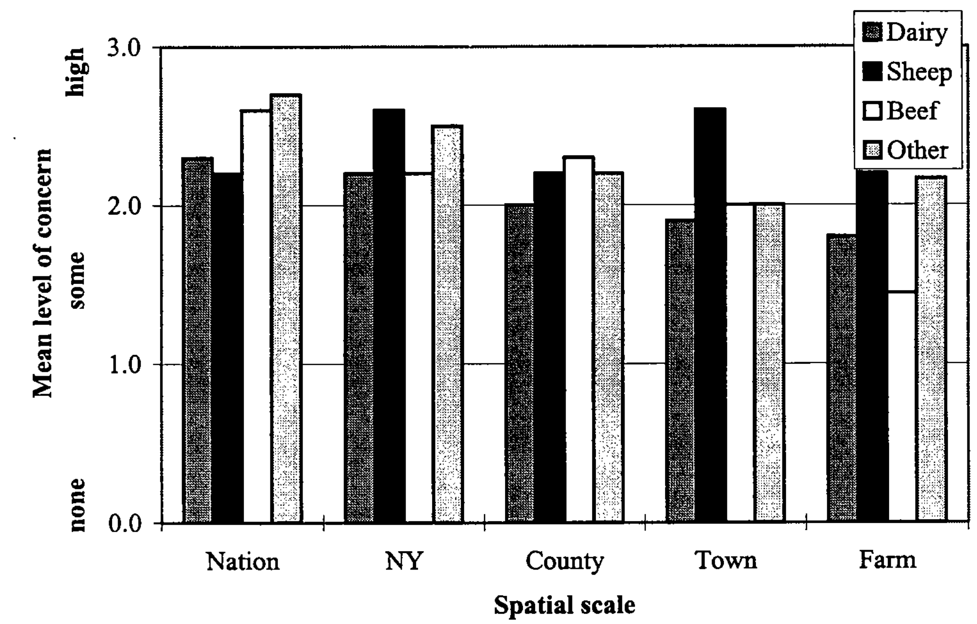

FIGURE 2: Farmers' concern about water quality by farm type, Dutchess County, NY.

pattern but the rise in concern on their farm may reflect a higher sensitivity in association with more active use of pesticides. Interestingly, sheep farmers do not display a pattern of concern based on locale. This may simply be a function of the small (n=5) sample size.

The questionnaire also asked for the level of agreement or disagreement with a variety of statements about agriculture and the environment. Several dealt with agricultural chemical use or economic issues associated with regulating chemicals. Some of the questions presented the perspective that chemicals were not necessarily a threat or that regulation of chemical use was burdensome. As Figure 3 indicates, beef and sheep farmers are less supportive of these positions than dairy and crop farmers. The latter groups, more likely to be using agricultural chemicals, tend to see their use as not being a threat when used as directed. While none of the groups openly support relaxing regulatory standards to promote economic growth, dairy and crop farmers clearly want to devote more attention to other problems and less to chemicals.

When presented with statements indicating water quality problems were limited to livestock farming, crop farming, or commercial and residential development (categories drawn from 1996 responses), the four groups present a uniform front (Figure 4). *All disagree that livestock was a source, are ambivalent about crops as a source, and agree with development as a source.*

Given the substantial reliance on voluntary participation by farmers in watershed management programs, a question was included about the sufficiency of this approach: "Voluntary response will provide sufficient response for any water quality problems. More regulation is not required." On average, there is slight disagreement with this for dairy, beef and crop farmers, -0.44 to -0.56, while sheep farmers disagree more strongly at -1.60.

Satisfaction scales

Finally, the four question sets developed to produce indices of satisfaction with environmental conditions and government involvement were aggregated to generate a cumulative score for each respondent. While the score could range from -12 to +12, and

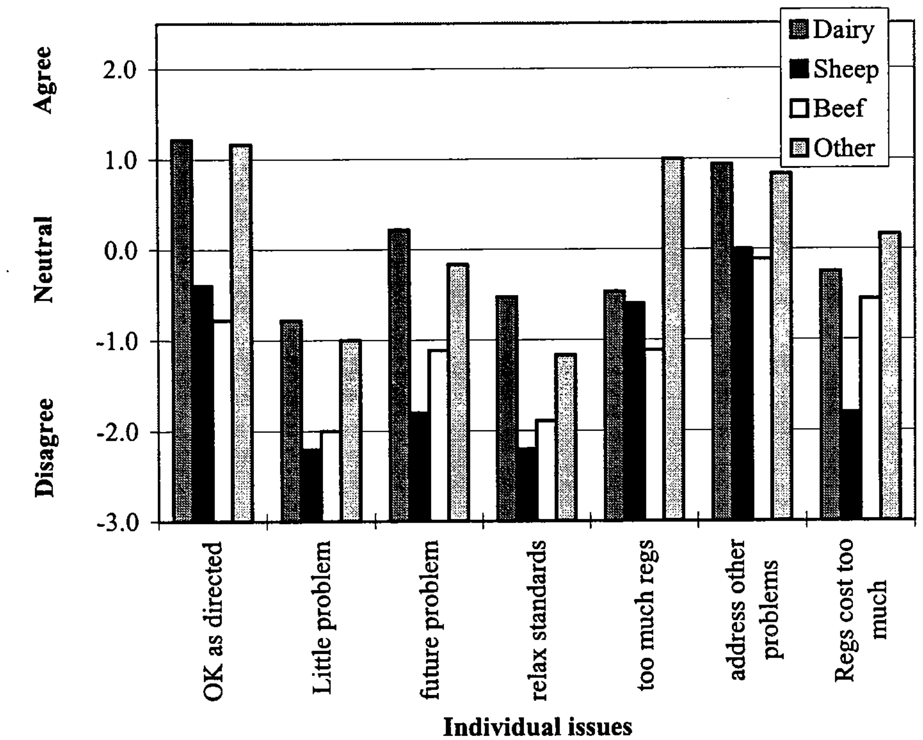

FIGURE 3: Agricultural chemical issues for 52 farmers in Dutchess County, NY.

did range from -10 to +9 for individual respondents, the mean scores are not that extreme. On the environmental satisfaction scale, crop farmers score the highest at 3.7, followed by dairy farmers at 2.5, beef farmers at 1.7, and sheep farmers showing slight dissatisfaction at -0.8. The government satisfaction scale tends to be lower with crop farmers at 2.7, dairy farmers at 1.4, sheep farmers at 1.0, and beef farmers at -1.4. Unsolicited side comments offered in association with government involvement questions provide some indication that dissatisfaction is often not with government effectiveness in addressing environmental concerns but the government's pattern of involvement with

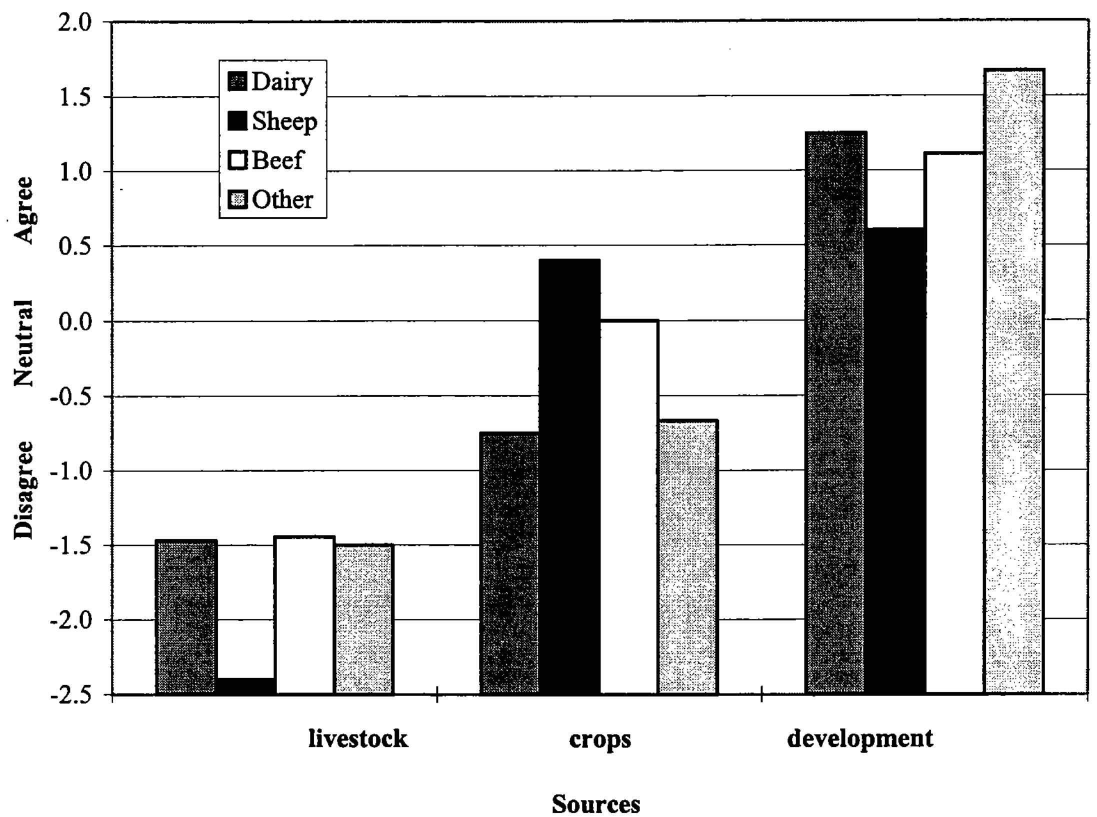

FIGURE 4: Farmers' opinion of predominant source of water quality problems, Dutchess County, NY.

the farmers' affairs. It was common for the statement – "In most ways, the quality of the government's environmental programs is very good." – to prompt expressions of disagreement based on frustration with pesticide regulations requiring substantial work for licensing and use reports.

Overall trends and connections

Reviewing the preceding characteristics and attitudes of the farmers and their farms indicates some patterns. Dairy farmers in Dutchess County are likely to be operating larger areas and herds than others. Most have their animals confined at some times and in pastures at other farms. They are scraping and spreading manure frequently. Almost all are raising hay and corn with additions of fertilizer and herbicides. They are, for the most part, lifetime farmers working on the family farm with at least a high school education. They rely primarily on the farm for financial support of their families, but up to a third feel profits are hard to come by. While we have a smaller sample of other types of farmers in Dutchess County, some characteristics are noteworthy. They typically have more formal education but are less likely to be lifetime farmers working family farms. Sheep and beef farmers generally have smaller herds at lower densities. They are much less likely to be raising crops (other than hay) and rarely use fertilizers or pesticides. They also are less likely to be making a profit. However, their farms play a reduced role in their families' finances. Crop farmers are more likely to be supporting their families with intensive operations using chemical inputs to maximize profits.

Farmers typically have some involvement with staff at the county offices and interact with each other in regard to their operations. They also receive various agricultural publications. The more commercially-oriented dairy and crop farmers are more likely to interact with sales representatives from farm supply companies. Among all farmers, two thirds have done some planning with government agencies. An almost equal

equal number have not received any government subsidies. Half of the latter group is simply not interested in receiving government financial support.

More farmers are satisfied with current environmental conditions, though beef farmers are less satisfied than dairy or crop farmers. Sheep farmers tend to be the least satisfied. *None* of them regard livestock as the primary source of water quality degradation, but beef and sheep farmers waiver about crops as a major source. *All* see development as a major source of problems, with dairy and crop farmers asserting this view somewhat more adamantly than others. While few farmers would dismiss the potential threat of agricultural chemicals, dairy and crop farmers regard it more as a problem for the future and feel that following label instructions will be sufficient. They also are more likely than beef or sheep farmers to favor focusing on other problems of farming (e.g., economic) and to assert regulation of agricultural chemicals has been excessive and costly. Overall, farmers are confident that voluntary approaches will adequately address any farm related environmental problems.

Regression analysis of responses does not convincingly link a farmer's background or type of activity to their concern for environmental problems or support for active management of those problems. Nor does satisfaction with the environment or concern for water quality relate to use of agricultural chemicals, conservation tillage, or animal waste management.

Several interesting and statistically significant correlations emerge from our survey results. Reduced concern about agricultural chemical use is positively correlated (r^2=0.40 for all farms; r^2=0.40 dairy farms only) with farm area. Similarly, reduced concern about agricultural chemical use is positively correlated (r^2=0.43 for all farms;

r^2=0.49 dairy farms only) with herd size. Perceptions about the sufficiency of voluntary programs parallel these trends showing positive correlations with farm area (r^2=0.41 for all farms; r^2=0.50 dairy farms only) and herd size (r^2=0.28 for all farms; r^2=0.43 dairy farms only). The level of concern among dairy farmers about water quality on their farm is positively correlated with years of education (r^2=0.41) and level of agricultural education (r^2=0.49). Concern about erosion is strongly correlated with frequency of government agency contact (r^2=0.63 for all farms; r^2=0.65 dairy farms only). This favorably reflects the long history and consistent message of soil conservation programs. By contrast, now that government agencies are placing more emphasis on water quality management fewer farmers regard them as a source of solutions (r^2=0.08 for all farms; r^2=0.19 dairy farms only).

SUMMARY

Clear associations between background factors and prevailing attitudes may be difficult to establish largely because of inherent variability. Stratifying farmers by farm type may reveal some differences. Our survey results indicate farmers running large, full-time, commercial operations – essentially dairy and crop farmers – may have different attitudes toward environmental issues, when compared to smaller scale, part-time, or not-for-profit farmers. This could significantly affect how they respond to structural changes implemented to promote preferred farm practices. Increasing the number of respondents in each farm type category may strengthen conclusions about possible differences (Babbie 1973). However, we expect substantial variation will remain within each category. Sampling a larger number of dairy farmers than our initial effort (Pinney and Barten 1997) did not substantially increase observable associations between background or structural factors and attitudes. Returning to an example highlighted in our 1996 study, two dairy farmers offer an interesting contrast. Each is about forty years old and operates the family farm. One farmer indicates more concern about water quality, agricultural chemical safety, and effectiveness of voluntary programs. The other is less concerned about these issues and more concerned about the economic burden of government regulation. The principal difference in their backgrounds is formal education. The former completed a college program in agriculture while the latter finished high school but did not attend college. But if this example clearly explained differences in attitudes, we would expect to see a stronger association between education – especially agricultural education – and attitudes than was existed for the entire sample.

The ability to elucidate stronger connections, while limited by what may be inherent variability among the subjects, could be enhanced by further refining the survey approach. Efforts this year to code responses as integer scores made statistical analysis more straightforward. However, categorization of responses may not completely represent the individual ideas and opinions. *We conclude a combination of quantifiable data and more subjective responses may facilitate statistical analyses that capture some important distinctions between individuals and groups*. There is every appearance that individual attitudinal distinctions affect how farmers respond to required regulations or voluntary initiatives that promote more environmentally friendly practices.

Research, education and subsidies have, over a period of several decades of direct interaction with farmers, led to substantial reductions in soil erosion. However our

survey results indicate a weak or non-existent association between farmers and government agencies wit respect to other water quality issues (e.g., pesticides, pathogens, and development versus agricultural effects). The potential impact of voluntary programs is diminished further when, at present, one third of farmers do not use agency technical support and would not accept subsidies. New and creative approaches to education, outreach, and technical support, designed in light of an accurate depiction of farmer attitudes and preferences, are needed to sustain improvements in watershed management.

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We gratefully acknowledge the support of the Tibor T. Polgar Fellowship Program and the Hudson River Foundation for Science and Environmental Research. We received valuable assistance from the staff at the Dutchess County Soil and Water Conservation District and at the Dutchess County Cornell Cooperative Extension office. The Hudson River National Estuarine Research Reserve provided important support. And finally, we thank all of the farmers who so willingly shared their time and ideas.

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THE NEW YORK/NEW JERSEY HARBOR DREDGING CONFLICT

A Final Report of the Tibor T. Polgar Fellowship Program

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ABSTRACT

Dredging projects can become stalled for several reasons, including interagency conflicts, inadequate dredged material management, insufficient information, and inconsistent funding. New York/New Jersey Harbor recently experienced stalled dredging projects. As New York/New Jersey Harbor's original depth, before dredging, was 18 feet, dredging is a necessity since today's tankers have a draft of 40-45 feet. In 1996, dredged material volume projections for the port were approximately five million cubic yards. Until the 1972 Marine Protection, Research, and Sanctuaries Act, the Army Corps of Engineers (COE) dumped most of the port's dredged material into the open ocean. After passage of this Act, the COE began to use an area called the Mud Dump, located about six miles east of the New Jersey Shore. Environmental regulations required any material destined for the Mud Dump to pass a toxicity test. In 1992, the EPA revised the test and found that instead of a five percent failure rate, they now had a sixty-six percent failure rate. Since material that failed the test could not be placed at the Mud Dump, new disposal options were needed for huge quantities of material. The new more sensitive test and the increased volume of contaminated material that had to be disposed of led to a conflict that resulted in a deadlock. It is my opinion that the main reasons for the dredging conflict were public misperception of the issue, fear of litigation on the part of policy makers, and failure to plan. Most important to preventing a reoccurrence are finding acceptable alternatives for disposal, decreasing sediment decontamination, and decreasing sediment loading.

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INTRODUCTION

This paper presents the results of a research project about the public policy aspects of the dredging conflict that occurred in the Port of New York and New Jersey between 1992 and 1996. The conflict came to a head in 1992, when it was proposed that the Mud Dump, located approximately six miles east of the New Jersey shore, should be closed and the Environmental Protection Agency (EPA) changed its testing standards for dredged material and the majority of dredged sediments were prohibited from being ocean dumped (Table 1). Suddenly, there was no place to dispose of dredged material and siltation buildup began in the port.

Ports play an essential role in the U.S. economy, defense, and environment. About ninety-five percent of imports and exports coming into the country have to pass through U.S. ports. In 1992, U.S. ports handled approximately 2.9 billion metric tons of cargo and supported over 15 million jobs (IWGDP 1994) Locally, the maritime industry of the New York/New Jersey (NY/NJ) region is a vital part of the economy, providing twenty billion dollars in annual revenue and supporting almost 170,000 jobs (New York Times 1996). Foreign trade makes up an important percentage of the Gross Domestic Product and is expected to grow in the future. Ports are important to defense for military navigation. Ports are strongly related to the environment in that they often are located in or near important wetlands, estuaries and fisheries (IWGDP 1994).

Until 1824, any port projects were carried out and paid for by state and local governments. In 1824, the General Survey Act passed and allowed Congress to make the first appropriations for port projects. Proposals and requests for funding had to be submitted by the Army Corps of Engineers (COE) to Congress, who approved each project individually and granted funding on a year to year basis. The use of year to year funding meant that even if a project got approved, the funding could dry up before the project was completed. Therefore, the success of a project could depend on how skilled the local Congressman was at getting appropriations for his district. (Marine Board 1985).

Starting in the early 1970s, Congress had trouble getting port projects approved for several reasons including: public concern with environmental consequences of construction projects, the increasing budget deficit, and changes in public attitudes toward federal public works projects. As environmental concerns became stronger, the COE assumed responsibility for assessing the environmental consequences of port projects. Citizens groups and state and federal agencies with environmental regulatory responsibilities also became involved in the decision making process, making it more complicated, time consuming, and expensive to get a project approved. The concern with reducing the budget deficit caused trade-offs to be made over which federal projects received funding. The public demand for decreases in big government also decreased opportunities for federal projects to be approved. Thus, these three issues, the case by case Congressional approval for projects, the annual funding appropriations, and the lack of national policy for port projects created a situation where there was no framework for prioritizing projects. (Marine Board 1985).

There are two types of dredging projects, federal and local. Federal projects are paid for by Congressional appropriations and carried out by the COE. Federal projects

generally involve construction and maintenance of major access channels. Local projects do not receive federal funding. They generally involve berths, minor channels, and landfill projects. Local projects are subject to regulatory review by the COE and the states (Marine Board 1985). Every year the COE dredges and disposes of approximately 300 million cubic yards of dredge material nationwide. An additional 100 million cubic yards is dredged by local permit holders. Though the COE issues the permits for local projects, the Environmental Protection Agency (EPA) develops the environmental criteria used by the COE to evaluate the permit applicants. (IWGDP 1994).

The Problem

As stated earlier, dredging projects can become stalled for several reasons. Interagency conflicts, inadequate dredged material management, insufficient information, and inconsistent funding are some of the additional causes for stalled projects. (IWGDP 1994). New York/New Jersey Harbor recently had a problem with stalled dredging projects. In its natural state, NY/NJ Harbor is 18 feet deep. Thus, dredging of channels and berths is a necessity because today's ships need drafts of at least 40 feet, and 45 feet will be the norm in the future. In 1996, dredged material volume projections for the Port of New York and New Jersey were approximately five million cubic yards (United States Army Corps of Engineers 1996).

Until the 1972 Ocean Dumping Act, the COE dumped most of NY Harbor's dredged material into the open ocean. After the Ocean Dumping Act, the COE started putting the dredged material in an area called the Mud Dump, located about six miles east of the New Jersey shore. Environmental regulations enacted in 1977 required any material destined for the Mud Dump to pass a toxicity test, referred to as the 'hard shell clam test.' This test involved placing some hard shell clams in a sample of dredged material for a specific amount of time and if they lived, the dredged material passed the test. If the clams died, it meant the dredged material was contaminated and had to be specially processed or dumped elsewhere. Using the 'hard shell clam test', about five percent of dredged material was deemed contaminated. In 1992, the EPA revised the test, and began requiring the use of more sensitive bottom dwelling organisms. Sixty-six percent of the dredged material failed the new, more sensitive test. More specifically, fourteen percent of dredged material was Category I, meaning it could be placed in the open ocean or on sandy beaches, twenty percent was Category II, meaning it could be dumped in the ocean if covered with clean material, and sixty-six percent was Category III, meaning it had to be placed in a confined area or treated (Munson 1996).

The new, more sensitive test and the increased volume of contaminated material to be disposed of, led to a conflict that resulted in a dredging deadlock in the NY/NJ Harbor. The White House attempted to resolve this deadlock in the summer of 1996, when it released a plan that allowed for continued use of the Mud Dump until September of 1997. However, this plan was rejected by Governors Pataki and Whitman, who were not consulted during any stage of the planning process (Munson 1996).

In October of 1996, the two Governors released their own plan, which called for the dredging of five million cubic yards of dredged material and is partly based on the White House plan with input from environmental groups (Office of Governor News

Release, October 7, 1996). The plan that Governors Whitman and Pataki have agreed to is essential to breaking up the three year dredging deadlock (Revkin 1996). The agreement, which is a partnership between New York, New Jersey, New York City, the federal government, and the Port Authority of New York and New Jersey (PANY/NJ) builds on a federal plan which clarified environmental testing procedures, streamlined the federal dredging permit issue process, and set a deadline of September 1, 1997 for ending the dumping of contaminated materials at the traditional dumping area near Sandy Hook, New Jersey (the Mud Dump; Table 1).

The Goal of the Project

The goal of this project was to analyze why the three year dredging deadlock occurred, the policy makers' solution to the deadlock, and steps taken to prevent a reoccurrence of the situation, from a public policy perspective. In order to reach this goal, several research questions were formulated. First, what are the underlying reasons for conflict in this issue? What is lacking institutionally that allowed the situation to get to the point that it did without resolution? Second, what is the current plan for the harbor? Is it being fully implemented? Is it moving quickly enough? What are the barriers and constraints to full implementation? What are the strengths and weaknesses of the plan? Third, will future problems and deadlocks be prevented, and if so, how? What will prevent a similar type of situation from occurring in the future? Finally, what lessons have been learned that are applicable to similar types of conflicts?

Possible causes for the dredging deadlock include a lack of regulatory framework, interagency and intergovernmental conflict, involvement of environmental groups, and lack of economically and technologically feasible disposal alternatives.

Table 1: Summary of activities leading to dredging deadlock and release of NY/NJ Bistate Agreement.

Year	**Activity**
Prior to 1977	Most dredged material dumped in the open ocean
1972	Passage of Ocean Dumping Act leads to use of Mud Dump
1977	EPA promulgates Ocean Dumping Act regulations and criteria
1992	Revised toxicity test for dredged material, closure of mud dump
1992 - 1996	No dredging, port loses business
Summer 1996	White House releases plan to break dredging deadlock, plan is not supported by Governors of NY and NJ
October 1996	Governors Pataki and Whitman release a bistate dredge plan, Mud Dump will remain in use for 1 year

METHODS

To carry out this research, interviews were conducted with representatives from the following organizations: New York Shipping Association, NYC Economic Development Corporation (EDC), Empire State Development Corporation (ESDC), New Jersey Department of Commerce and Economic Development, New Jersey Department of Environmental Protection (DEP), Environmental Protection Agency (EPA), Army Corps of Engineers (COE), Port Authority of New York/New Jersey, Coalition for the Bight, American Littoral Society, and Clean Ocean Action. The Hudson River Foundation provided essential background material.

Primary documents were analyzed, including the Hudson River Estuary Management Action Plan, the Joint Dredging Plan for the Port of New York and New Jersey (NY/NJ Bistate Agreement), and the Dredged Material Management Plan for the Port of New York and New Jersey Interim Report.

RESULTS

Tables 2 through 6 present the abbreviated responses to the interview questions asked of the representatives of the organizations listed in the Methods section. The interviewees have been divided into four groups: maritime companies (shippers) and economic interests, regulators, the Port Authority and environmentalists. The New York Shipping Association, EDC, ESDC, and the New Jersey Department of Commerce and Economic Development form the first group. The second group is composed of the

NJDEP, EPA, and COE. The third group is composed of representatives from the Port Authority. The fourth group includes Coalition for the Bight, American Littoral Society, and Clean Ocean Action. The numbers in parenthesis after the headings in the tables represent how many people answered the question. The interview questions are located in the Appendix.

Table 2 presents the responses to the interview question 'How would you describe the state of the New York/New Jersey Harbor dredging issue currently?' Answers range from stalemate to chaos to progress. Each person has a different perspective, which may reflect their agencies' goals or the wishes of their different constituencies.

Reasons for the conflict include the port's lack of visibility, the public misperception of the dangers of dredged material on land, a failure to plan for the consequences of closing the Mud Dump, an assumption that ocean dumping would always be available, and lack of political will (Table 3).

Table 4 asks the question 'Why did a solution take so long to develop?' Fear of litigation is one answer that was also mentioned as a reason for the conflict (Table 3). Other answers included bulkiness of the government process, lack of communication, lack of a clear leader, and lack of political will.

Table 5 presents the combined results of interview questions 6 and 9. In order to ensure necessary dredging in the future, it is essential to decrease sediment loading and decrease sediment contamination. Three out of four groups (Shippers, Regulators, and Environmentalists) stated long term pollution prevention as a necessity.

Table 2: How would you describe the state of the NY/NJ Harbor dredging issue currently?

SHIPPERS/ECONOMIC(4)	REGULATORS (4)
Significant dredging is occurring for the first time in four years	Chaos, politicized to the point where decisions aren't being made on a scientific basis, its hard for the port to be competitive
There has been progress in the last year, but we still have a long way to go	Back on track, controversy and conflicts are on a path to being resolved; political will is lacking, along with money and disposal options
The situation cannot get any worse	Chaotic, no overall coordination or direction; politics are a factor; its hard to get a decision made
In good shape; has come a long way but still need regional consensus	We are making a lot of progress, we have the plan and are taking steps forward
PORT AUTHORITY (2)	**ENVIRONMENTALISTS (3)**
Best since 1994	We are at a stalemate, the White House closed the Mud Dump too quickly
There are several issues that must be resolved and the port authority must take the lead	Extraordinary progress has been made; the approach being taken is very integrated
	Up in the air

Table 3: What are the reasons for conflicts in this issue?

SHIPPERS/ECONOMIC(4)	REGULATORS (4)
Public perception; lack of visibility of the port; single issue groups; shutting down the Mud Dump without a replacement Each group tries to get optimal results for itself, which results in suboptimal results for society; there is no framework for resolution; any action can be stopped by going to court Imbalance of concern resulting from a vulnerability to the legal system Failure to plan, everything was ad hoc until the crisis; people expect government to do everything for the them all the time; no one aspect of the port community took charge	Political gridlock; environmental advocates working outside the system Strong support for the beaches and environment in New Jersey; no political will to make a decision about where to place dredge Its a NIMBY issue; public misperception The issue has grown very quickly and as environmental regulations became stricter the issue came to a head
PORT AUTHORITY (2)	**ENVIRONMENTALISTS (3)**
Confrontational attitudes; litigation instead of consensus building Shippers versus fisherman; badly put together regulatory system; political issues; lack of coordination between agencies	Political problems; fear of litigation; personal agendas coming before the good of the port Assumption that there would always be ocean dumping Dumping was a cheap, easy solution and rules changed without preparation

Table 4: Why did a solution take so long to develop?

SHIPPERS/ECONOMIC (4)	REGULATORS (3)
The rules keep changing, there is no solution Bulkiness of the government process; single issue groups; the permit process The issues keep changing and at the same time, science is also changing; its a complex market; there are many political levels to deal with Lack of communication between agencies	Fear of litigation; there is no one solution, in the long term, there will have to be a group of solutions There is no one solution Same as reasons for the conflict-lack of awareness of the issue
PORT AUTHORITY (2)	**ENVIRONMENTALISTS (3)**
People don't know how to work together; people used to not having to worry about the dredging situation No one took the lead	Lack of political will Not easy to find alternatives because of the volume of material and the population density of the area Resistance to change; reliance on ocean dumping in the past

Table 5: What will it take to ensure necessary dredging in the future/is the current solution likely to "stick"?

SHIPPERS/ECONOMIC (4)	REGULATORS (4)
Quicker action is needed	Decreased sediment loading and contamination; take care of Superfund sites; decreased non point source pollution
Consensus; an action program that is binding and credible, need to be able to take action without fear of litigation; all groups have to make concessions	An alternative to disposal, proper funding; assurances for shippers
Clean up the pollution; use of confined ocean disposal	Funding; alternatives with enough volume
All agencies have to agree on a direction for the future	The proper balance of options
PORT AUTHORITY (2)	**ENVIRONMENTALISTS (3)**
It needs to become a self sustaining process; a decision about the desired utility of the port has to be made; the value of the port will drive a vision for the port and allow a long term solution	Need pollution clean up and sediment decontamination
	Long term pollution prevention
Need feasible disposal capacity; people have to decide the port is in the region's best interest	Reduce volume of dredged material; expedite implementation of existing decontamination technology; implement pollution prevention; clean up Superfund sites

Table 6 shows the biggest remaining problems include: public education, finding acceptable alternatives, implementation, and lack of time for the future of the port to be decided, as the shipper's leases are coming up for renewal.

Table 6: What are the biggest remaining problems?

SHIPPERS/ECONOMIC (4)	REGULATORS (4)
Making sure dredging needs are met	Public education; more scientific basis for the regulatory decisions that are made
Education; achievement of bipartisan support to remove the issue from its politicized existence	Finding alternatives; getting communities to accept a facility
Costly alternatives	Getting the framework worked out for making decisions; getting accurate information to the public; basing decisions on accurate scientific information
Agencies reaching consensus; public perception; keeping everyone talking	Implementing the chosen alternatives; getting the long term alternatives into place
PORT AUTHORITY (2)	**ENVIRONMENTALISTS (3)**
Time, because the shipper's leases are due soon	Consensus on the future of the port; willingness to compromise; public misperception
Dredge disposal capacity; making the decision about the future of the port	Getting regulatory agencies to use better science
	Reducing pollution

While there is no single solution to the dredging conflict, we can look to the *Joint Dredging Plan for the Port of New York and New Jersey* (*Bistate Agreement*) as a foundation or starting point towards resolution. The fundamental principles for dredged material management as stated in the *Bistate Agreement* are to utilize the most economically and ecologically efficient management and disposal options. The specific objectives of the *Bistate Agreement* are to strengthen the economic vitality of the port, to take a coordinated approach to dredged material management in the region, to identify short and long term disposal requirements and options, to eliminate contaminants at the source, and to remediate contaminated material. In order to facilitate the dredging process, permit advance teams have been created to conduct preapplication meetings with applicants. The purpose of the meetings is to identify disposal options and testing requirements in order to increase efficiency and cost effectiveness for the permit applicants. The teams are composed of representatives from the EPA, COE, NJ DEP and NY Department of Environmental Conservation.

In the *Bistate Agreement*, the states commit to several short term initiatives (Table 7). Long term initiatives committed to by the states are shown in Table 8.

Table 7: Short term initiatives agreed to by New York and New Jersey (*Bistate Agreement*).

Construction of nearshore and upland demonstration projects
Development of confined disposal facilities
Investigation of new technology to contain material in confined disposal sites
Development of beneficial use projects
Development of transportation projects using dredge material
Use of decontamination technology
Development of consistent regulatory policies between the states
Working with Congress to insure appropriate federal actions are taken

Table 8: Long term initiatives agreed to by New York and New Jersey (*Bistate Agreement*).

Funding the recommendations in the Comprehensive Conservation and Management Plan
Implementation and enforcement of combined sewer overflow abatement controls
Additional studies of highly contaminated sediment
Pursuit of recovery of damages
Development of a large, long term capacity containment facility
Sponsorship of the Hub Port Study
Studies to increase knowledge of characterization of sediments, in order to make valid scientific and regulatory decisions

DISCUSSION

The diversity of answers in Table 2 shows that although a group of people serve on the same committees and have access to the same information, they can have vastly different perceptions of a situation. As stated by Cicin-Sain (1992), when different agencies are involved with an issue, conflicts can occur because the agencies carry out different missions; have different modes of action; and respond to different constituencies. This can explain why one person thinks the current state of the harbor is in chaos and another thinks it is in good shape.

Based on the responses from the interviewees, the main reasons for the dredging conflict appear to be public perception of dredge disposal, fear of litigation and failure to plan (Table 3). Complicating the disposal of dredged material is the lack of understanding of the issue by the general public. This lack of understanding impacts negatively on community acceptance of disposal alternatives. Those who are aware of the issue often confuse dredged material disposal with disposal of garbage, sewage sludge, and medical waste (Birgeles 1993). The COE has proposed many alternatives for dredged material disposal which are met with fear, suspicion and hostility by the public (Revkin 1997a). As evidenced in Table 6, public education is sorely needed to counter this problem. It has been stated that one of the reasons why the deadlock occurred was because regulators were slow to act out of fear of litigation by environmental groups. In fact, a lawsuit was filed by local environmental groups and fishermen to stop dredging under a permit issued for Port Elizabeth/Newark (Wahrman 1996). The threat that a lawsuit can be filed every time a permit is issued can pose a large deterrent to taking

action. Closing the Mud Dump without an alternative way to dispose of the dredged material also had ramifications. To keep from repeating past mistakes, and in an effort to reassure shipping companies that New York and New Jersey are committed to keeping the port open, the Port Authority has budgeted $1.2 million for a plan to revitalize wharves in Brooklyn and Bayonne (Revkin 1997c). The goal of the plan is to determine how the states can maximize economic benefit from investments in new wharf space, cargo handling equipment, and road and rail lines (Revkin 1997c).

In an important step toward cleaning up pollution, which is necessary to ensure dredging projects run smoothly in the future and the current solution holds (Table 5), New York State has joined a federal effort to determine the costs of environmental damage to the Hudson River from toxic chemicals (Revkin 1997b). Under the federal Superfund law, compensation could be sought for damages to the river. New York state's participation in the investigation is important because when the individual state joins the federal effort, a broader array of environmental damages can be assessed under the law (Revkin 1997b).

As shown in Table 6, finding acceptable alternatives for disposal is essential. In the continuing effort to find a place to dispose dredged material, New York, New Jersey, and Pennsylvania have recently agreed to use mud dredged from the port to seal abandoned coal mines in Pennsylvania (Revkin 1997d). A pilot project is underway, testing 500,000 tons of mud. If the pilot project is successful, it could lead to a win-win situation for the three states, as there are more than 9,000 abandoned mine areas in Pennsylvania.

By comparing the *Bistate Agreement* and other efforts toward solving the dredging conflict to the *Report to the Secretary of Transportation, the Dredging Process in the*

United States: An Action Plan for Improvement (The Interagency Working Group on the Dredging Process 1994) an evaluation of attempts to resolve the port conflict can be made. The *Report to the Secretary of Transportation* (IWGDP 1994) states several problems that can occur during the dredging process and then goes on to make recommendations to resolve those problems.

The Port of NY/NJ was affected by several problems that also occur nationwide, which involve the planning process (IWGDP 1994). These problem were: inadequate early planning at all levels, as the port functioned in an ad hoc manner; inadequate communication and coordination; planning decisions based on incomplete analysis of the effects of the plan; long term planning not linked with broader watershed management; and port dredging and dredged material management not linked with landside transportation system planning.

To resolve these problems, four recommendations were suggested in the *Report to the Secretary of Transportation* (IWGDP 1994). The recommendations were: ensure that the planning process reflects the mix of environmental, political, and economic circumstances of the region; make planning strategies flexible to integrate new science and technology; have regional and local planning interests develop direct mechanisms for early coordination and advanced planning for dredging activities; and broaden public participation to ensure widespread understanding of the issues including, the role of the port, the availability of options, and the risks of those options.

Applying these recommendations to the Port of NY/NJ, there has been a great effort to reflect the mix of environmental, political, and economic circumstances in the

planning process, for example, the Dredged Material Management Interagency Working Group (DMMIWG) has broad representation, strategies are flexible, and the *Bistate Agreement* deals with decontamination technology (Tables 7 and 8). The lack of early coordination and advanced planning is part of the cause of the conflict and efforts are being made now to avoid a repeat in the future (Tables 7 and 8). There is every opportunity for public participation, but understanding of the issues is lacking and needs improvement (Table 6).

The Port of NY/NJ was also affected by two other problems listed in the *Report to the Secretary of Transportation* (IWGDP 1994). One problem was that for many projects, the dredging approval process takes too long and is unpredictable. The permit process was a factor in the dredging conflict (Table 4). To resolve this problem, the recommendation suggested in the *Report to the Secretary of Transportation* (IWGDP 1994) was to improve and coordinate dredging policies and planning and expand information sharing. The *Bistate Agreement* did create permit advance teams for this purpose.

The last problem discussed in the *Report to the Secretary of Transportation* (IWGDP 1994) that affected the Port of NY/NJ was dredging results in large quantities of material that has to be disposed of in an environmentally sound manner. Four recommendations were offered: minimize uncertainties to make better management decisions; improve guidance used to evaluate bioaccumulation of contaminants from dredged materials; identify barriers to managing contaminated material and ways to overcome the barriers; and identify ways to reduce the volume of material that has to be dredged. Applying these recommendations to the Port of NY/NJ, the *Bistate Agreement* does call for studies to clarify understanding of scientific issues and guidance used to evaluate bioaccumulation of contaminants from dredged materials (Table 8). The *COE Interim Report* comprehensively lists all the alternatives for disposal of dredged materials. The *Bistate Agreement* calls for design and implementation of projects to handle and reduce dredged material (Tables 7 and 8).

CONCLUSIONS

At the outset of the project, it was thought that possible causes for the dredging deadlock, or conflict could include a lack of regulatory framework, interagency and intergovernmental conflict, involvement of environmental groups and lack of economically and technologically feasible disposal alternatives. But, as stated earlier, based on the interviews, the main reasons for the dredging conflict appear to be public perception, fear of litigation and failure to plan. Thus, lack of regulatory framework and interagency and intergovernmental conflict were not factors that contributed to the conflict. Also, it was not the lack of available economically and technologically feasible disposal alternatives as much as a NIMBY (Not In My Back Yard) attitude on the part of many communities to the available alternatives. As for lessons learned, it is obvious that a well thought out, agreed upon plan is needed before action is taken and that environmental concerns cannot be dismissed or ignored for that plan to be successful.

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APPENDIX

Interview Questions:

1. How are you involved with this issue?

2. How would you describe the state of the NY/NJ Harbor dredging issue right now?

3. What are the reasons for conflict in this issue?

4. What is your institution's (fill in appropriate institution) relationship with the other agencies/groups that you work with?

    Prompt (if necessary): Did you create any new processes with -----?

    Prompt: Do you have any difficulties working with -----?

5. Why do you think a solution took four years to develop?

6. What will it take to ensure that necessary channel dredging continues in the future?

7. What has been solved with the plan?

8. What are the biggest remaining problems?

9. Is the current solution likely to "stick" (continue over the long term)?

ASSESSING THE EFFECTS OF LAND USE ON WATER QUALITY AND BIOTIC INTEGRITY IN THE SAW KILL (RED HOOK, NY) USING TWO MACROINVERTEBRATE INDICES AND CHEMICAL DATA

A Final Report of the Tibor T. Polgar Fellowship Program

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ABSTRACT

Chemical studies have been the focus for determining water quality, but biological considerations are also becoming a more integral part of assessing aquatic ecosystems. Here, two biotic indices were calculated and compared with chemical data and correlated to land use that occurs in the Saw Kill watershed. The two macroinvertebrate indices used were the New York State Department of Environmental Conservation's Biological Assessment Profile and the Ohio Environmental Protection Agency's Invertebrate Community Index. Chemical data (nitrates, phosphates, sulfates, and chlorides) were collected by personnel of the Hudson River National Estuarine Research Reserve (HRNERR) from June, 1991 to December, 1994. In summer of 1997, macroinvertebrate collections were taken at or near the same stations monitored by HRNERR, with the addition of two mainstem stations. In September 1997, surface waters at these sites were analyzed for nitrate, phosphate, sulfate, chloride, and seston. Chemical water tests and the indices did not significantly correlate, but there was correlation between the two indices. The macroinvertebrate indices suggested residential land use degraded water quality and biotic integrity more than any other land use. Comparison of the costs of the two biological methods suggested the New York State method to be most efficient and effective. The use of both chemical and biological methods and the analysis and comparison of these methods, to each other and land use, is recommended to serve as a model for assessing water quality in streams and rivers.

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INTRODUCTION

The Clean Water Act has brought about goals for national " ... restoration and protection of freshwater ecosystems..." (Davis and Simon 1995). Bode (1989) stated that the purpose of the Water Pollution Control Act, Section 101(a) is "...to restore and maintain physical, chemical, and biological integrity of the Nation's waters." Often it is assumed that aquatic ecosystems and thus biotic integrity, are protected when chemical contaminants are regulated or prevented from entering the system (Karr 1995). Yet, chemical monitoring cannot always detect all of the anthropogenic sources of pollution (Karr 1981). It has been suggested that biological monitoring of fresh water is a more comprehensive mechanism for measuring the integrity of a stream or river (Keller 1995). Simpson and Bode (1980) maintain that biological integrity cannot be sufficiently evaluated without accurate identification of the aquatic inhabitants. Since it has been suggested that measuring the integrity of a stream or river (Karr 1981) is more useful than simply using chemical tests, biological measurements are recommended in conjunction with chemical and physical monitoring (Rosenberg and Resh 1993). Physical, or habitat structure, and chemical conditions as well as measuring biotic integrity will often "....identify likely causes of recognizable perturbations of aquatic biological communities..." (Saylor and Ahlstedt 1990). The US Geological Survey's National Water-Quality Assessment Program incorporates this multidisciplinary approach of collecting biological, physical, and chemical data to measure water quality in a river basin (Cuffney et al. 1993).

Matthew defines biological monitoring in Rosenberg and Resh (1993): "...as the systematic use of biological responses to evaluate changes in the environment with the intent to use this information in a quality control program. The changes often are due to anthropogenic sources...". Biological monitoring began in Europe, in the beginning of the twentieth century, with the idea of "...saprobity (the degree of pollution) in rivers as a degree of contamination by organic matter (primarily sewage) and the resulting decrease in dissolved oxygen..." (Cairns and Pratt 1993). The earlier methods of biological monitoring or the "European Saprobien system" is being replaced by more quantitative methods requiring more sampling and detailed statistical analysis (Resh and Jackson). Since many of these methods are very labor intensive, rapid assessment approaches are also being used to study "long-term regional changes in water quality " (Resh and Jackson 1993, pg. 195). Resh and Jackson (1993) compared the use of rapid assessment approaches by a freshwater ecologist with that of a doctor using a thermometer to quickly assess the condition of his/her patient.

Macroinvertebrate indices of water quality or of biotic integrity were developed following the methods of the Index of Biotic Integrity (IBI) for fish created by Karr in 1981 (DeShon 1995, Davis 1995). The rationale for using macroinvertebrate communities and not solely upon chemical tests, as an indication of what is happening to a stream, is supported by many in the scientific community. Macroinvertebrates are important to survey, since they tend to live in or near the sediments of a streambed and have life cycles that can be almost immediately affected by adverse conditions (Cuffney et al. 1993). Since many macroinvertebrates are sensitive to environmental degradation, they can be a more reliable indicator of pollution than an occasional chemical test (Cuffney et al. 1993).

The Hudson River National Estuarine Research Reserve (HRNERR) conducted research (Nieder 1998) to analyze the chemical effects of land use practices within the watershed of the Saw Kill. The Saw Kill sampling was from March 10 to 16, 1992, which included a storm event on March 11. Six additional storm events were monitored from April 16 to October 18, 1993. Five subwatershed sites included one site in each of the following land use categories: forested, row crop, orchard, and residential. The other four sites were in the mainstream and included mixed land uses. The chemical data

demonstrated significant amounts of nitrates, phosphates and chlorides loading into the Saw Kill. The relationship between the concentrations of nitrates and the storm events indicated that they were from point sources, since the concentration was lower after a storm event and then rebounded. This would indicate that septic systems from residential areas were a source of nitrate loading. Statistical analysis indicated that the residential land use had the ".... greatest effect on water quality, more so than agricultural activities within the Saw Kill watershed" (Nieder 1998).

Creating biotic indices was appropriate for assessing water quality and biotic integrity as chemical data collection has been extensive in the Saw Kill, and this allows for comparison of biological data to current chemical data. Using two biotic indices created two discrete data sets to compare with the chemical data and allowed for the two methods to be compared. One of the two methods of forming biotic indices, using macroinvertebrates, was the New York State Department of Environmental Conservation's (NYS DEC) Biological Assessment Profile (BAP) (Bode et al. 1997, Bode et al 1993a, Bode et al. 1993b). This method was chosen, because it has been developed and used through out New York State (Bode et al. 1997). The other method was the Ohio Environmental Protection Agency's (Ohio EPA) Invertebrate Community Index (ICI) (Ohio EPA 1989). This method is similar to NYS DEC's method, as similar species are found in both states and can be used without ecoregional modifications as the ecology, climate, and macroinvertebrate taxonomy are similar (per conversation with Dr. Robert Schmidt 1996).

Even though the BAP was created for New York State rivers and streams, the Ohio ICI also was sensitive to ecological interaction within the stream. The ICI is a "...measure of the overall macroinvertebrate community condition..." (Ohio EPA 1989). It evaluates biological integrity in the "...designation of aquatic life uses, or the determination of evaluation of aquatic life use attainment..." (Ohio EPA 1989). In contrast, the NYSDEC BAP method measures water quality. It is a method that integrates chemical and physical water quality tests (Cuffney et al. 1993). The BAP assesses water quality to determine the major factors that affect the water-quality conditions and trends. It determines the source of pollution and type of pollution (Bode et al. 1996).

The significance in creating indices from the data collected at each of the stations studied by Nieder (1998) was to study the biotic integrity and water quality of these same stations in which Nieder's data indicated that the residential land use was adding the most sulfates, nitrates, chlorides, and phosphates. The additional stations at Linden Acres and South Tivoli Bay detect were meant to detect the biotic integrity and water quality of the stream, after it flowed through the entire residential and urban area, and just prior to it flowing into Tivoli South Bay and the Hudson River.

METHODS

STUDY SITE

The Saw Kill is located in northwestern Dutchess County, New York, on the east side of the Hudson River about 62 km north of New York City (Fig. 1). Its watershed encompasses the townships of Milan and Red Hook. The mouth, which is tidally influenced, is in Tivoli South Bay near the Bard College Field Station and is part of the HRNERR. The watershed of the Saw Kill is 6886 hectares (Reichheld and Barton 1991, Pitt and Barten 1994).

Stations were set up at or near the same nine stations that Nieder (1995) established (Fig. 1). Two main stream stations were added, a tenth station on the west end of Linden Acres, near Kelly Road, and an eleventh station near the mouth of the river, in South Tivoli Bay, just above the tidal influence. At stations that were not located at Nieder's (1998) original sites, land uses and watershed areas were estimated from existing literature (Pitt and Barton 1994, Riechheld and Barten 1991, Wagner 1981).

Subwatershed 1 (S1) - Forest: This station is located about 30 meters below a culvert that goes under Milan Hill Road and is approximately 0.2 km (0.12 miles) west of the intersection of Willow Glen Road. It includes an area of 68.25 hectares (0.265 sq. mi.) that is 95% forested or wetland. Five percent is hayfield (Pitt and Barton 1994).

Subwatershed 2 (S2)- Landfill: This was originally to be S2, but due to the drought and not enough water to make a macroinvertebrate collection, this station was not used.

Subwatershed 3 (S3) - Mixed Agriculture: This station was moved approximately 1 km to Cokertown at the intersection between Hapeman Hill Road and the road to Spring Lakes because Nieder's (1995) original station was dry. The land use is approximately 36% forested, 57% agriculture, and 7% residential (Pitt and Barten 1994). The watershed encompasses approximately 370 ha (1.43 sq. mi..) (Pitt and Barten 1994).

Subwatershed 4 (S4) - Orchards: The original site was on Echo Valley Road, south of the intersection with Fraleighs Road. It was dry, so the station was moved to a mainstream station west of Route 9 (approximately one mile southwest of Nieder's site). The land uses are 47% orchard, 17% hayfield, 28% forest and 8% wetland (Pitt and Barton 1994). The watershed encompasses approximately 4662 ha (18 sq. mi.).

Subwatershed 5 (S5) - Residential: This station is located north of the Village of Red Hook, on Aspinwall Road, west of Route 79. The sampling was done on the north side of the Red Hook Department of Public Works' pond. The watershed encompasses 49 ha (0.19 sq. mi.) and the land uses are 20% forest, 5% agricultural, and 75% residential (Pitt and Barton 1994).

Main stream 1 (M1) - Primarily Forest: This is located in Rock City, off of Route 199, below the old mill dam. A diesel fuel truck overturned on June 6, 1997 and dumped 7,000 gallons of fuel onto the road and into a subcatchment of the Saw Kill (Poughkeepsie Journal; June 7, 1997). The site is 20 meters above the subcatchment tributary that was

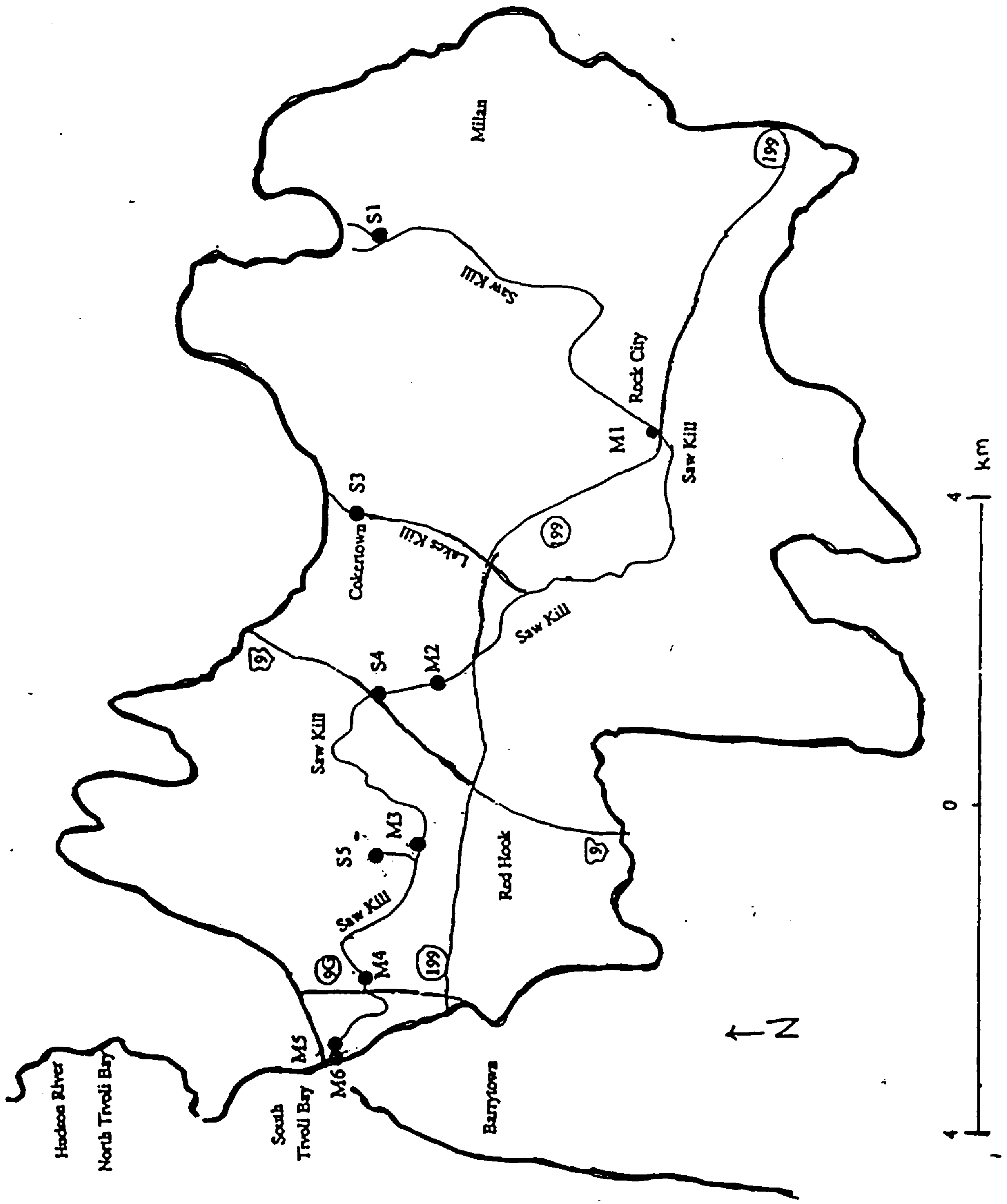

Figure 1. This delineates the Saw Kill watershed and shows were the 10 station are located.

contaminated by the diesel fuel. The land use is over 90% forested. The watershed encompasses 1634 has (6.31 sq. mi.) (Wagner 1981).

Main stream 2 (M2) - Primarily Forest and Agriculture: This is located on Echo Valley Road about one mile north of Route 199. The land uses are approximately 70% agriculture and 30% forest. The estimated watershed area is 3786 ha (14.62 sq. mi.).

Main stream 3 (M3)- Primarily Urban and Residential: This station is about 0.5 miles north of Linden Avenue Middle School on Linden Avenue. The Red Hook Department of Public Works' storm pipe effluent discharges in the Saw Kill above this station. The land uses are approximately 90% residential. The watershed encompasses 5413 ha (20.9 sq. mi.) (Wagner 1981).

Main stream 4 (M4) - Primarily Residential: This is an additional station located on the Saw Kill after it flows through more recent residential development as well as Linden Acres. It is located on Kelly Road near Route 9G. The land use is approximately 90% residential. The watershed encompasses approximately 5853 ha (22.6 sq. mi.).

Main stream 5 (M5)- Tivoli South Bay: This was the same station as Nieder's (1995) site and is located on the road to the Bard College Field Station. This site is above the falls and the effluent pipe from the Bard College sewage treatment plant. At this point in the river the land use includes most of the watershed and the totals are 55% forested, 27% agriculture and 18% residential (Riechheld and Barton 1991). The watershed encompasses approximately 6475 ha (25 sq. mi.).

Main stream 6 (M6)- Tivoli South Bay: This station includes the entire watershed. This is an additional station that is below the falls and above the tidal influence. This is the last station before the Saw Kill flows into the Hudson. It is also located just off the road that goes to the Bard College Field Station. The Bard College sewage effluent enters the stream at this station. The land use is considered the same as

M5, as they are within a few hundred feet of each other (Riechheld and Barton 1991). The watershed encompasses 6886 ha (26.59 sq. mi.) (Pitt and Barton 1994).

THE TWO MACROINVERTEBRATES INDICES

One of the two methods used was the Ohio Invertebrate Community Index Hester-Dendy multiple-plate artificial substrate sampler in conjunction with qualitative dip net sampling developed in 1987 (DeShon 1995). The other method was New York State Department of Environmental Conservation's Biological Assessment Profile that used the rapid assessment traveling kick sample that formed the following indices: Species Richness (SPP), the Hilsenhoff Biotic Index (HBI), the EPT (Ephemeroptera, Plecoptera, and Trichoptera), a Percent Model Affinity, (PMA) and an Impact Source Determination index (ISD).

THE OHIO ENVIRONMENTAL PROTECTION AGENCY'S INVERTEBRATE COMMUNITY INDEX (ICI)

FIELD METHODS: A total of 64 Hester-Dendy multiple-plate artificial substrate samplers were placed at the ten stations. Each station had six Hester-Dendy samplers, except for S1, which had only four since the low water level did not allow for six. They were made of 1/8 inch tempered hardboard cut into eight pieces, each three square inches. One inch square spacers of the same material were allowed for three spaces, three double spaces, and one triple space between the plates. This was held together by a 1/4 inch eyebolt and creates an artificial substrate area of 135.6 square inches (Ohio EPA 1989). Two multiple plate samplers were bolted to a patio block. These samplers were placed in the water during the third week of June and retrieved the first week of August.

At retrieval time, while the samplers were submerged, they were unbolted from the block and the plates were placed into labeled containers inverted onto the river bank and

fixed in less than 10% formalin and preserved in 70% ethanol. At retrieval time, a qualitative sampling of macroinvertebrates in the natural substrate was done by using a triangular D-frame 20- mesh dip net. Rocks and debris was scraped and hand picked above the net. All segments of the stream (runs, riffles, margins, and pools), and for no less that 30 minutes, were sampled until no new taxa were retrieved. After the macroinvertebrates were collected, they were fixed in less than 10% formalin and preserved in 70% ethanol (Ohio EPA 1989, per conversation with Jeff DeShon 1997).

LABORATORY METHODS: For both the Hester-Dendy and dip net sampling, all of the sample from each station was sorted and identified, except from stations M2 and S5. These stations were quarter-sampled as the immensity of their populations prohibited sorting and identifying the entire sample. The quarter sampling was done by pouring the sample into a pan and a fourth of the sample was removed and sampled. The counts were then multiplied by four. At the time of collection of the Hester-Dendy plate, a dip net sampling of the natural strata was taken. For both the dip net sampling and the Hester-Dendy multiple plate samplers, all specimens were identified to the recommended Ohio EPA taxonomic level. The specimens from the Hester-Dendy collection were preserved in 24 mL bottles containing 70% isopropyl alcohol.

DATA ANALYSIS: The Ohio ICI is comprised of ten compositional and structural community metrics (DeShon 1995). Each metric scores either 6, 4, 2, or 0 points, based on a comparison with a set of ecoregional reference sites (DeShon 1995). Six points constitutes values comparable to an undisturbed, clean stream, four points are given if a metric value reflects a good community (Ohio EPA 1988), two points are given to a metric if it slightly deviated from the expected range of good values (Ohio EPA 1988), and a score of 0 indicates that the metric values strongly deviated from the expected range of good values (Ohio EPA 1988). The summation of the scores results in the ICI. See Table 1 for the description of the results for each metric.

Table 1. Ohio ICI metrics are described below (Ohio EPA 1988).

METRIC	DESCRIPTION
1	Total taxa: If the score is high, then the biological conditions are stable indicated by high species richness and diversity.
2	The total number of mayfly taxa: Mayflies are intolerant to pollution and the greater the number of taxa, the greater the score, as greater mayfly taxa indicates high biotic integrity.
3	The total number of caddisfly taxa: As with mayflies, abundant caddisfly taxa indicates better biotic integrity. This metric depends on drainage area size, If the drainage area is less than 155,400 ha (600 sq. mi.) the total score will be more dependent upon this metric.
4	The number of dipteran taxa: Dipteran display the greatest range of pollution tolerance and are often the major component of invertebrate collections. The greater the number of taxa, the higher the score.
5	Percent Mayflies: Even if only a few mayflies are present, the station will score at least a 2 in this metric.
6	Percent caddis flies: As in metric 3, this metric depends on drainage area size, If the drainage area is less than 155,400 ha (600 sq. mi.) the total score will be more dependent upon this metric.
7	Percent Tanytarsini midges: This taxa is pollution sensitive and the higher the percentage, the greater the score.
8	Percent other dipteran and non-insects: This is a negative metric, as the greater the percent the more tolerant pollution organisms there are, thus indicating poor biotic integrity.
9	Percent tolerant organisms: This differs from metric 8 as the organisms will predominate under extremely polluted conditions. It, too, is a negative metric as the greater the percent, the lower the score.
10	EPT of natural substrata: When the Hester-Dendy samplers are collected, the total number of Ephemeropter, Plecoptera, and Trichoptera taxa are collected in the riffle, runs, margins, and pools and counted. The greater the taxa number, the better the score.

THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION'S BIOLOGICAL ASSESSMENT PROFILE

FIELD METHODS: In August, macroinvertebrate collections were made using the traveling kick method. This was done by positioning a D-frame aquatic net 10 in. x 12 in.

with a mesh opening of 0.8 mm x 0.9 mm about 0.5 m downstream from the collector. The stream bed was disturbed by the collector kicking and dislodging organisms that were captured by the net. This macroinvertebrate shuffle was performed for 5 minutes for a distance of 5 meters. The direction of sampling was taken in a diagonal transect of the stream. The contents of the net were emptied into a pan of stream water and major groups of organisms were noted. Larger debris was removed after the organisms had been extracted and the contents of the pan was sieved with a US no. 30 standard sieve. This material retained by the sieve was transferred to a plastic quart jar containing 70% alcohol. The jar was labeled and ready for identification. Prior to performing another sampling, the net was thoroughly rinsed in the stream (Bode et al. 1996).

LABORATORY METHODS: The samples were drained through a US no. 30 sieve to remove the alcohol and transferred to an enamel pan. A small amount of the sample was randomly removed and placed in a petri dish. This was examined under a stereomicroscope. Organisms were sorted into major groups, counted, and identified. The identification was completed when 100 organisms had been removed. The specimens were identified to recommended NYS DEC taxonomic levels, labeled, and preserved in 24 mL vials containing 70% isopropyl alcohol (Bode et al. 1996).

DATA ANALYSIS - To calculate the BAP, 100 organisms were identified from each station. The Species Richness (SSP) was the total number of taxa found in a sample, higher SSP values indicate cleaner water (Bode et al. 1996). The EPT was calculated by totaling the number of mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) and indicates mostly clean-water organisms (Bode et al. 1996). The Hilsenhoff Biotic Index (HBI) was calculated by multiplying the number of the individuals of each species by an assigned tolerance value for each species that ranges from 0 to 10, 0 being intolerant and 10 being tolerant to pollution. High HBI values indicate organic pollution and low values indicate clean-water conditions (Bode et al. 1996). The Percent Model Affinity (PMA) is a measure of similarity to a model non-impacted community based on percent abundance in 7 major groups (Bode et al. 1996). This was based upon the percent abundance of 40% Ephemeroptera, 5% Plecoptera, 10% Trichoptera, 10% Coleoptera, 10% Chironomidae, 5% Oligochaeta, and 10% other. The taxa identifications and percentages of each station were compared to the Impact Source Determination (ISD) community types. If the station community exhibited a similarity of greater than 50% to the ISD community type, then it was classified as that ISD community type. The community types are as follows: 1. Natural, 2. Nutrient Additions, Non-point sources, and 3. Toxic (Bode et al. 1996). If the samples indicated Nutrient Additions, Non-point sources or Toxic, then these communities were matched to ISD communities that have been identified to have a definite source for the pollution. These are listed as Sewage Effluent, Animal Wastes, Municipal/Industrial, Siltation, and Impoundment.

CHEMICAL WATER TESTS: For the purpose of obtaining more direct correlation between chemical tests and biotic indices, water samples were collected in clean polyethylene bottles on September 23, 1997 and sent to the Institute of Ecosystem Studies to be analyzed for levels of phosphates, nitrates, sulfates, and chlorides using ion chromatography or Alpkem autoanalyzer. Seston, alkalinity, and pH tests was determined in the HRNERR lab at the Bard College Field Station.

Nieder's 1993 chemical data collected April 15-20, October 12-18, and November 1-5 were rank for stations M1, S3, M2, M3, S4, and M5, because these were located in the same station as the chemical and biological data gathered for this research (Table 2).

CORRELATIONS: To obtain correlation for the ICI, BAP, and the water chemical index for statistical analysis, all three indices were normalized by ranking the scores and a ten-point scale. For the biotic indices, the lowest score ranked a one and the highest score ranked a ten. Similarly, for each chemical test, the highest concentrations ranked a 1 and the lowest ranked a 10. Ranks between one and ten were calculated by subtracting the lowest score or chemical reading from the highest and dividing by nine. This figure was added to the lowest score or chemical reading until the tenth rank was

reached. Finally, each station was ranked according to the scale for each biotic index and the water chemical index.

Station S1 is an outlying data point throughout the results, so I made correlations both with and without this station. When the Hester-Dendy substrata were set out, only four substrata were set out as there wasn't enough water for six, as in the other stations As the summer progressed, S1 became a standing pool. This resulted in the lowest scores for both the Ohio ICI and the NYS DEC BAP. S1 was located what should have been a pristine site, as it was located in the headwaters of the forest.

RESULTS

Chemical test results from this research and Nieder's (1993) research can be found in tables 2 and 3. The Ohio ICI results can be found in table 4 and the NYS DEC BAP can be found in tables 5 and 6. The total number of individuals captured in the Ohio ICI was 3,020 with a total of 83 taxa. The total number of individuals captured in the NYS DEC BAP method was 927 with a total of 151 taxa. Refer to Appendices 1 and 2 for the species lists for both the Ohio Hester-Dendy artificial substrata and the NYS DEC's traveling-kick method.

Table 2. Seston, pH, nitrate, sulfate, chloride, and phosphate (mg/L) results from water samples of the Saw Kill that were taken on September 23, 1997.

	Stations									
	S1	M1	S3	M2	S4	M3	S5	M4	M5	M6
seston	3.00	0.00	2.00	0.70	0.30	2.40	1.50	89.0	0.30	0.40
pH	7.20	7.44	8.46	7.98	8.17	7.65	7.97	7.85	7.98	8.13
nitrates	0.29	0.35	3.71	3.49	3.60	6.87	7.28	7.27	5.79	6.20
sulfates	19.51	13.56	14.18	18.84	19.07	23.02	32.54	26.36	25.69	26.60
chlorides	91.13	21.28	22.89	22.79	23.92	30.04	62.29	37.22	37.04	39.04
phosphates	0.017	0.005	0.074	0.0125	0.011	0.008	0.006	0.006	0.017	0.086

Table 3. Nitrate, sulfate, chloride, and phosphate (mg/L) mean chemical data from Nieder (1993). They were collected on April 15-20, Oct. 12-18, and Nov. 1-5, 1993.

	M1	S3	M2	M3	S5	M5
nitrates	0.93	1.20	1.80	2.70	9.55	2.59
sulfates	19.99	23.04	30.71	30.54	39.94	31.71
chlorides	16.88	18.54	15.47	16.18	36.86	18.42
phosphates	0.007	0.007	0.007	0.008	0.014	0.008

There was no significant correlation between the Ohio ICI and either of the water chemistry indices (Figure 2) , nor the NYS DEC and either of the water chemistry indices (Figure 3). Figure 4 does demonstrate a weak, significant correlation between the two biological indices.

Figure 5 represents the three categories of land uses found in the Saw Kill, what percentage of land use occurs at each station, and the biotic integrity, or the rank of the

Table 4. Numbers of individuals and taxa captured at each station, from the Saw Kill, using the Ohio ICI method from June 16 through July 27, 1997. The resulting ICI score for each station is also listed.

	Stations									
Totals	S1	M1	S3	M2	S4	M3	S5	M4	M5	M6
Individuals	98	112	466	352	346	248	454	151	389	404
Taxa	7	12	23	19	27	16	15	16	20	16
ICI score	6	26	36	30	36	20	8	28	36	34

Ohio ICI, of each station. M1 is in the forested land use and demonstrates good biotic integrity, as would be expected. S1 does not fit the model of good biotic integrity that would be found in a forested region, due to the conditions of the stream, as previously discussed. The agricultural land use is not deteriorating the biotic integrity of the Saw Kill in stations M2, S3, and S4 as much as the residential land use of S5, M3, and M4. Stations S5, M3, and M4 are predominantly residential and score some of the lowest

Table 5. Numbers of individuals and taxa captured at each station using the NYS DEC BAP method, on the Saw Kill, from July 22 and 23, 1997. The HBI, EPT, PMA calculations are also included for each station.

	Stations									
Totals	S1	M1	S3	M2	S4	M3	S5	M4	M5	M6
individuals	27	100	100	100	100	100	100	100	100	100
SSP	2	13	9	23	16	18	13	21	18	18
HBI	8.25	5.02	2.44	3.45	3.99	3.97	7.46	4.27	4.30	3.61
EPT	0	3	3	11	6	5	3	7	8	10
PMA	21	41	38	74	35	39	41	62	53	33

Table 6. The NYS DEC BAP total scores for the SSP, HBI, EPT, and PMA and mean for each of the ten stations.

	Stations									
totals	S1	M1	S3	M2	S4	M3	S5	M4	M5	M6
SSP	0.00	3.38	2.20	6.47	4.20	4.85	3.38	5.88	4.85	4.85
HBI	3.00	6.85	9.40	8.60	8.10	8.03	3.80	7.73	7.70	8.39
EPT	0.00	3.61	3.61	8.00	5.40	4.72	3.61	5.91	6.36	7.27
PMA	0.10	3.63	3.20	8.46	2.85	3.31	3.63	7.10	5.65	7.24
MEAN	0.78	4.37	4.60	7.88	5.14	5.23	3.61	6.65	6.14	5.69

ranks. This suggests that residential land use is respectively affecting the biotic community of the station more than agriculture and forested land uses. Stations M5 and M6, at the mouth of the Saw Kill , score the same, highest rank and exhibit a recovery from the deteriorating conditions that occur at the three previous stations (S5, M3, and M4). At M5 and M6, it can be estimated that the land use returns to be more forested than residential and this change in land use allows the biotic integrity of the Saw Kill to improve prior to it reaching the Hudson River.

Figure 6 also represent where the stations fit into the three land use categories and how the type of water quality that occurs, or the rank of the NYS DEC BAP.

When S1 is not included in the data, a slight negative correlation occurs between

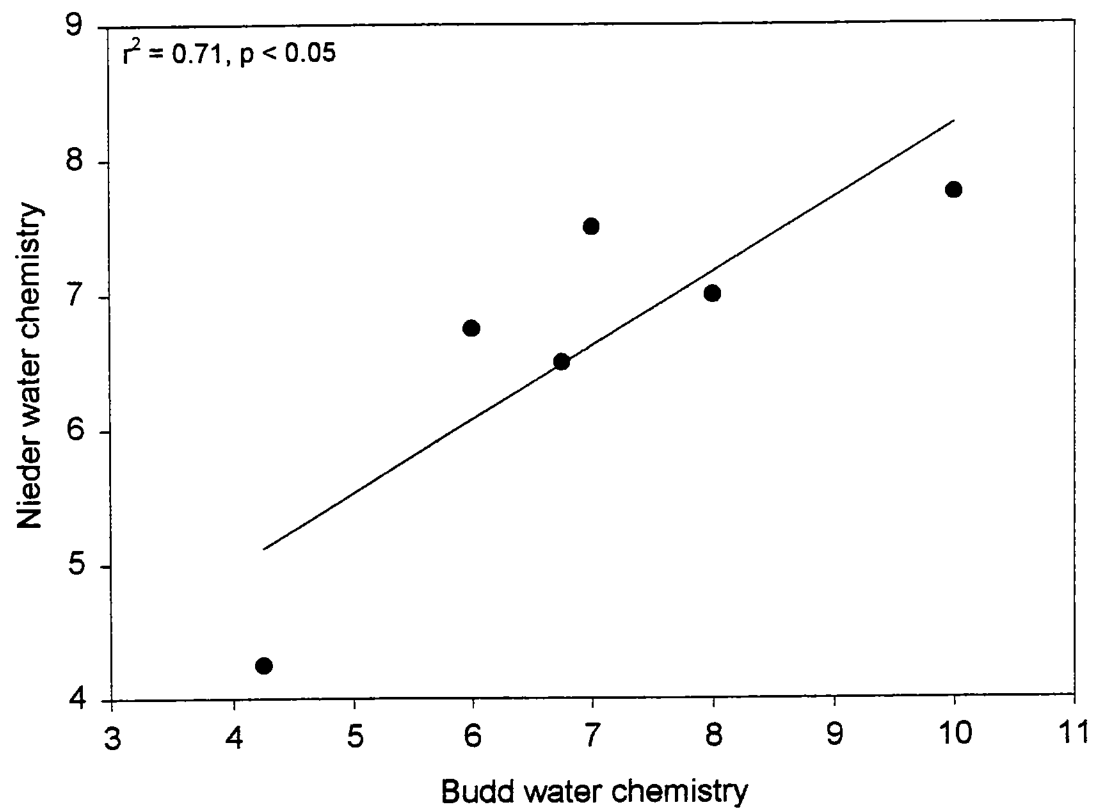

Figure 2. Regression line and correlation coefficient (one tailed test) between water chemistry data collected for this research (Sept. 23, 1997) and Nieder's (1993) chemical data.

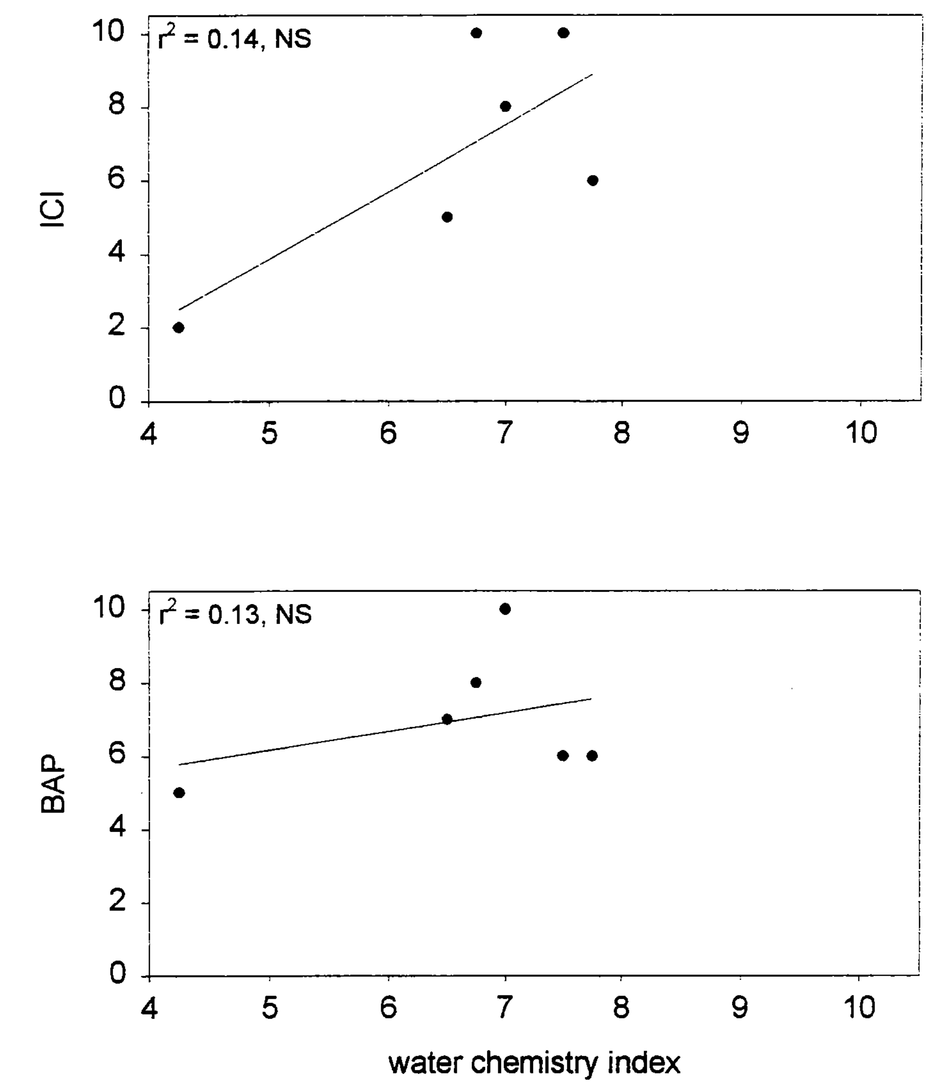

Figure 3. Regression lines and correlation coefficients (using one tailed tests) between the water index generated from this research and the ICI (upper graph) and the BAP (lower graph) Sept. 23, 1997

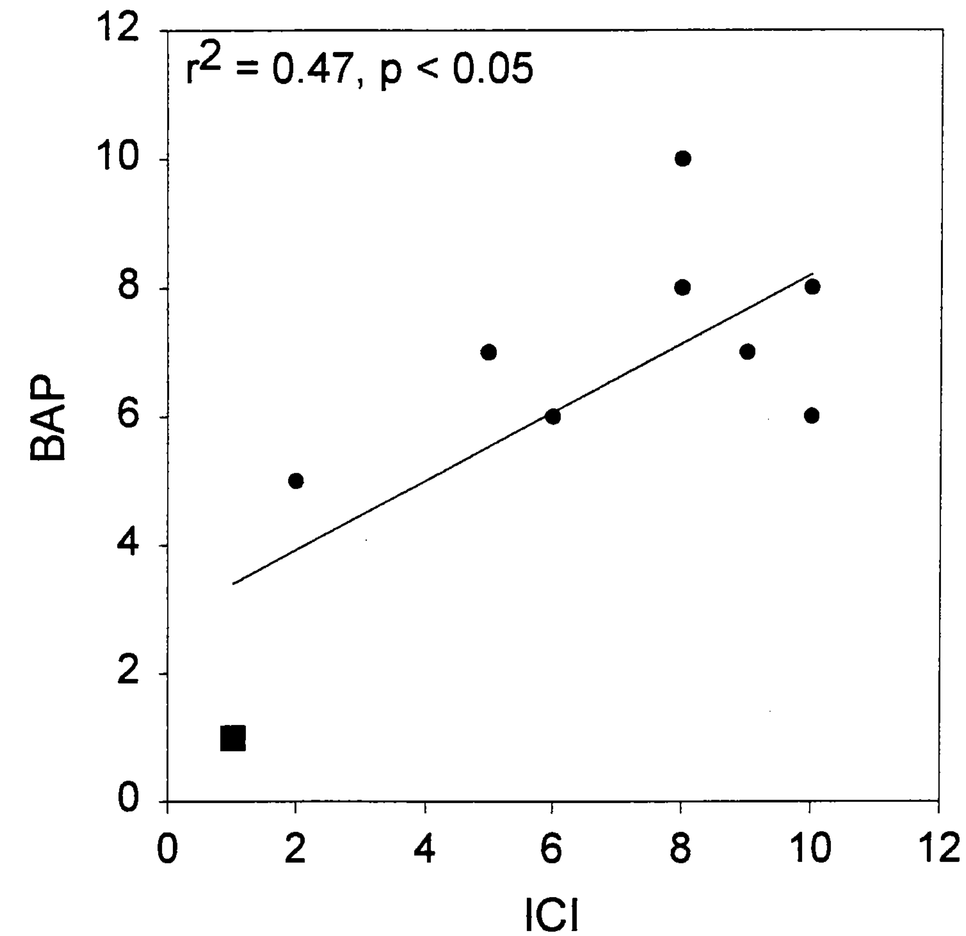

Figure 4. Regression line and correlation coefficient between the ICI and the BAP.

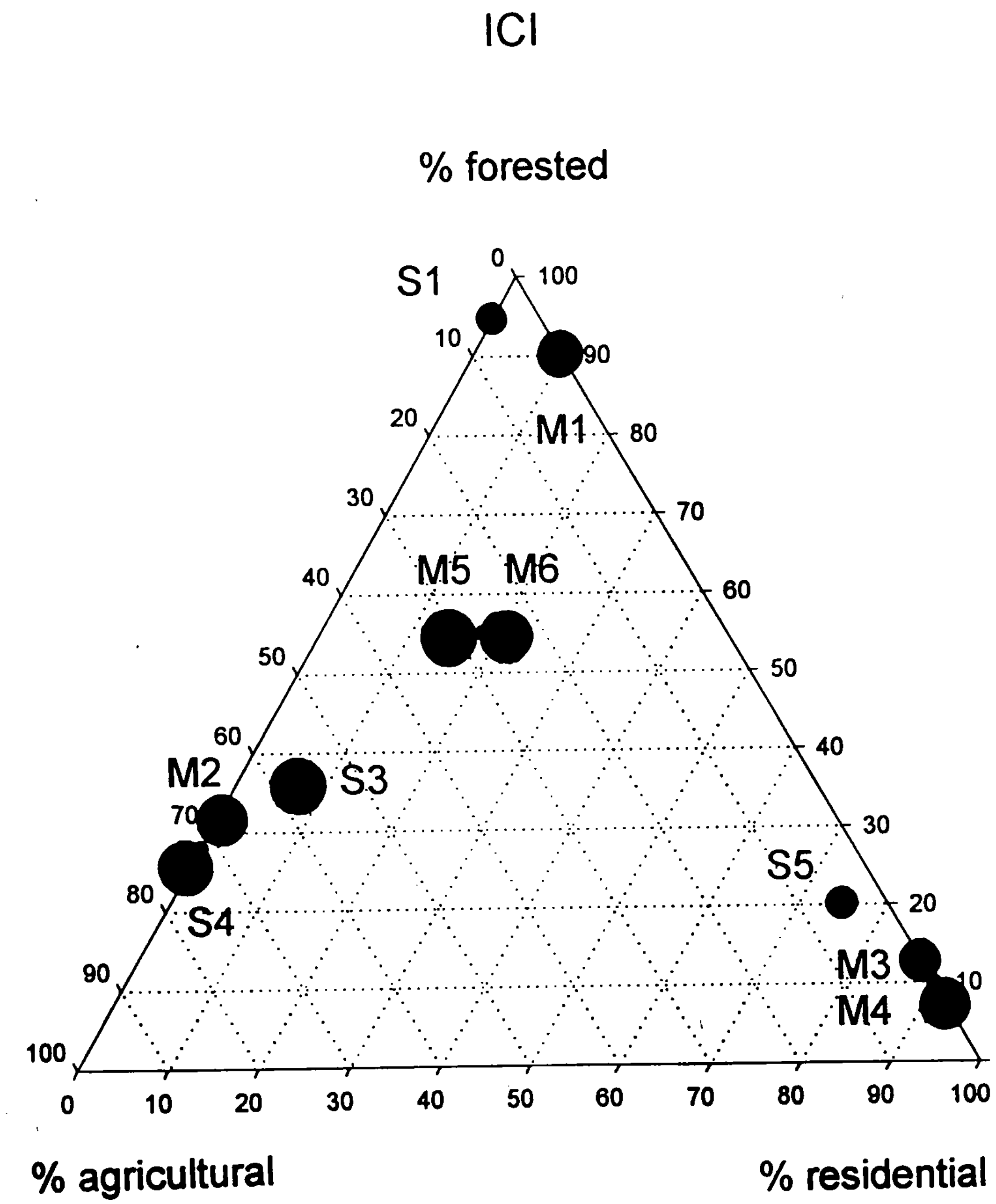

Figure 5: The three predominant land uses of the Saw Kill and the ICI are illustrated here. The smaller the circle, the worse the biotic integrity of the station. S indicates a substream station and the primary land use is as follows: S1 is forested, S3 and S4 are agricultural, S5 is residential. M indicates the main stream of the Saw Kill and the primary land use for each station is as follows: M1 is forested, M2 is agricultural, M3 and M4 are residential, and M5 and M6 return to forest.

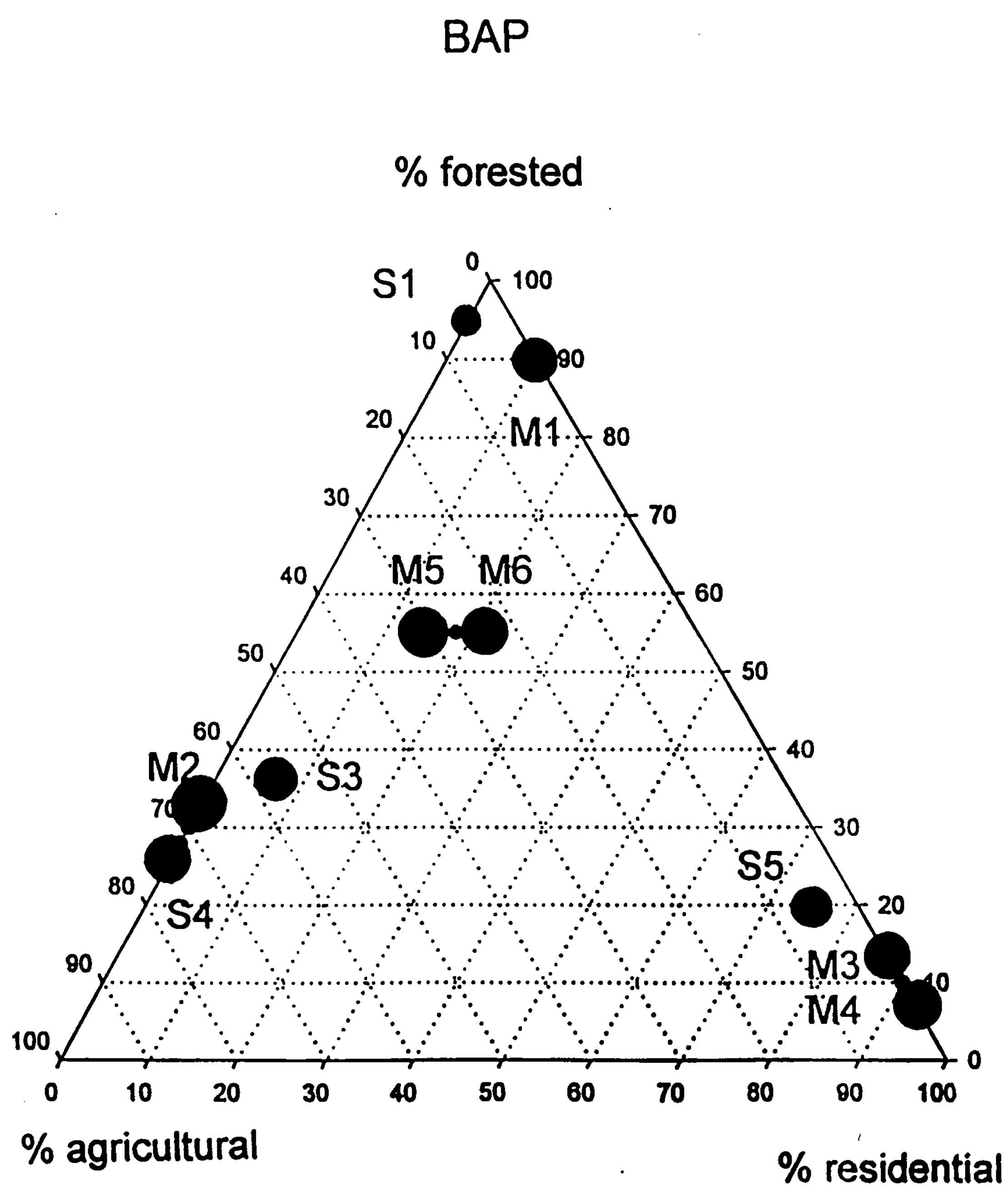

Figure 6: The three predominant land uses of the Saw Kill and the BAP are illustrated here. The smaller the circle, the worse the biotic integrity of the station. S indicates a substream station and the primary land use is as follows: S1 is forested, S3 and S4 are agricultural, S5 is residential. M indicates the main stream of the Saw Kill and the primary land use for each station is as follows: M1 is forested, M2 is agricultural, M3 and M4 are residential, and M5 and M6 return to forest.

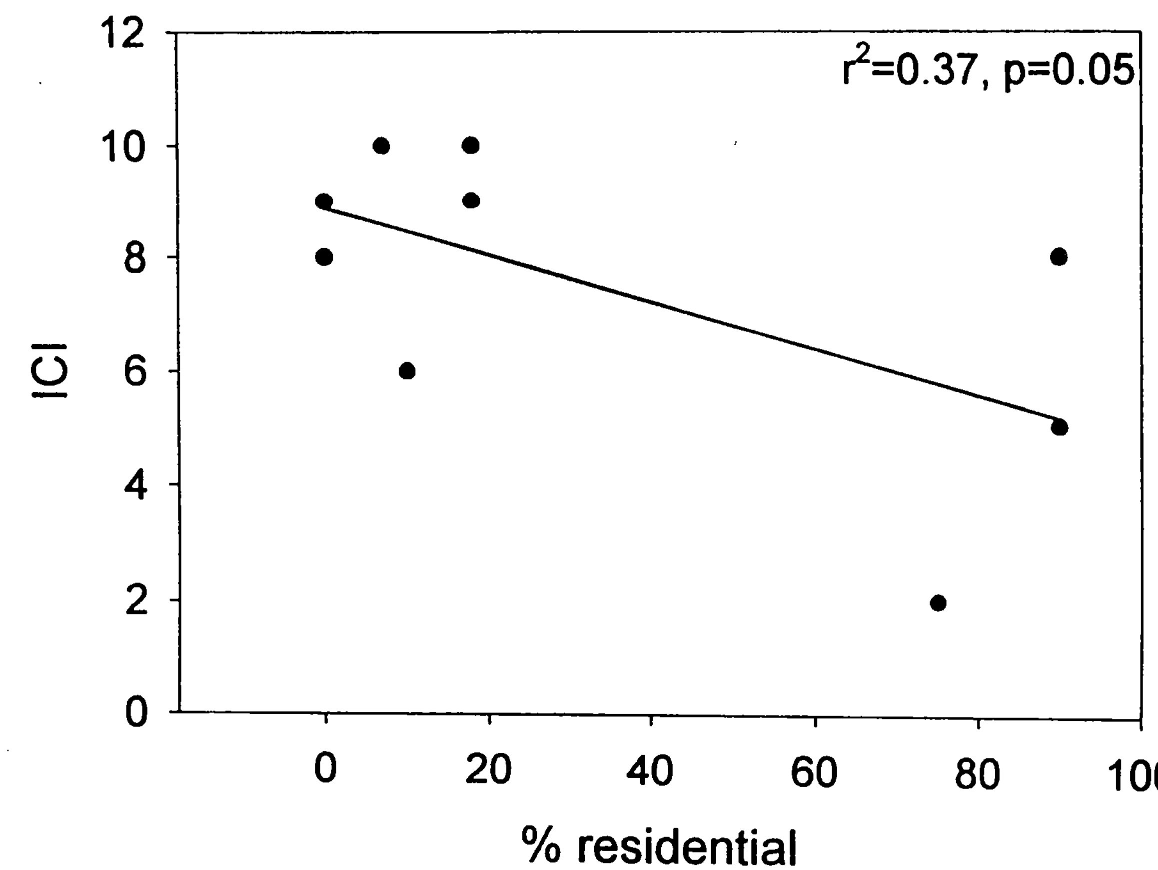

Figure 7. This demonstrates a slight negative correlation between the ICI and residential land use. S1 was excluded from the analysis.

Table 7: Cost comparison of the two methods. Labor cost is set at $20.00 per hour.

	Ohio ICI	NYS DEC BAP
1 pair of feather weight waders & boots	$ 299.23	$ 299.23
2 D-frame aquatic dip nets	179.00	179.00
36 1L sample jars	105.66	105.66
2 qts. isopropyl alcohol/method	1.80	1.80
Hester-Dendy substrata materials	160.00	0.00
24 mL specimen vials	71.82	63.42
Total cost	$ 817.51	$ 649.11

residential land use and the ICI or biotic integrity of the Saw Kill as shown in Figure 7. This does not occur when S1 is included with the ICI or the BAP results.

For both methods, expenses were recorded for a cost comparison (Table 7). If the labor was taken into account, for each of the sampling methods, the cost comparison differs substantially. The Ohio ICI took over 64 hours to assemble and set out the substrata. The NY BAP method did not required approximately one fourth of the time and effort to obtain samples. The time spent on identification for each method were more similar. Approximately 42 hours for the Ohio ICI method and 36 hours for the NY BAP method.

DISCUSSION

Chemical data from this research and Nieder's (1993) chemical tests had a significant correlation. Yet, neither of the chemical tests correlated with the biotic indices.

The two biological collections were made at different times and the conditions varied. The summer was dry, especially during the biotic collections. There had been more rain prior to the September collection of the water samples. This indicates that chemical tests results can diverge from the biotic results in a relatively short period of

time. These results support the idea that chemical tests, alone, may not reflect the water quality and biotic integrity of the macroinvertebrate community.

For most of the stations, this would indicate that to some extent, the two indices resulted in similar scores of biotic integrity, in the Ohio ICI, and water quality, in the NYS DEC BAP. The weakness of the correlation may be a result of the collections taking place at different times. Also, the two methods differ in where the collections are made in the river. The ICI is collected in a run of a river where there is greater depth to ensure that the Hester-Dendy substrata are covered with water. The BAP is collected in riffles where shallower water occurs. The fact that they do correlate, yet are two different methods of collecting, does indicate that similar communities, thus water quality and biotic integrity, do exist in most of the stations.

The water quality of M1 appears to be similar to the biotic integrity (of the ICI) and S1 again scores poorly. The water quality of M2 is not as good as the biotic integrity, yet S4 and S3 exhibit better water quality than biotic integrity. S3, M2, and S4 again show better water quality than the residential stations S5, M3, and M4. S5 does appear to have better water quality than biotic integrity. This may be due to the difference in collecting methods. For example, leeches and snails (responsible for lower scores) may not be as easily collected in a dip net as they are on artificial substrata. The collection, at S5, from the BAP methods, did not have the number of leeches and snails as the ICI method did. The water quality at M3 does rank higher than the biotic integrity, but at M4, the water quality is the same as the biotic integrity. M5 and M6 do not rank the same, as they did for the ICI, though the water quality of M6 is only one rank lower than the biotic integrity of the ICI. This, again, demonstrates a recovery of water quality conditions prior to the Saw Kill entering the Hudson River and further supports the buffering capacity of a forested region to allow for upgrading of a river water conditions prior to it entering a major body of water.

A slight, but significant correlation exists between residential land use and the ICI or biotic integrity of the Saw Kill as shown in Figure 7. This indicates that residential land use does adversely affect the biotic integrity of the Saw Kill more than any other land use. This coincides with Nieder's (1995) data that residential land use causes more pollution:

> "Regression analyses indicate that residential land use has the greatest effect on water quality, more so than agricultural activities within the Saw Kill watershed. Surface water concentrations of all constituents (nitrates, phosphates, sulfates, and chlorides) increased with an increase in residential area ($p<0.01$). None of these nutrients exhibited a positive correlation with increases in agricultural land use during this study, in fact nitrate loading appeared to decrease as area coverage of agriculture increased" (Nieder 1995).

This research supports chemical test results, through the Ohio ICI indices, that biotic integrity is most adversely affected by residential land use than any other land use on the Saw Kill.

The NYS DEC BAP method cost less than half as much as the Ohio ICI (see Table 7). Yet, the BAP method resulted in 68 more taxa than the ICI method and have broadly similar results (Figure 4). Much more time and effort in collecting is needed for the ICI, yet the substrata appear to capture fewer species than the taxa assessment method of the BAP. It would appear that the NYS DEC BAP is much more efficient and economical.

CONCLUSION

Water chemical tests, both generated from this research and Nieder's (1993) water sampling did not display significant correlation with Ohio ICI nor the NYS DEC BAP. The ICI and the BAP were correlated, indicating that the biotic integrity, detected by the ICI, and the water quality, detected by the BAP, were somewhat similar. This indicates concurrence between the two biological methods and supports the idea that the effects of the environmental conditions of the Saw Kill are being detected by the type of macroinvertebrate communities that exist in the Saw Kill.

Correlations between land use and the two macroinvertebrate indices indicate that the residential land use is deteriorating the biotic integrity of the Saw Kill more than any other land use. This is in agreement with Nieder's (1995) water chemical results.

Even though there is biotic integrity degradation on the Saw Kill in the residential area, recovery occurs in the forested area that exists at the mouth of the river. The buffer zone that this forested region provides allows for the environment of the Saw Kill to improve prior to it entering the Hudson River.

The NYS DEC BAP method is recommended as a index to use as the BAP proved to be more effective and less expensive.

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APPENDIX 1: Macroinvertebrates collected using the Ohio EPA Hester-Dendy artificial substrata. Collections occurred June 15 to August 22, 1997.

TAXA	S1	M1	S3	M2	S4	M3	S5	M4	M5	M6
ECTOPROCTA										
Phylactolemata sp.	-	-	-	-	-	-	130	-	-	-
COELENTERATA sp.	-	-	5	-	1	2	-	-	1	-
PELECYPODA sp.	-	-	-	-	1	-	-	-	-	-
GASTROPODA										
Physidae:										
Aplexa elongata	-	-	-	-	-	-	-	-	-	-
Physella sp.	15	-	15	-	-	-	44	-	4	-
Planorbidae:										
Planorbella companulata	-	-	-	-	-	-	24	-	2	-
PLATYHELMINTHES										
Turbellaria:										
Planariidae sp.	-	-	-	-	5	-	12	-	-	-
ANNELIDA										
Oligochaeta:	-	-	1	-	1	-	-	1	-	-
HIRUDINEA:										
Glossiphoniidae										
Batracobdella sp.	-	-	1	-	-	-	-	-	-	-
Helobdella stagnalis	-	-	3	-	-	-	32	-	-	-
H. fusca	-	-	1	-	-	-	32	-	-	-
Glossiphonia complanata	-	-	-	-	-	-	20	-	-	-
Pisciolcola sp.	-	-	-	-	-	-	20	-	-	-
CRUSTACEA										
Decapoda sp.	-	-	-	4	-	-	-	-	-	-
Asellidae:										
Caecidota sp.	-	-	59	4	1	-	-	-	-	-
Lirceus sp.	-	-	-	-	-	-	24	-	-	-
Gammaridae:										
Gammarus sp.	-	-	4	-	-	-	-	-	-	-
Talitridae:										
Hyalella azteca	-	-	-	-	-	3	44	-	2	-
HYDRACARINA:										
sp.	-	-	4	-	-	-	-	3	-	-

APPENDIX 1 (continued): Macroinvertebrates collected using the Ohio EPA Hester-Dendy artificial substrata to create the ICI. Collections occurred June 15 to August 22, 1997.

TAXA	S1	M1	S3	M2	S4	M3	S5	M4	M5	M6
EPHEMEROPTERA										
Siphlonuridae:										
Siphlonurus sp.	-	-	2	-	10	-	-	1	-	1
Ameletus sp.	-	-	7	-	-	-	-	-	-	-
Baetidae:										
Acentrella sp.	-	-	-	-	14	-	-	-	-	-
Diphetor sp.	-	-	-	-	10	-	-	-	2	1
Oligoneuriidae:										
Isonychia	-	-	-	4	8	-	-	5	44	19
Heptageniidae:										
Undeterminec sp.	-	-	-	-	2	-	-	-	-	-
Stenacron sp.	-	-	-	-	-	3	-	-	-	-
Stenonema femoratum	-	6	-	-	3	1	-	-	-	-
S. modestum	-	-	-	4	3	-	-	-	3	1
S. pulchellum	-	-	2	-	-	-	-	-	-	-
S. smithae	-	16	3	48	31	6	-	6	20	2
S. terminaturm	-	9	-	-	-	-	-	-	-	-
Leptophlebiidae:										
Leptophlebia sp.	-	-	11	4	-	-	-	-	-	-
Ephemerellidae:										
Serratella sp.	-	-	-	-	-	1	-	-	-	-
Tricorythidae:										
Tricorythodes sp.	-	-	-	4	1	2	-	-	-	-
Caenidae:										
Caenis sp.	-	-	-	-	-	-	8	-	-	-
ODONATA										
sp.	-	-	-	-	-	-	8	-	-	-
Aeschnidae:										
Anax junicus	-	-	-	4	-	-	44	-	-	-
PLECOPTERA										
Pteronarcyidae:										
Pteronarcys sp.	-	-	-	-	-	-	-	6	8	22
Capniidae:										
Allocapnia granulata sp.	-	-	53	52	1	-	-	-	-	-
Perlidae:										
Agnetina sp.	-	-	-	4	-	-	-	-	-	-
Paragnetina sp.	-	-	-	-	20	-	-	-	-	-
Perlodidae:										
Isoperla sp.	-	-	1	-	-	-	-	-	-	-
COLEOPTERA										
Elmidae:										
Macronychus glabratus	-	-	-	8	-	-	-	-	-	-
Optioservus sp.	2	-	3	-	-	-	-	-	-	-
Stenelmis sp.	-	-	-	-	3	13	-	4	10	15

APPENDIX 1 (continued): Macroinvertebrates collected using the Ohio EPA Hester-Dendy artificial substrata to create the ICI. Collections occurred June 15 to August 22, 1997.

TAXA	SITES S1	M1	S3	M2	S4	M3	S5	M4	M5	M6
MEGALOPTERA										
Sialidae:										
Sialis sp.	-	-	-	-	1	-	-	-	-	-
Corydalidae:										
Nigronia serricornis	-	-	-	4	-	-	-	15	13	4
TRICHOPTERA										
Philopotamidae:										
Chimarra sp.	-	-	-	-	5	-	-	-	3	24
Polycentropodidae:										
Polycentropus sp.	-	-	-	-	-	24	-	1	-	-
Neureclipsis sp.	-	-	-	-	-	-	-	-	6	-
Hydropsychidae:										
Cheumatopsyche sp.	-	-	-	-	-	14	-	23	13	1
Hydropsyche sp.	-	-	-	92	130	-	-	-	128	266
Parapsyche sp.	-	-	-	-	-	-	-	-	-	17
Rhyacophilidae:										
Rhyacophila sp.	-	-	-	-	8	-	-	-	2	-
Hydroptilidae:										
Hydroptila sp.	-	-	-	-	-	-	-	22	-	-
Limnephilidae:										
sp.	-	1	-	-	-	6	-	-	-	-
Anabolia bimaculata	-	-	-	4	-	-	-	-	-	1
Asperophylax sp.	-	-	1	-	-	-	-	-	-	-
Grensia sp.	-	-	6	-	-	-	-	-	-	-
Glyphopsyce sp.	1	-	-	-	-	-	-	-	-	-
Hesperophylax sp.	-	-	-	-	-	-	-	-	-	-
Hydatophylax argus	-	-	-	8	1	10	-	-	-	-
Lepidostomatidae:										
Lepidostoma sp.	-	-	268	-	-	-	-	-	-	-
DIPTERA										
Simuliidae:										
Simulium sp.	-	-	-	-	2	-	-	-	-	1
Empididae:										
sp.	-	-	-	-	-	-	-	-	2	-
Hemerodromia sp.	-	-	-	-	2	-	-	5	-	-
Oreogeton sp.	-	-	-	-	-	-	-	4	-	-
Tipulidae:										
Antocha sp.	-	-	-	-	1	-	-	-	-	-
Tipula abdominalis	-	-	-	4	-	-	-	-	-	-
Chironomidae:										
Tanypodinae:										
Pentaneura sp.	6	-	-	-	-	-	-	-	-	-
Procladius sblettei	-	-	-	4	-	-	-	-	-	-
Thienemannimyia gr. spp.	-	14	-	20	22	-	-	16	17	-

APPENDIX 1. (continued): Macroinvertebrates collected using the Ohio EPA Hester-Dendy artificial substrata to create the ICI. Collections occurred June 15 to August 22, 1997.

TAXA	SITES S1	M1	S3	M2	S4	M3	S5	M4	M5	M6
DIPTERA										
Orthocladinae:										
Brillia flavifrons	-	-	-	-	-	-	-	-	-	25
Heterotrissocladius marcidus gr.	-	-	10	-	-	-	4	-	-	-
Parametriocenemus lundbecki	-	21	-	-	-	3	-	-	-	-
Chironominae:										
Chironomini:										
Chironomus decorus gr.	38	-	-	-	-	-	-	-	-	-
Chironomus sp.	-	-	-	56	-	-	-	-	-	-
Microtendipes sp.	18	-	-	-	-	80	-	-	-	4
Polypedilum sp.	-	31	-	20	59	80	8	25	50	-
Tanytarsini:										
Zaverelia sp.	18	14	5	-	-	-	-	14	59	-
TOTALS	98	112	466	352	346	248	454	151	389	404

TOTAL NUMBER = 3020 **TOTAL NUMBER OF TAXA = 83**

APPENDIX 2 - Macroinvertebrates collected using the New York State DEC Traveling - Kick method. Collections occurred on August 14, 1997.

TAXA	SITES S1	M1	S3	M2	S4	M3	S5	M4	M5	M6
ANNELIDA										
Oligochaeta:	-	1	-	-	1	-	7	-	-	4
Hirudinea:										
Glossiphoniidae sp.	-	-	-	-	-	-	8	-	-	-
GASTROPODA										
Physidae:										
Aplexa elongata	-	-	-	-	-	-	2	-	-	-
Physella sp.	-	1	-	-	-	-	-	-	-	-
P. heterostropha	-	-	-	-	-	-	-	-	-	1
P. magnalacustris	-	-	-	-	-	-	-	-	2	-
Planorbidae:										
Planorbella campanulata	-	1	-	-	-	-	-	-	-	-
Helisoma anceps	-	-	-	-	-	-	2	-	-	-
CRUSTACEA										
Decapoda sp.	-	-	-	-	-	1	-	-	-	-
Asellidae:										
Caecidota sp.	-	-	15	-	-	-	4	-	-	-
Talitridae:										
Hyalella azteca	-	1	-	-	-	1	42	-	-	-
HYDRACARINA:										
sp.	-	1	-	1	-	-	1	-	-	-
EPHEMEROPTERA										
Siphlonuridae:										
Siphlonurus sp.	-	-	2	1	-	-	2	-	-	-
Ameletus sp.	-	-	7	-	-	-	-	-	3	-
Baetidae:										
Uknown sp.	-	-	-	2	-	-	-	-	-	-
Baetis sp.	-	-	-	-	-	-	-	-	1	7
Callibaetis sp.	-	-	-	-	3	-	-	-	3	-
Centroptilum sp.	-	1	-	-	-	-	-	-	-	-
Olgoneuriidae:										
Isonychia sp.	-	-	-	-	-	-	-	-	-	2
Ephemeridae										
Hexagenia sp.	-	-	-	-	-	-	-	1	-	-
Heptageniidae:										
Unknown sp.	-	-	-	-	2	-	-	-	-	-
Anepeorinae sp.	-	-	-	-	-	-	-	-	-	-
Macdunnea sp.	-	-	-	4	-	-	-	-	-	-
Stenocron sp.	-	-	-	-	-	-	-	-	-	-
Stenonema femoratum	-	-	-	-	-	-	-	-	-	-
S. mediopunctatum	-	-	-	-	-	-	-	-	1	-
S. modestum	-	-	-	-	-	-	-	7	-	-
S. pulchellum	-	-	-	13	-	-	-	-	-	-

APPENDIX 2 (continued): Macroinvertebrates collected using the New York State DEC Traveling - Kick method to create the BAP. Collections occurred on August 14, 1997.

TAXA	SITES S1	M1	S3	M2	S4	M3	S5	M4	M5	M6
EPHEMEROPTERA										
Stenonema smithae	-	-	-	-	-	8	-	3	-	1
Unknown sp.	-	-	-	-	2	-	-	-	-	-
Caenidae:										
Caenis sp.	-	-	-	1	-	-	3	1	-	-
ODONATA										
Gomphidae:										
Lanthus sp.	-	-	-	-	-	1	-	1	-	1
Stylogomphus sp.	-	-	-	-	-	-	-	2	1	-
Aeshnidae:										
Anax junicus	-	-	-	1	-	-	-	-	-	-
Macromiidae:										
Macromia sp.	-	-	-	-	-	-	4	-	-	-
Coenagrionidae:										
Enallagma sp.	-	-	-	-	-	-	1	-	-	-
PLECOPTERA										
Chloroperlidae:										
Utaperla sp.	-	-	27	16	-	-	-	-	-	-
Pteronarcyidae:										
Pteronarcys sp.	-	-	-	-	1	-	-	-	-	-
Capniidae:										
Allocapnia granulata	-	-	-	-	10	1	-	-	-	-
Perlidae:										
Acroneuria ruralis	-	-	-	2	-	-	-	-	-	-
COLEOPTERA										
Psphenidae:										
Ectopria sp.	-	1	-	3	-	1	-	-	-	1
Elmidae:										
Dubiraphia bivittata	-	-	-	-	2	2	-	-	-	-
Macronychus sp.	-	-	-	-	-	-	-	4	-	-
Olimnius sp.	-	-	3	6	16	22	-	-	-	-
O. latiusculus	-	-	-	-	-	-	-	-	-	4
Optioservus sp.	-	-	30	-	-	20	-	12	2	-
O. trivittatus	-	-	-	-	-	-	-	-	-	3
Promoresia tardellae	-	2	-	-	-	-	-	1	-	-
P. elegans	-	-	-	5	-	-	-	-	-	-
P. sp.	-	-	-	-	3	-	-	-	-	-
Stenelmis mirabilis	-	1	-	-	-	-	-	-	-	-
S. sp.	1	-	11	4	11	-	-	1	-	-
Sciritidae:										
Unknown sp.	-	-	-	-	1	-	-	-	-	-

APPENDIX 2 (continued): Macroinvertebrates collected using the New York State DEC Traveling - Kick method to create the BAP. Collections occurred on August 14, 1997.

TAXA	S1	M1	S3	M2	S4	M3	S5	M4	M5	M6
					SITES					
MEGALOPTERA										
Corydalidae:										
Nigronia serricornis	-	-	-	4	-	5	-	23	6	11
NEUROPTERA										
Unknown sp.	-	-	-	-	-	-	-	1	-	-
TRICHOPTERA										
Philopotamidae:										
Chimarra sp.	-	-	-	1	3	10	-	-	5	14
Polycentropodidae:										
Neureclipsis sp.	-	-	-	1	-	-	-	3	2	3
Hydropsychidae:										
Cheumatopsyche sp.	-	3	-	-	-	-	-	6	1	-
Diplectrona sp.	-	-	4	-	-	-	1	-	-	-
Hydropsyche sp.	-	-	-	-	37	17	-	-	47	28
H. slossona	-	61	-	7	-	-	-	-	-	-
Potamyia sp.	-	-	-	-	-	2	-	-	-	9
Rhyacophilidae:										
Rhyacophila sp.	-	-	-	-	-	-	-	-	4	-
R. fuscula	-	-	-	1	4	-	-	-	-	9
Hydroptilidae:										
Stactobiella sp.	-	-	-	-	-	-	-	1	1	-
Limnephilidae:										
Hydatophylax sp.	-	-	-	1	-	-	-	-	-	-
Unknown sp.	-	-	-	-	-	-	-	-	-	1
Lepidostomatidae:										
Lepidostoma sp.	-	-	-	-	-	-	-	-	-	1
DIPTERA										
Athericidae:										
Atherix sp.	-	-	-	1	-	-	-	-	-	-
Ceratopogonidae:										
Unknown sp.	-	-	-	-	-	1	-	-	-	-
Simuliidae:										
Simulium sp.	-	1	-	-	-	-	-	-	-	-
Empididae:										
Uknown sp.	-	-	-	-	1	3	-	2	1	-
Scathophagidae:										
Uknown sp.	-	-	-	-	-	2	-	-	-	-
Tanpanidae:										
Unknown sp.	-	-	-	-	-	-	-	1	-	-
Tipulidae:										
Unknown sp.	-	-	1	-	-	1	-	-	-	-
Antocha sp.	-	-	-	1	-	-	-	-	-	-

APPENDIX 2 (continued): Macroinvertebrates collected using the New York State DEC Traveling - Kick method to create the BAP. Collections occurred on August 14, 1997.

TAXA	S1	M1	S3	M2	S4	M3	S5	M4	M5	M6
					SITES					
DIPTERA										
Chironomidae:										
Tanypodinae:										
Ablabesmyia sp.	-	-	-	-	-	-	23	27	-	-
Natarsia sp.	-	25	-	-	-	-	-	-	-	-
Procladius subletti	26	-	-	-	-	-	-	-	-	-
Thienemannimyia gr. spp.	-	-	-	-	1	2	-	1	10	-
Polypedilum fallax gr.	-	-	-	-	2	-	-	-	-	-
P. illinoense	-	-	-	24	-	-	-	1	-	-
Paratendipes sp.	-	-	-	-	-	-	-	-	3	-
Tanytarsini:										
Zaverelia	-	-	-	-	-	-	-	1	7	-
TOTAL	27	100	100	100	100	100	100	100	100	100

TOTAL NUMBER = 927 **TOTAL TAXA = 84**

Comparison of Fish Communities in Open and Occluded Freshwater Tidal Wetlands in the Hudson River Estuary

A Final Report of the 1997 Tibor T. Polgar Fellowship Program

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ABSTRACT

Original nearshore fish community data was collected using beach seines in open shallows and pop nets in *Trapa natans* beds in the freshwater tidal Hudson River at Norrie Point (NP) and Tivoli South Bay (TSB) to determine if the occlusion by the railroad bridges caused a difference in the fish community structure in these areas. The data collected allow the detection of changes in the fish communities of these nearshore habitats of the Hudson River. The two sampling methods at two sites resulted in four different fish community assemblages in open shallows and vegetated shallows. Fourspine sticklebacks and common carp were dominant in *T. natans* in TSB, but brown bullheads, redbreast sunfish, and tessellated darters were the main fishes in the NP *T. natans*. Cyprinids and moronids were dominant in the open water at TSB, while clupeids, cyprinids, and centrarchids dominated the open water at NP. Our TSB pop net data are consistent with previous work, but this does not imply that the fish community in the *T. natans* is representative of the rest of the river. Catch per unit effort differed significantly between the pop net efforts at the two sites and with the two sample methods at TSB. Water temperature significantly differed between the beach seines at the two sites.

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INTRODUCTION

Tidal wetland management is an important aspect of the mission of the National Estuarine Research Reserve (NERR) Program. The Hudson River NERR manages four sites including over 1295 ha of brackish and freshwater tidal wetlands. Tidal fresh wetlands are relatively rare globally and are located primarily along the Atlantic coast of the northeastern United States (Mitsch & Gosselink 1993).

Tidal wetlands are important as areas of high diversity and productivity. A number of economically and ecologically valuable freshwater and anadromous fish species are dependent upon the spawning and nursery habitat of marshes and vegetated shallows (Mitsch & Gosselink 1993). In the freshwater Hudson River, these include forage fish (river herrings, Clupeidae and shiners, Cyprinidae), as well as game fishes (basses and sunfishes, Centrarchidae; and striped bass, *Morone saxatilis*). The forage fish are important for exporting marsh productivity to the main river as fish biomass (Smith & Schmidt 1987). Fish community data exist for a number of fresh tidal marshes on the Hudson River.

The majority of the coastal wetlands of the Hudson River were affected by railroad construction along the shores in the mid-1800s. Cara Lee, environmental director of Scenic Hudson Inc., believes the railroad was second only to the construction of the Federal Dam at Troy as a significant impact upon the river (1996, personal communication). Both projects affected tidal flow and historic spawning areas. The railroad bed added approximately 800 ha of land to connect islands and fill in small coves (Young & Squires 1990). Causeways were constructed in order to straighten the track. Open channels in the causeways allow for water and material exchange between these embayments and the river. In many instances, the channels proved inadequate, constraining circulation and creating sediment traps (Squires 1992). As these embayments filled with sediment, they became sites of new growth of emergent vegetation. These former vegetated shallow water bays have become emergent marshes and later successional stages.

Vegetated bays will gradually fill with sediments as the vegetation decreases the kinetic energy of suspended materials within the currents and tides. This increases the succession rate as the open bay succeeds to a wetland with emergent vegetation replacing the submerged and floating-leafed vegetation. Areas where free current flow and material exchange are inhibited will make this change more rapidly. Kiviat (1978) believed that limited tidal circulation was the greatest threat to the existing open water and low marsh in the Tivoli Bays ecosystem. Pools in Tivoli North Bay (TNB) have been filling in since 1971 (Kiviat 1991).

European water chestnut (*Trapa natans*) is an exotic, floating leafed plant with a distinctive spiked seedpod. It was inadvertently introduced to the Hudson River watershed in the 1860s. It thrives in calm, shallow, nutrient-rich waters and is now established in a majority of these areas on the Hudson, including Tivoli South Bay (TSB). *T. natans* provides significant habitat and provides for a complex food web within the vegetated bays (Yozzo & Odum 1989). The stand of water chestnut in TSB has caused this wetland to begin to act as a more efficient sediment trap (Goldhammer & Findlay 1988). This increasing sedimentation in TSB could result in an emergent marsh like TNB in "several decades" (Kiviat 1978, 1991).

Do Occlusions to Marshes and Bays Affect Fish Communities?

We hypothesized that fish community diversity will be lower in partially occluded sites in comparison to open sites. Species density will be affected by the causeway by trapping fish within the occlusion. This research involved the collection of original ecological data on fish community structure in tidal wetlands and a review of the existing Hudson River fisheries literature. This information can be used to determine potential trends in the fisheries and fish ecology in the Hudson River. Implications for management of resource species can be drawn from the results. This information can also be used for tidal wetland management. We compared the fish communities among vegetated bays and within fresh tidal marshes in an open tidal flow area (Norrie Point) to a partially occluded area

METHODS & MATERIALS

Description of the Study Area

The Dutchess Community College Norrie Point Environmental Site (NP) is located in Mills-Norrie State Park in Staatsburg, N.Y. (lat 41°49.80' N, long 73°56.40' W) (Figure 1). The site is on a peninsula on the east bank of the Hudson River, 85 mi. (137 km) north of the mouth of the Hudson River at the Battery (Manhattan). Norrie Point has a beach at the east cove with a soft silty bottom that is filled with *T. natans* and water-milfoil (*Myriophyllum spicatum*) from May through October.

Tivoli South Bay (TSB) (lat 42°01.22' N, long 73°55.20' W) (Figure 2) is located at Hudson River Mile (HRM) 98 (HRKM 158). It has a soft silty mud bottom with a small area of rock and gravel at the mouth of the Saw Kill and a small deeper pool at each railroad bridge. This is similar to the east cove at NP. With the exception of restrictions and barriers to tidal flow, the sites are very similar; both have southern exposures, exposed mud flats at low tide, a similar tidal range (ca. 1.2 m) and similar vegetation.

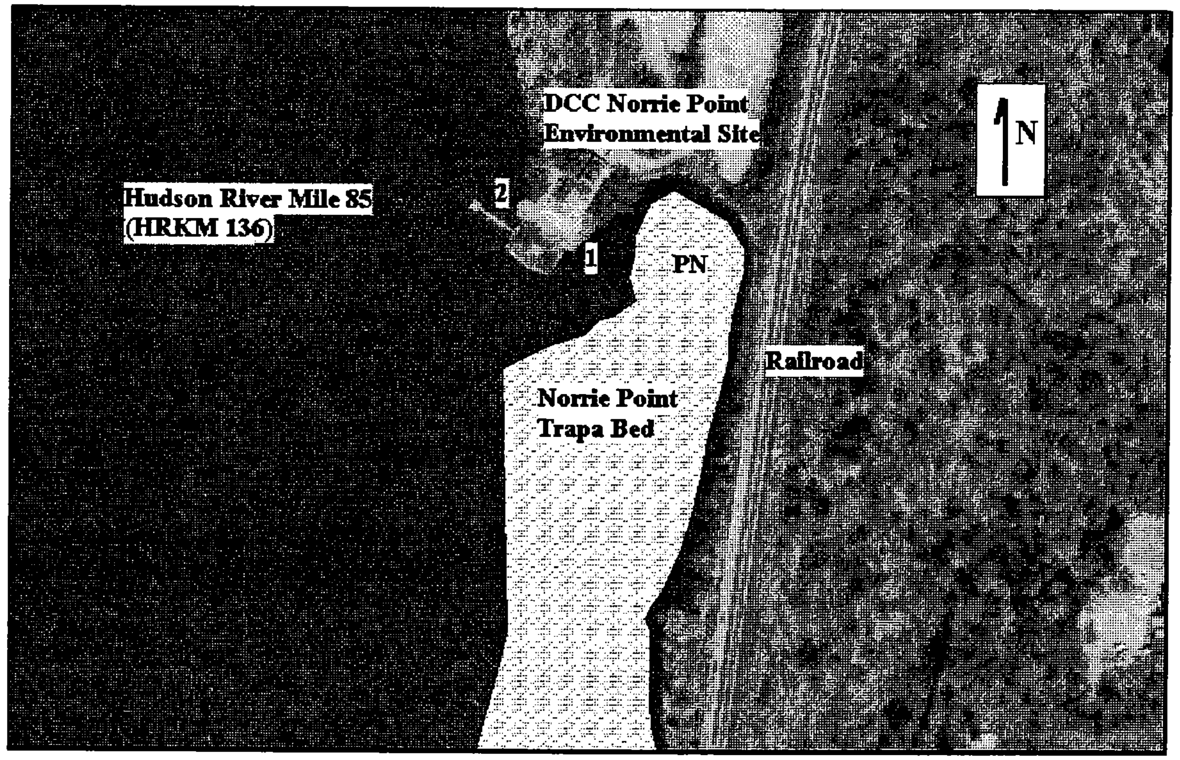

Figure 1: Norrie Point Study Site. The *T. natans* bed is crosshatched and the open water and channel are solid. The number 1 indicates the seining beach and PN indicates the area where pop netting occurred.

TSB is approximately 115 ha. Of this, *T. natans* covers about 95% of the surface from mid-May through October (Anderson & Schmidt 1989). The *T. natans* can grow quite dense. Goldhammer & Findlay (1988) determined the peak dry biomass was 400 $g{\cdot}m^{-2}$; this is denser than most other submerged aquatic vegetation (SAV).

Tidal exchange between the river and TSB is restricted to three bridge openings across the railroad causeway, which represents 3% of the original linear interface. Tidal flow comprises approximately 90% of the annual water budget for the bay (Lickus &

Barten 1989, Zelewski & Armstrong 1997). During sampling, it became evident that differences in tidal flow and scouring existed between NP and TSB. Many logs, trees, and anthropogenic debris presented hazards to wading at TSB. The lack of barriers to tidal flow at NP allows the flotsam and jetsam to typically wash freely in and out of the coves.

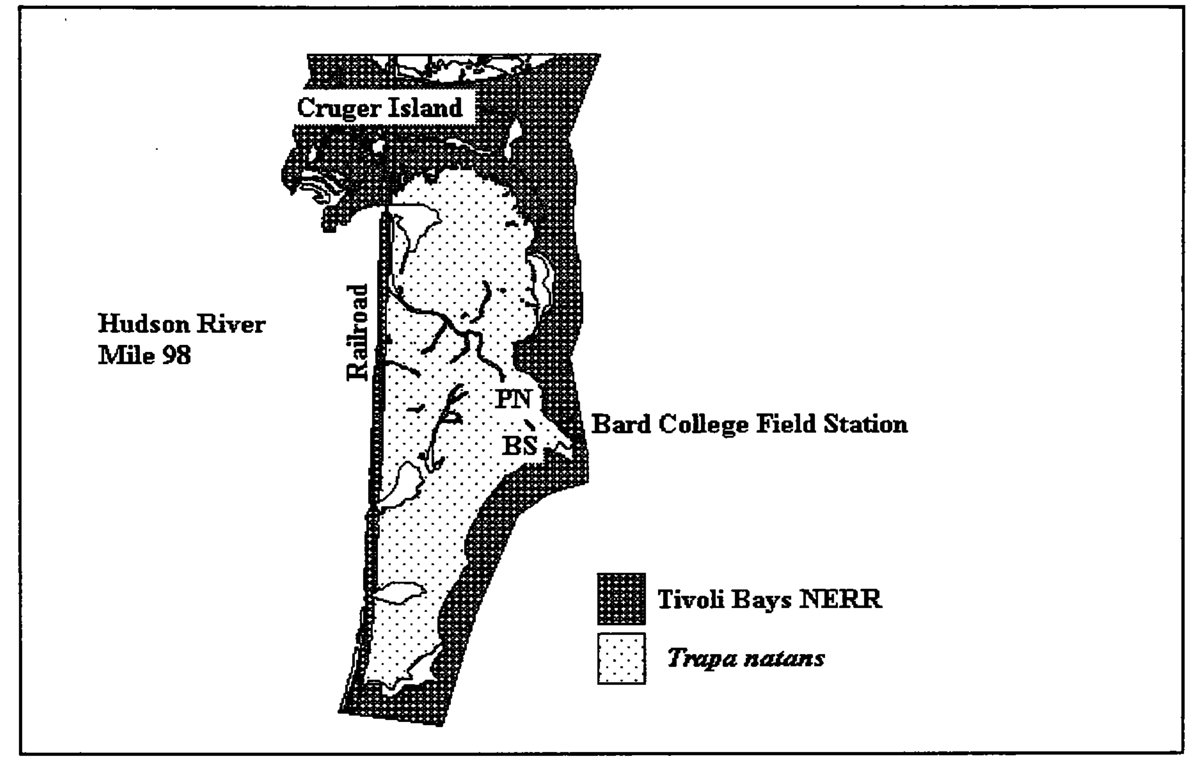

Figure 2: Tivoli South Bay Study Site. PN and BS denote the pop net area and beach seine beaches respectively. The *T. natans* bed is lightly shaded and the open water and channels are solid white.

Collection of Fish in Vegetated Shallows

Modification to Pop Nets

Using the existing pop nets (Figure 3) constructed by my predecessors (Pelczarski & Schmidt 1991; Hankin & Schmidt 1992), I modified the weighted hoop to provide added submerged weight with no carrying or transportation weight penalty. The 1" (2.54 cm) I.D. plastic water pipe and steel reinforcement rods were replaced by 1.5" (3.81 cm) PVC and 3 kg of pea gravel per length. The PVC pipes were drilled through perpendicular axes with ¼" holes at 5 cm intervals. The ends of the tubes were fitted with 3.8 cm diameter x 5 cm long wooden plugs to prevent the gravel from migrating around the elbows during storage and transport (Figure 4). Before setting the net, we shook it to distribute any gravel that had settled in the ends throughout the lengths of the pipes. This modification eliminated any inherent buoyancy of the previous designs. The water added weight to the bottom of the pop net when submerged, but readily drained when lifted to allow easier movement and transport.

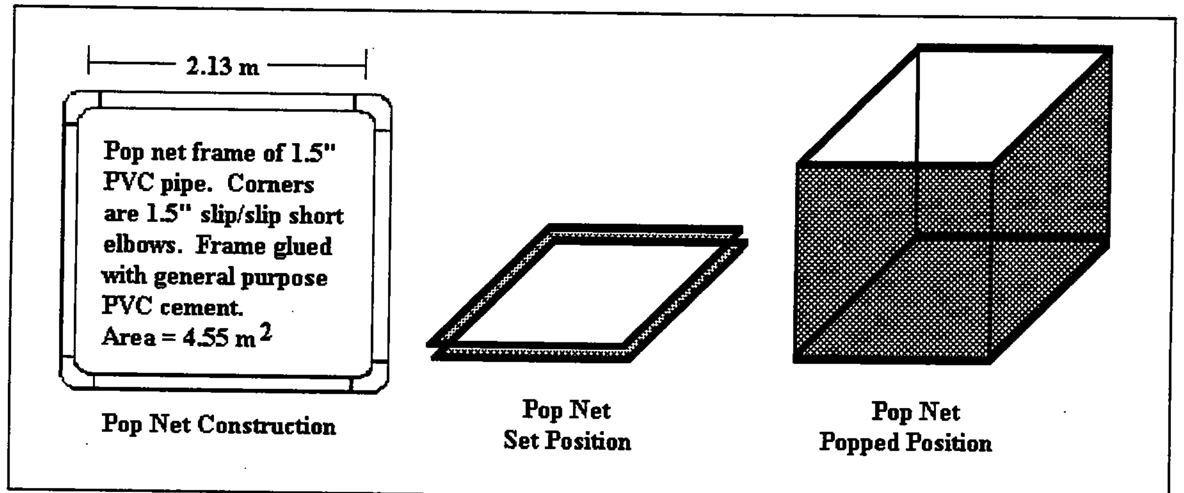

Figure 3: Pop net (L to R) Construction and top view; side views (set and popped).

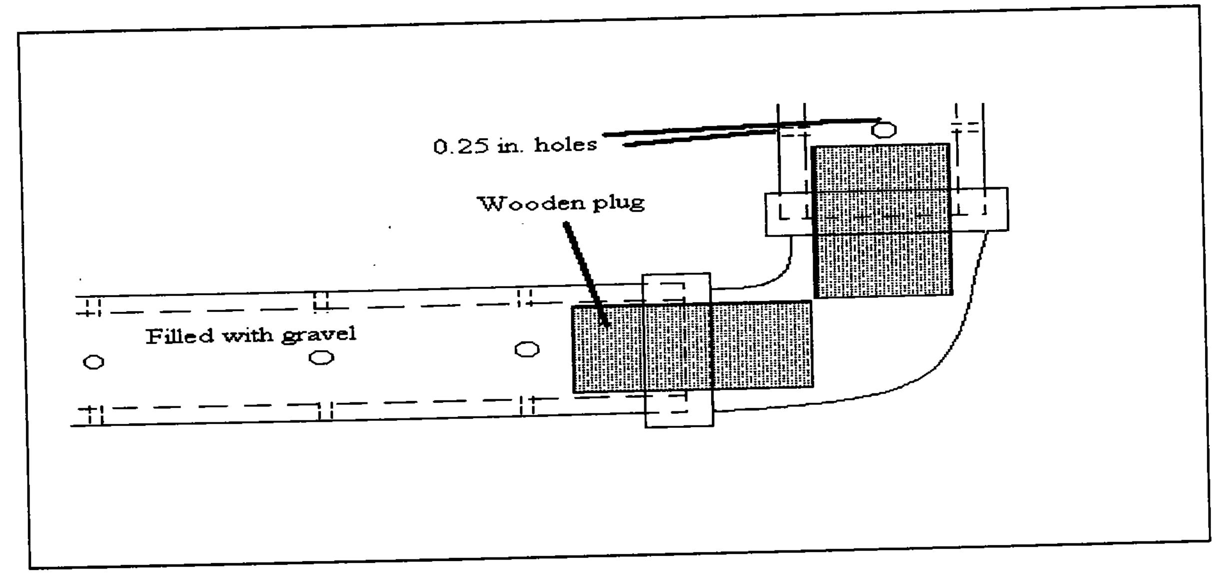

Figure 4: Cross section of pop net modifications to bottom frames.

The trigger clips were also redesigned after speaking with Dennis Mildner (HRNERR) about a potential safety factor. Galvanized U-bolts were previously used and the threads were covered with duct tape. On one occasion, the tape or threads stuck on the netting; when the trigger was pulled, the bolt became a ballistic projectile and injured someone. The new triggers were constructed of 3 x 25 mm aluminum plate bent to fit the pipe frame (Figure 5). The aluminum provided a lower friction surface and easier trigger release. Rubber bands were used to secure the clips to the nets.

Figure 5: Trigger design for pop nets

The trigger release technique was also modified to eliminate possibilities of injury. Rather than pulling the trigger line upward from shoulder height, the trigger pullers would place a foot on the line and hold the buoy. By sliding the foot away from the net and pulling the line using the foot as a pivot point, the clips would release underwater without any possibility of cranial impact.

Collections with Pop Nets

The modified pop nets (after Hankin & Schmidt 1992) were used to sample the fish communities in the densely vegetated areas. The pop nets were set at low tide at random locations within a predetermined sampling area (Figs. 1 and 2). When setting the net, care was taken to clear any debris that may tear the netting. The frames had to be set on the bottom and not upon any vegetation. All *T. natans* rosettes had to be moved either to the inside or outside of the net to prevent the bottom frame from floating or pulling up when the net was popped.

The nets remained in place for approximately 8 h, and were popped 2 h after high tide. Once the net was popped, the *T. natans* was cleared from within the net and around the perimeter to allow sampling with seines. A 6 x 1.2 m nylon seine with 2 mm mesh was used to sample the interior of the pop net. The pop net was seined four times in one direction and then rotated around the pop net in a clockwise manner. The sampling continued until we hauled five consecutive empty seines. This allowed the sampling to be quantitative.

This sampling was most efficient when done by at least three people. This allowed two to pull the seine and the third to collect the fish. Small dip nets were used to make catching of fish in the corners of the pop net easier. Sampling, cleanup, and fish counting typically took 2 to 3 h. A foam "boogie" board served as an effective floating work and transport platform.

Collection of Fish in Open Shallows

Open water sampling was done with a 25 x 1.5 m bag seine of 5 mm square knotless nylon mesh in shallow open waters. Seines were pulled in flowing water at two

hours after low tide. The seine was extended perpendicular to shore and then encircled to the starting point. The seine hauls covered approximately 300 m^2 of water surface area at NP and 150 m^2 at TSB. Seining is a qualitative sampling method used to document species not caught in the pop net (Hankin & Schmidt 1992). This can help to provide a better picture of the species composition within the overall fish community. Additional surveys were also attempted using snorkeling and documenting with underwater still photography (Whitworth & Schmidt 1980; Kirker 1989).

We sampled for seven weeks, between 8 July and 21 August 1997. The sites were sampled on an approximately weekly basis. Sampling times were based on the tides and the total process time (pop net set to pop net clean and count), which required up to 13 h. The times were chosen so that the net could be popped and sampled during daylight. This allowed comparison to previous Polgar efforts, which were all diurnal surveys.

Data Quantification

Fish were transferred to pails of river water, identified, and counted. Common fish were identified on sight. Unknown fish were identified using Smith (1985). Recognized experts on regional fish fauna (Tom Lake and Robert Schmidt) verified fish identifications. A representative subsample was preserved in 10% formalin and the fish were measured to the nearest millimeter in total length.

Water temperature, state of tide, and other observations were gathered for each collection. Voucher specimens were maintained at the Dutchess Community College Norrie Point Environmental Site. Additional specimens will be provided to the New York State Museum.

Data were analyzed by comparing relative abundance by species using chi-square analysis. I compared my TSB and NP pop net data against those of my predecessors (Pelczarski & Schmidt 1991; Hankin & Schmidt 1992). At NP, I have a weekly beach seine data set (unpublished) from ice-out to ice-in (4 March 1996 to 6 January 1997) for 1996. Since this is the most comprehensive data for the site, this was set as the expected composition against the NP pop net and beach seine Polgar data. Densities (fish·m^{-2}), catch per sample effort, and water temperatures were analyzed with student *t*-tests. Significance was determined at an $\alpha = 0.05$ level for all tests.

RESULTS

Seven sets of weekly samples (beach seine and pop net) were done at each site (TSB and NP). A total of 1987 fish representing 11 families and 23 species were caught (Tables 1 and 2). Overall, more individuals, species, and families were found at NP than TSB. TSB pop net densities were higher than NP. Pop net densities at both sites were one to two orders of magnitude greater than the densities of the beach seines. Pop netting at both sites caught an equal number of species (13), but the community composition was different. Species diversity in beach seines was higher at NP compared to TSB.

Table 1: Summary of fish caught by location and sampling method. NP = Norrie Point, TSB = Tivoli South Bay, BS = Beach Seine, PN = Pop Net

Sample Location	Sample Method	Number Of Fish	Mean Fish per Sample	Number of Species	Number of Families	Mean Density (fish/m^2)
NP	BS	1270	181.4	20	10	0.61
NP	PN	219	31.3	13	7	6.88
NP	**Total**	**1489**	**106.4**	**20**	**10**	**3.64**
TSB	BS	133	19.0	12	7	0.13
TSB	PN	365	52.1	13	7	11.46
TSB	**Total**	**498**	**35.6**	**17**	**9**	**10.89**

The two sample methods at the two different locations resulted in four different fish communities (Table 2). The fish community assemblages were expected to be different between the two sampling methods since they sample different areas and water conditions. Anderson & Schmidt (1988) found a difference between the ecotone community and the TSB *T. natans* beds and open water areas in both species composition and density due to current. Due to the limited area covered, the ecotone was determined to not present a significant habitat in TSB.

This is not necessarily the case at NP. The ecotone at NP, because of the lack of the railroad causeway, is the entire interface between the main river and the channel. NP has 4.25 ha more open shallow water than TSB. Our hypothesis was that the overall communities would differ between NP and TSB due to the difference in occlusion of tidal flow by railroad bridges and isolation from the main river.

Table 2: List of families and species by location and sampling method. (NP = Norrie Point, TSB = Tivoli South Bay, BS = Beach Seine, PN = pop net)

	Location Sampling Method	NP BS	NP PN	TSB BS	TSB PN
Anguillidae	**Freshwater Eels**				
Anguilla rostrata	American Eel	♦	♦		♦
Clupidae	**Herrings**				
Alosa aestivalis	Blueback Herring	♦			
Alosa pseudoharengus	Alewife	♦	♦		
Alosa sapidissima	American Shad	♦			
Cyprinidae	**Carps & Minnows**				
Cyprinus carpio	Common Carp	♦	♦	♦	♦
Luxilus cornutus	Common Shiner	♦	♦	♦	
Notemigonus crysoleucas	Golden Shiner	♦	♦	♦	♦
Notropis hudsonius	Spottail Shiner	♦	♦	♦	♦
Catostomidae	**Suckers**				
Catostomus commersoni	White Sucker	♦		♦	
Ictaluridae	**Bullhead Catfishes**				
Ameiurus nebulosus	Brown Bullhead	♦	♦		♦
Belonidae	**Needlefishes**				
Strongylura marina	Atlantic Needlefish	♦			
Fundulidae	**Killifishes**				
Fundulus d. diaphanus	Eastern Banded Killifish	♦	♦		♦
Fundulus heteroclitus	Mummichog			♦	♦
Gasterosteidae	**Sticklebacks**				
Apeltes quadracus	Fourspine Stickleback			♦	♦
Moronidae	**Temperate River Basses**				
Morone americana	White Perch	♦		♦	
Morone saxatilis	Striped Bass	♦		♦	
Centrarchidae	**Sunfishes**				
Ambloplites rupestris	Rock Bass			♦	♦
Lepomis auritus	Redbreast Sunfish	♦	♦		♦
Lepomis gibbosus	Pumpkinseed Sunfish	♦	♦		♦
Lepomis macrochirus	Bluegill Sunfish	♦	♦		
Micropterus salmoides	Largemouth Bass	♦	♦	♦	♦
Percidae	**Perches**				
Etheostoma olmstedi	Tessellated Darter	♦	♦	♦	♦
Perca flavescens	Yellow Perch	♦			

The fish communities in the TSB *T. natans* beds have been studied in two previous Polgar Fellowships (Pelczarski & Schmidt 1991; Hankin & Schmidt 1992). These were the only two Hudson River *T. natans* pop net surveys I was able to find. This proj-

ect attempted to determine if TSB's fish community was representative of the rest of the Hudson River *T. natans* beds. We compared our data (Table 3) to those of Hankin & Schmidt (1992) using a chi-square test. They were not significantly different ($\alpha = 0.05$). Our community data, however, were significantly different ($X^2=27.46$) from those of Pelczarski & Schmidt (1991). Our pop net sampling caught more fish per netting effort, more total fish, and more species than my predecessors, but we are unable to explain why this was the case.

Table 3: Fish caught in pop nets at Tivoli South Bay. RA represents Relative Abundance (percent) of fishes caught. Catch frequency is the frequency that a species was caught in seven samples. The 1991 data are from Hankin & Schmidt (1992) and 1990 data are from Pelczarski & Schmidt (1991).

Species	Common Name	Catch Freq.	Total Fish	1997 RA	1991 RA	1990 RA
Apeltes quadracus	Fourspine Stickleback	7/7	204	55.9	64.0	75.3
Cyprinus carpio	Common Carp	7/7	99	27.1	29.0	18.5
Fundulus d. diaphanus	Banded Killifish	2/7	31	8.5	1.3	2.5
Notropis hudsonius	Spottail Shiner	5/7	11	3.0	---	0.7
Ambloplites rupestris	Rock Bass	4/7	5	1.4	4.0	---
Micropterus salmoides	Largemouth Bass	1/7	4	1.1	---	---
Ameiurus nebulosus	Brown Bullhead	2/7	2	0.5	---	---
Etheostoma olmstedi	Tessellated Darter	1/7	2	0.5	---	2.2
Lepomis auritus	Redbreast Sunfish	1/7	2	0.5	---	---
Lepomis gibbosus	Pumpkinseed	2/7	2	0.5	---	---
Anguilla rostrata	American Eel	1/7	1	0.3	---	0.4
Fundulus heteroclitus	Mummichog	1/7	1	0.3	---	---
Notemigonus crysoleucas	Golden Shiner	1/7	1	0.3	1.3	---
Morone americana	White Perch	---	---	---	---	0.4
Carassius auratus	Goldfish	---	---	---	1.3	---
	Total Fish Collected		**365**	**365**	**75**	**275**
	Mean Catch/Pop Net		**52.1**	**52.1**	**9.4**	**30.6**

The species composition and relative abundance comparisons of the NP beach seine to the NP pop net and the comparisons of NP to TSB all failed the chi-square analysis at an $\alpha = 0.05$ level of significance (Tables 4-6, Fig. 6). Catch frequencies (frequency that a species was caught in seven samples) did not necessarily reflect the relative abundance. American eels were caught in each pop net at NP, but they were ranked sixth of 13 species. Brown bullheads were caught in only two samples, but ranked first.

Table 4: Fish caught in pop nets at Norrie Point. Mean catch per sample was 31.3 fish.

Species Name	Common Name	Catch Frequency	Total Fish	Relative Abundance
Ameiurus nebulosus	Brown Bullhead	2/7	71	32.4
Lepomis auritus	Redbreast Sunfish	2/7	30	13.7
Notropis hudsonius	Spottail Shiner	4/7	28	12.8
Etheostoma olmstedi	Tessellated Darter	6/7	26	11.9
Lepomis gibbosus	Pumpkinseed	2/7	16	7.3
Anguilla rostrata	American Eel	7/7	12	5.5
Cyprinus carpio	Common Carp	3/7	10	4.6
Fundulus d. diaphanus	Banded Killifish	3/7	9	4.1
Micropterus salmoides	Largemouth Bass	4/7	6	2.7
Alosa pseudoharengus	Alewife	2/7	5	2.3
Notemigonus crysoleucas	Golden Shiner	1/7	3	1.4
Lepomis macrochirus	Bluegill	1/7	2	0.9
Luxilus cornutus	Common Shiner	1/7	1	0.5
			219	**100.0**

Table 5: Fish caught in beach seines at Tivoli South Bay. Mean catch per seine was 19 fish. No fish were caught on 22 July 1997.

Species Name	Common Name	Catch Frequency	Total Fish	Relative Abundance
Notemigonus crysoleucas	Golden Shiner	2/7	47	35.3
Morone saxatilis	Striped Bass	2/7	37	27.8
Notropis hudsonius	Spottail Shiner	4/7	16	12.0
Morone americana	White Perch	1/7	8	6.0
Luxilus cornutus	Common Shiner	1/7	6	4.5
Catostomus commersoni	White Sucker	2/7	6	4.5
Ambloplites rupestris	Rock Bass	1/7	4	3.0
Apeltes quadracus	Fourspine Stickleback	1/7	3	2.3
Cyprinus carpio	Common Carp	1/7	2	1.5
Etheostoma olmstedi	Tessellated Darter	1/7	2	1.5
Micropterus salmoides	Largemouth Bass	1/7	1	0.8
Fundulus heteroclitus	Mummichog	1/7	1	0.8
			133	**100.0**

On 8 July 1997, a school of 988 juvenile spottail shiners (*Notropis hudsonius*) was caught in the NP beach seine. The fish averaged 9 mm TL and approximately 1 mm

dia. The majority of these fish would typically be able to swim through the mesh, but the site was filled with filamentous green algae (*Spirogyra*) that clogged the net. These are forage fish, the majority of which would probably have become food for a piscivorous fish in the next few months. This catch skewed the overall catch ratio of the beach seine. After conferring with Bob Schmidt and Dr. Mark Halsey, Professor of Mathematics at Bard College, this school of fish was excluded from the statistical analysis. The revised NP beach seine results are in Table 6 as "Adjusted Total" and "Adjusted Relative Abundance."

Table 6: Fish caught in beach seines at Norrie Point. Total Fish = All fish caught in this survey; RA = Relative Abundance (%); Adj. Total = total of fish without the anomalous spottail shiner school; Adj. RA = Adjusted Relative Abundance (%), recalculated without the shiner school. Mean number of fish per seine was 181.4 and 40.3 without the shiner school.

Species Name	Common Name	Catch Freq.	Total Fish	RA (%)	Adj. Total	Adj. RA
Notropis hudsonius	Spottail Shiner	3/7	1012	79.7	24	8.5
Alosa aestivalis	Blueback Herring	5/7	89	7.0	89	31.6
Lepomis gibbosus	Pumpkinseed	5/7	35	2.8	35	12.4
Micropterus salmoides	Largemouth Bass	5/7	27	2.1	27	9.6
Notemigonus crysoleucas	Golden Shiner	3/7	26	2.0	26	9.2
Luxilus cornutus	Common Shiner	3/7	19	1.5	19	6.7
Alosa pseudoharengus	Alewife	4/7	17	1.3	17	6.0
Fundulus d. diaphanus	Banded Killifish	5/7	14	1.1	14	5.0
Lepomis auritus	Redbreast Sunfish	2/7	7	0.6	7	2.5
Alosa sapidissima	American Shad	1/7	6	0.5	6	2.1
Cyprinus carpio	Common Carp	4/7	6	0.5	6	2.1
Morone saxatilis	Striped Bass	1/7	3	0.2	3	1.1
Ameiurus nebulosus	Brown Bullhead	1/7	2	0.2	2	0.7
Anguilla rostrata	American Eel	1/7	1	0.1	1	0.4
Catostomus commersoni	White Sucker	1/7	1	0.1	1	0.4
Etheostoma olmstedi	Tessellated Darter	1/7	1	0.1	1	0.4
Lepomis macrochirus	Bluegill	1/7	1	0.1	1	0.4
Morone americana	White Perch	1/7	1	0.1	1	0.4
Perca flavescens	Yellow Perch	1/7	1	0.1	1	0.4
Strongylura marina	Atlantic Needlefish	1/7	1	0.1	1	0.4
			1270	**100.0**	**282**	**100.0**

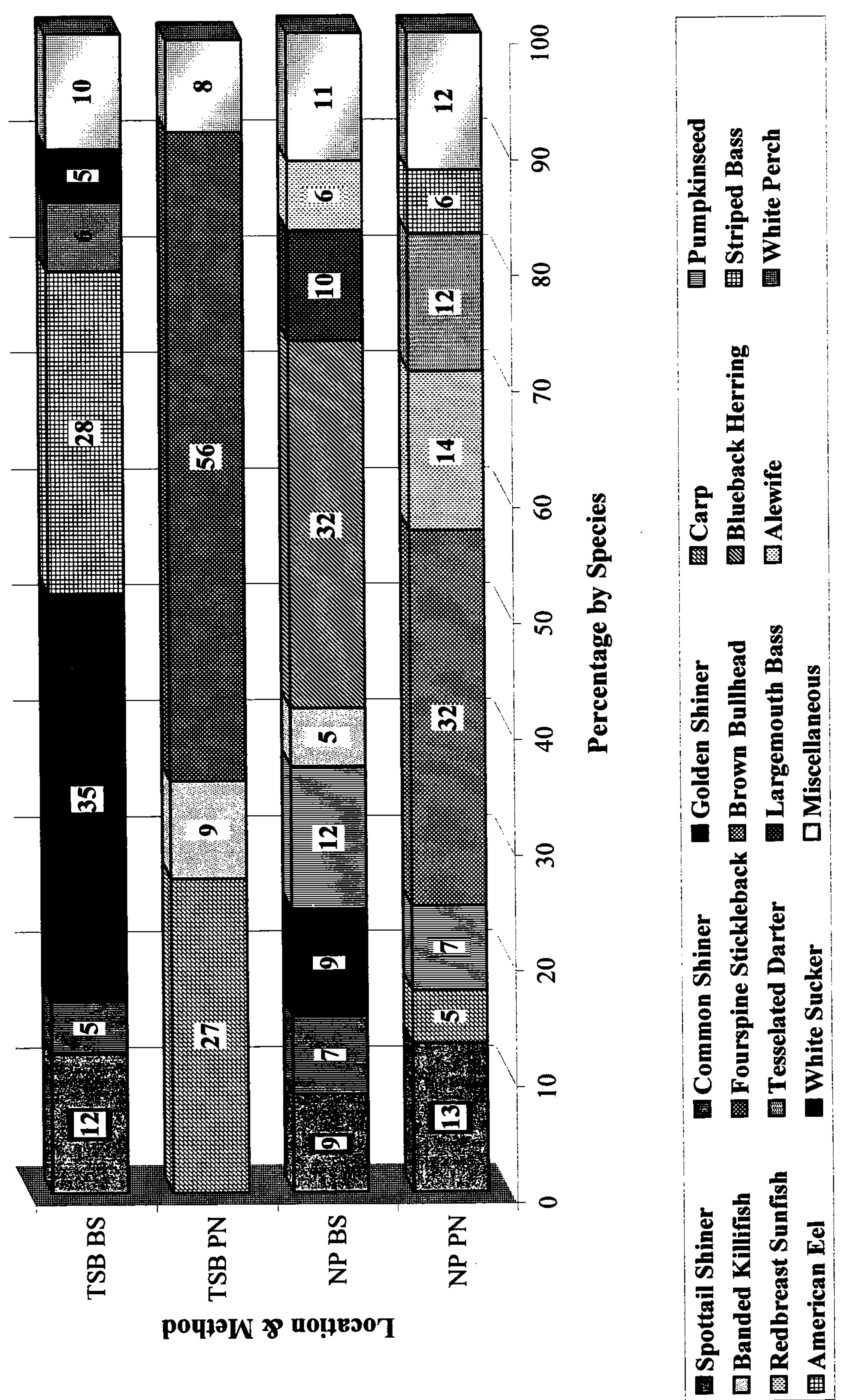

Figure 6: Comparison of fish communities by location and sampling method. TSB = Tivoli South Bay, NP = Norrie Point, BS = Beach Seine, PN = Pop Net. Species ranking 5% or greater are graphed. "Miscellaneous" accounts for the remaining species.

Catches per unit effort (seine or pop net) were analyzed using two-tailed student *t*-tests. On 1 August 1997, a large hole was torn in the perimeter netting of the pop net at NP. This may have been the cause of the low number of fish (14) caught in that particular sample. The fish catches in the pop nets at the two sites were significantly different ($t = -2.488$). The mean fish catches in the two methods at TSB were also significantly different ($t = 3.579$). No significant differences were found between the two sampling methods at NP ($t = -0.919$) and the beach seine sampling at the two sites ($t = -2.032$). The results are summarized in Table 7.

Water temperature data were recorded with each sampling effort (Fig. 7). The statistical analysis was done on these data using student *t*-tests (Table 8). There was a significant difference between the mean temperature during the beach seines at the two sites ($t = 2.746$). All other comparisons were considered statistically insignificant.

Table 7: Summary of statistical comparison of fish catch efforts. (NP = Norrie Point, TSB = Tivoli South Bay, PN = pop net, BS = beach seine, SIG = significant, NSD = no significant difference). The *t* values were considered significant at $\alpha_{0.05(6)}$ Δ ±2.447.

Comparison	*t* value	Significance
NP PN v. TSB PN	-2.488	SIG
NP PN v. NP BS w/o spottail shiner school	-0.919	NSD
TSB PN v. TSB BS	3.579	SIG
TSB BS v. NP BS w/o spottail shiner school	-2.032	NSD

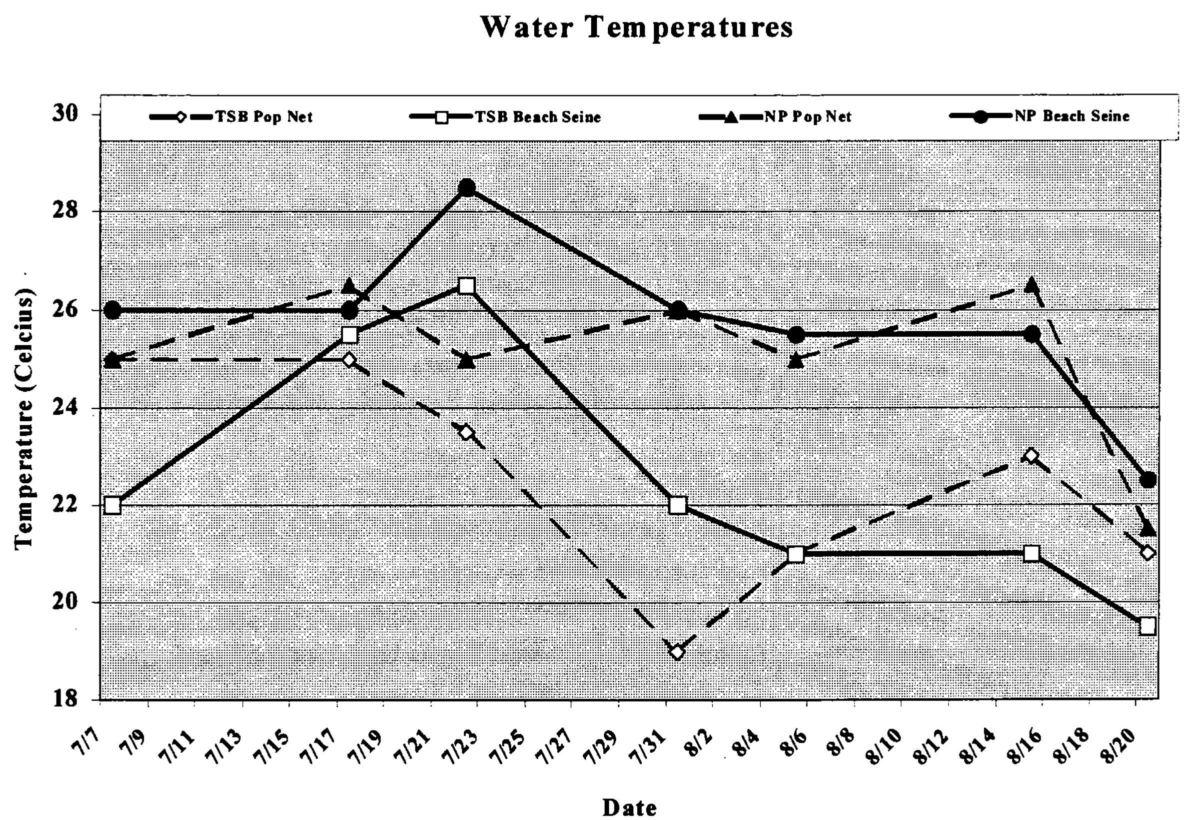

Figure 7: Graph of water temperatures by location and sampling method. A rain squall on 31 July 1997 at TSB lowered the PN temperature by 3° C.

Table 8: Summary of statistical comparison of water temperature during sampling. (NP = Norrie Point, TSB = Tivoli South Bay, PN = pop net, BS = beach seine, SIG = significant, NSD = no significant difference). The *t* values were considered significant at $\alpha_{0.05(6)}$ Δ ±2.447.

Comparison	*t* value	Significance
NP PN v. TSB PN	2.397	NSD
NP PN v. NP BS	-0.693	NSD
TSB PN v. TSB BS	0.000	NSD
NP BS v. TSB BS	2.746	SIG

DISCUSSION

By determining if occlusions and impoundments affect fish communities, this research can be used to determine habitat requirements for maintaining resource species. If railroad beds and bridges truly represent blockages to spawning and nursery areas in the majority of Hudson River tidal wetlands, approaches to restore natural and proper hydrology must be planned and implemented.

Our TSB pop net data are consistent with those of Pelczarski and Schmidt (1991) and Hankin and Schmidt (1992). This implies that this fish community has been relatively stable for the last eight years. TSB has been the site for the majority of Hudson River *T. natans* research. It does not necessarily imply that TSB accurately represents the fish communities in other *T. natans* beds.

Our data at NP show a significant difference in overall communities when compared to TSB (Fig. 6). NP had more adult and larger fish (primarily spawning centrarchids) than TSB in the open water and channel areas, particularly earlier in the sampling period. Total fish density was nearly three times higher in TSB than NP (Table 1).

Our pop net data show that most of the fish found in the *T. natans* beds are juveniles, thus confirming the hypothesis that these areas serve as nurseries. A number of adult banded killifish (*Fundulus d. diaphanus*), fourspine sticklebacks (*Apeltes quadracus*), and a 38 cm American eel (*Anguilla rostrata*) were present at TSB during the first two weeks of sampling (7-17 July). At NP, a single 192 mm redbreast sunfish (*Lepomis auritus*) was found on 15 August; all other fish caught were juveniles. No white suckers (*Catostomus commersoni*) were found in the *T. natans* at either site.

The fish species caught in the seines at TSB were more variable than those at NP were. Spottail shiners were found in four of the seines. All of the other fish species were only found in one or two seines. The NP community seems more consistent; six species were found in at least four seines. The summer data are consistent with my 1996 full year data. All fish, except the Atlantic needlefish (*Strongylura marina*), are commonly seen at NP.

The water temperature data show differences between sites, particularly in the beach seine samples. The open water is more apt to fluctuate in temperature due to water exchanges and mixing. The *T. natans* also causes a "greenhouse effect" by trapping heat energy. NP was consistently warmer than TSB. I believe this is due to the cool influx of water from the Saw Kill. A rain squall occurred on 31 July 1997 at TSB that lowered the water temperature by 3°C in about 6 h. This did not statistically affect the comparison between the pop net samples.

I contend that these differences are partly due to the railroad causeway, but I require more data to reach a definitive conclusion. I recommend that this project be continued at additional occluded and open sites to provide more data for analysis. Understanding the ecology of fresh tidal marshes and vegetated bays will allow for more scientifically-sound management practices.

CONCLUSIONS

Maintenance of coastal environments is a primary goal of a number of programs and agencies. The Hudson River Estuarine Management Action Plan (1996) makes managing aquatic resources the highest priority. Commitments exist to "conduct submerged

habitat inventor[ies] to define nursery areas most in need of protection for Hudson River fishes, blue crab, and food chain species" and to "study the feasibility of restoring Hudson River habitats." I believe that shallow vegetated bays are habitats that are vital to fish species and require management and restoration.

The plan includes provisions for wetland restoration and enhancement as well. "Improving tidal flow" and "removal of exotic nuisance vegetation" are listed as examples. The occlusion of tidal flow in TSB minimizes flushing currents that preclude the heavy growth of *T. natans*. This growth is somewhat controlled at NP by currents from the river, an intermittent stream, and recurrent seining activity. Rozsa (1995) described a number of wetland restorations that involve the return of original tidal regimens to flush sediments and to control emergent vegetation.

Continued community surveying will add to a database that can be used to determine if significant changes to the fish fauna are occurring in the freshwater tidal wetlands and vegetated shallows of the upper Hudson estuary. The most significant changes should be a result of changes to habitat quality. Restoration of historical tidal magnitudes and cycles to occluded areas will slow sedimentation and succession, thus preserving and restoring these disturbed coastal environments that are critical spawning and nursery habitats.

Surveys can also provide information on new exotic or transient species as they enter the Hudson watershed. Collection efforts at NP have discovered the first recorded specimens of two species for the mid-Hudson estuary: (1) bowfin (*Amia calva*) by my predecessor, Mark Warnecke, on 13 April 1988 (Smith & Lake 1990; Lake 1997), and (2) brook silverside (*Labidesthes sicculus*) by Todd Castoe and myself on 4 March 1996 (Lake 1996).

A juvenile walleye (*Stizostedion v. vitreum*) was caught on 29 June 1997 by Todd Castoe and members of the 1997 Norrie Point Summer Scholars Program. These are considered rare species for the mid-Hudson estuary according to Tom Lake (1997; personal communication). These rare occurrences are discovered due to a continuous, long-term sampling effort at NP. Comparable efforts are needed elsewhere to allow documentation of changes in fish fauna communities in the river.

RECOMMENDATIONS

The water at NP was more turbid. This, combined with fewer submerged obstacles, allowed for much better fish catching than TSB. The clearer water at TSB made sampling more difficult. Fish were observed to swim into and then out of the net. Many fish were seen swimming during the seining and were not found in the net. Use of an observed-fish versus caught-fish index, as a qualitative comparison, may be appropriate. Numerous obstacles also frequently hung the net and pulling the seine through SAV caused the net to roll upon itself. Overall, the seine allowed a qualitative look at the open water species.

I recommend the use of a 30-50 m experimental gill net with a number of mesh sizes to attempt to sample nearshore open water in the future (Montgomery & Schmidt 1992; Schmidt & Hamilton 1992). These surveys caught different fish than the seines and pop nets in this research caught (white sucker, *Catostomus commersoni*; white catfish, *Ameiurus catus*; Rudd, *Scardinius erythrophthalmus*; and gizzard shad, *Dorosoma*

cepedianum). I did make one attempt at TSB, but the submerged branches and logs presented significant hazards to the net. There are no gill net data from NP.

Based on differences in community structure between the two sites, I would recommend an additional season of pop netting for further comparisons. The TSB pop net data are consistent with previous work, but more work should be done to determine if either TSB or NP's fish community structure is more representative of a "typical" Hudson River *T. natans* bed. Due to the proximity to NP and TSB, I recommend another season of NP pop netting and additional work at Esopus Meadows (HRM 86-87) (open) and either Vanderburgh Cove (HRM 87) or Roosevelt Cove (HRM 79) (RR enclosed). These additional data should be compared to this work to determine any potential effects of occlusions upon fish communities.

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