GASTROPODS OF THE HUDSON RIVER SHORELINE: SUBTIDAL, INTERTIDAL, AND UPLAND COMMUNITIES

A Final Report of the Tibor T. Polgar Fellowship

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ABSTRACT

The tidal Hudson River shore zone is a unique and dynamic ecotone, supporting a great abundance of wildlife and fulfilling numerous ecological roles, but simultaneously subject to intense human activity. A survey was completed for gastropods inhabiting six dominant shore zone types along the Hudson River, including natural and altered shoreline structures: sand, bedrock, unconsolidated rock, riprap, sea wall and timber cribbing. Each of these shore zone types was surveyed at three river sections, lower, mid and upper, from Poughkeepsie to Albany. Three elevations were sampled at each site: sub-tidal, inter-tidal and upland. Eighteen sites between Poughkeepsie and Albany were sampled in June during two intensive trips, resulting in a total of 23 taxa of gastropods. Of these, three were exotic, including *Bithynia tentaculata*, which was represented by only one specimen, indicating a significant decline for this species since the mid-1980s. Three aquatic species were new records for the Hudson River, including *Floridobia winkleyi*, which was present in significant numbers, as well as the recently recorded *Littoridinops tenuipes*, also present in large numbers. Another new record was the presence of two specimens of the New York state listed snail *Valvata lewisi*. Two landsnails, *Pomatiopsis lapidaria* and *Vallonia costata* were also found below high tide. ANOVAs examining abundance and diversity of gastropods by shore type, elevation and river section, indicate that mid-river sites, in combination with riprap and unconsolidated rock, at inter-tidal elevations, contain significantly higher abundances and diversity of gastropods. Regression analysis indicated that fine-scale environmental variables such as site slope, rugosity and complexity do not explain the abundance and diversity of gastropods at this level of analysis. Additional analysis included NMS ordination and qualitative analysis.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

INTRODUCTION

The Hudson River is tidal for 248 kilometers from New York City to Troy. Its shoreline is complex and dynamic, and like many ecotones, supports a very diverse fauna. At the same time, the tidal shoreline is not well understood ecologically (Strayer and Smith 2000) and the human impact on it is of great significance (Limburg and Schmidt 1990). Large-river shorelines like the Hudson have sustained significant damage to their original ecological functions by virtue of the destruction of wetlands, the replacement of natural shoreline habitats with artificial and erosion-resistant riprap and bulkheads, development and pollution. Moreover, they continue to support a great deal of human activity through recreation, fishing, transportation and water withdrawals for commercial, agricultural and urban needs (Daniels et. al. 2005). Shorelines at once serve as the point of impact for many of these human activities, while simultaneously providing significant ecological services as a dynamic interface between the aquatic and upland communities.

One class of organisms common along shorelines is the gastropods (Jokinen 1992). There are at least 50 species of freshwater snails in the Hudson River Valley, of which at least four are exotic (non-indigenous to North America), and another 4-6 may be invasive (introduced from other North American regions) (Strayer 1987). In addition, there are at least 85 species of land snails in New England (Nekola 2005), most of which can be found in the Hudson Valley, though not necessarily on shore lines. Gastropods are well known as being sensitive to ecological change, particularly sensitive to pollution, and a substantial resource base for fish, crayfish, waterfowl and small mammals (Dillon

2000, 2005). However, the understanding of the role of these invertebrates within the multitude of habitats in which they exist is minimal.

Efforts to understand and conserve invertebrates was not a pressing issue for most states until the mid 1980’s, and the understanding of their ecological role remains weak (McCollough 1997). Currently there are 23 snail species on New York State’s rare animal list (NYSDEC 2008), and the status, trends and ecological needs of most of these species are poorly known.

While invertebrates make up nearly 99% of all animal diversity, they have received significantly less attention than vertebrates, with mollusks receiving even less attention despite their being considered one of the most threatened groups of animals (Lydeard et al. 2004). Between 1500-2008, 257 gastropods became extinct (37% of all animal extinctions during that time) and the number of gastropods on the International Union for Conservation of Nature Red List of Threatened Species in 2008 was 883 (IUCN 2008). Despite these numbers, less than 2% of known mollusk species have been properly assessed (Lydeard et al. 2004). Given the general decline of snail species in the United States, as well as the loss of habitat associated with that decline (Burch 1989; Lydeard et al. 2004), the ecological importance of snails (Kabat and Hershler 1993), the contribution of rare invertebrates to species richness in aquatic systems (Cao et al. 1998), and the relative lack of knowledge of gastropods, there is a need to develop a greater understanding of the gastropod communities in the Hudson River shore zone. This report provides baseline data on shoreline gastropods, and contributes to the understanding of gastropod communities along the Hudson River.

This project is part of a larger study, the *Ecological Functions of Hudson River Shorelines*, being conducted by David Strayer and Stuart Findlay of the Cary Institute of Ecosystem Studies in collaboration with the Hudson River National Estuarine Research Reserve (HRNERR). One key objective of this broader study is to provide basic information required for maintenance and restoration of the shore zone, and to articulate the different functions of natural and engineered structures and ecological communities. Operating within this framework, gastropods were examined across six shoreline types: sand, unconsolidated rock, bedrock, riprap, timber cribbing and sea wall (revetment and sheet pile). Two main questions were addressed: 1) is the abundance and diversity of snails greater on complex habitats and diverse substrates, and 2) is the abundance and diversity of snails associated with exposure to disturbance? Under the first hypothesis habitats with greater diversity of plant cover, complexity of substrate and higher levels of organic material would contain greater densities and higher diversity of snails (Lodge et. al 1987, Thorp et. al 1997, Strayer and Smith 2000). Under the second hypothesis increased exposure to wind, waves and human disturbance would result in lower numbers of snails (Strayer and Smith 2000).

In addition to contributing to the understanding of the ecological importance of gastropod communities in the shore zone, this study provides critical information for understanding the impact of current and future alien species (Loo et. al. 2007), notably the established *Bithinia tentaculata,* the anticipated New Zealand Mud Snail (*Potamopyrgus antipodarum*), and the recently discovered molluscivore, the Chinese mitten crab (*Eriocheir sinensis*) (Schmidt 2008, pers. comm.). The full impact of invasives remains unknown but continues as a significant concern (Mills et al. 1996).

METHODS

Gastropod communities from three sections of the Hudson River (lower, mid, upper), from Poughkeepsie to Albany (Fig. 1), were sampled across six shoreline types: sand, unconsolidated rock, bedrock, riprap, timber cribbing and sea wall. For each of these shoreline types data were collected on three elevation zones: subtidal, intertidal and upland. Sampling took place during two overnight field trips in the early summer of 2008, the first taking place June 1st through the 3rd, and the second June 29th through July 1st. Each site was identified using GPS coordinates provided by Dr. Strayer and HRNERR.

Because of the variety of habitat structures found among the shoreline types and elevations, a variety of sampling techniques were employed, using a 3x3 quadrat design at each site (Fig. 2). The sub-tidal zone is that portion of the river bank that lies just below low-tide level, the intertidal zone is that portion of the river bank that is cyclically inundated with water as the tide rises and falls, and the upland zone is the shore bank immediately above the high-tide mark. These three zones mark the dynamic interface between the river and the surrounding landscape, with each providing different species composition, habitat structure and function.

Site Protocols

Three different collection protocols were used to cover the three elevations at each of the sites. These protocols combine quantitative plot sampling with full-site visual

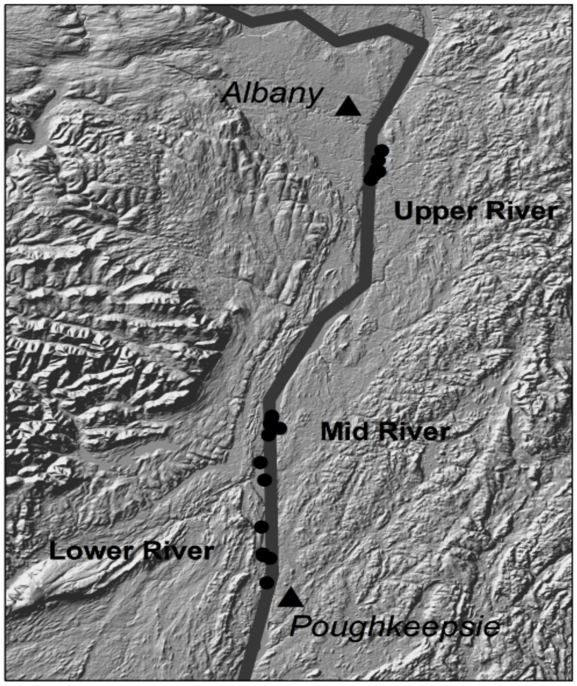

Figure 1. Map of the study area showing sample sites at each river section.

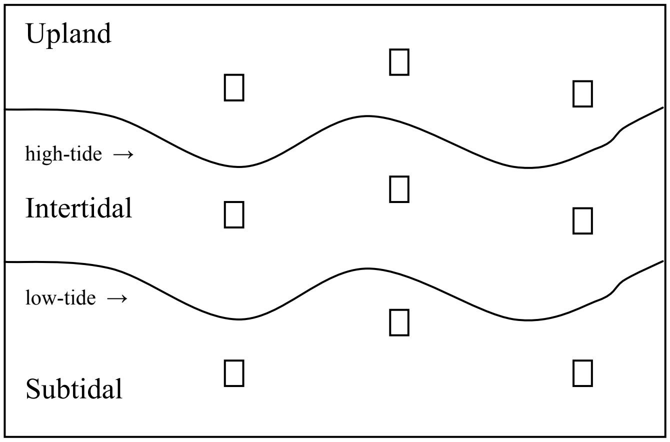

Figure 2. Illustration of site with sample quadrats and their relative position.

inspections to capture unusual habitats or species. For each of the 18 sites, three quadrats along 100 meter transects were laid parallel to the shoreline for each elevation. Figure 2 shows an idealized quadrat arrangement, but it does not indicate the complexity of habitat structures for a given site; thus, actual layout in the field was more complex. For example, sea wall sites were typically in deep water and therefore the idealized shore profile did not exist. Regardless, in all cases this basic design was employed, sampling parallel to the shoreline with each quadrat at least 10 meters apart.

In the sub-tidal zone, three 30-second sweeps of substrate were completed with a 1,200 µm mesh D-net. Each sweep covered one-meter square, at one-meter depth below mean low tide. The selection of sample plots was selected in-situ based on appropriateness of habitat (e.g., inclusion of vegetation, exclusion of sharp rock substrate, etc.). Due to low visibility, in most cases a priori determination of vegetation was not possible, but vegetation was included in the sample whenever possible.

In the intertidal zone, three one-meter square plots were sampled at mid slope (during low tide), using a combination of handpicking and a 1.4 mm sorting sieve. Depending on substrate type, picking frequently included turning over of rocks, pulling of submerged vegetation and the washing of sediments. In a few cases, snails were exceptionally abundant in the inter-tidal zones. In these cases quadrats were divided into either half or quarters and total numbers determined accordingly.

For the upland zone, sampling took place within 10 meters of the high tide mark. This habitat was by far the most complicated, including multiple scaled structures and micro-habitats. Selection of quadrats attempted to include as broad a range of habitats as possible. Handpicking and a 6.6 mm and 1.4 mm sieve were used for sorting the detritus, soil, and rocks. Sampling included the examination of large rocks, plants, and trees.

A number of abiotic response variables have been identified including: mean slope, shoreline complexity, rugosity, sediment grain size, organic content, vegetation structure, coarse woody debris, wrack, turbidity, peak wave energy and exposure (D.

Strayer and S. Findlay, pers. comm.). Mean slope, complexity and rugosity are included in analysis here. Slope was determined using two methods, first using a line level from 1 meter below low tide to 1 meter above high tide, and second, using a depth finder to determine slope from the 1 meter point below low tide, to 5 meters perpendicular off shore. Complexity was measured using 1 meter calipers and measuring the shoreline as it ran parallel to the 100 meter straight measure, using the ratio of the length measured by the calipers to the taut 100 meter line. Complexity equals 1 for a shoreline that runs exactly parallel to the 100 meter line, or higher for shorelines that deviate from the 100 meter line. Rugosity is the vertical roughness of the shoreline substrate, and was measured using a 1 meter chain lain as closely as possible to the substrate contours. The covered distance is then measured by a taut tape, and a ratio determined for chain length (1 meter) to the tape length.

Sample Processing

While all sub-tidal samples were collected with a dip net, the inter-tidal and upland samples were typically handpicked or run through sieves to collect all snails greater than 2 mm. All snails collected were preserved in full strength, 95% analytic grade ethanol for later identification and possible genetic analysis (Dillon 2005). Snails were identified in the lab to genus or species using standard references (Pilsbry 1939-1948; Harman and Berg 1971; Burch 1962, 1989; Jokinen 1992). Voucher specimens will be deposited at the National Museum of Natural History, Washington, D.C.

Analysis

Because of the distinctive elevation community types (subtidal, intertidal, and upland) and the different sampling techniques and conditions, statistical comparisons across elevations should be viewed cautiously. Statistical analysis includes ANOVAs for density (abundance) and diversity on elevation, shore type and river section, as well as regression analysis for diversity and density against exposure, rugosity and slope. For diversity, both species richness as well as Shannon's diversity index (H′) were used. Non-metric multidimensional scaling (NMS) (McCune and Grace 2002) was also used to assess differences in gastropod community composition across different types of shorelines. Statistical analysis includes only the data collected as part of the primary 3x3 sampling design for each site as described above, and does not include data collected as part of each site survey, or from additional sampling. These additional data are included in qualitative analysis.

RESULTS

Qualitative Analysis

The diversity of aquatic gastropods collected in this project is consistent with previous studies (Strayer 1987), representing 14 of the 30 taxa known from the river (Table 1). In addition, three newly reported aquatic species in the Hudson were documented in this study. Figure 3 includes pictures of the selected species discussed below. Table 1 lists all reported historical records and covers dozens of separate studies (Strayer 1987). Three of the species in Table 1 are known exotics, and four are suspected invasives via the Erie Canal, of which one of each was collected in this study. *Bithynia* *tentaculata* is an exotic snail and is known to be an intermediate host for a number of lethal waterfowl trematodes (Sauer et al. 2007). The suspected invasive is represented by a single recently empty shell of *Pleurocera acuta*. No detrimental effects of this invasive have been reported.

Live specimens of three previously unreported species for this section of the river were also collected during this study. Several *Littoridinops tenuipes* were found throughout the lower and mid river study sites, and, although this species was reported for the first time in the lower river in 2001 (Strayer & Smith 2001), this is their first documented finding north of Poughkeepsie. Two individuals on the New York state list of species of special concern, *Valvata lewisi*, and several *Floridobia winkleyi,* were also found. It is important to note that the original identification of *F. winkleyi* in this study was *Marstonia lustrica*, a species previously reported from the river by a number of researchers, and morphologically almost identical to *F. winkleyi*. After the original identification, genetic analysis was completed on several specimens for the mitochondrial gene COI (Liu pers. comm.). These results unequivocally identified these snails to be *F. winkleyi*. No specimens of *M. lustrica* were identified in this study. This first record of *F. winkleyi* in the river, and in the state of New York, represents a significant shift in its known range, with the only other records occurring in tidal coastal fresh and brackish waters extending from Connecticut to Maine (Davis & Mazurkiewicz 1985; Smith 1994).

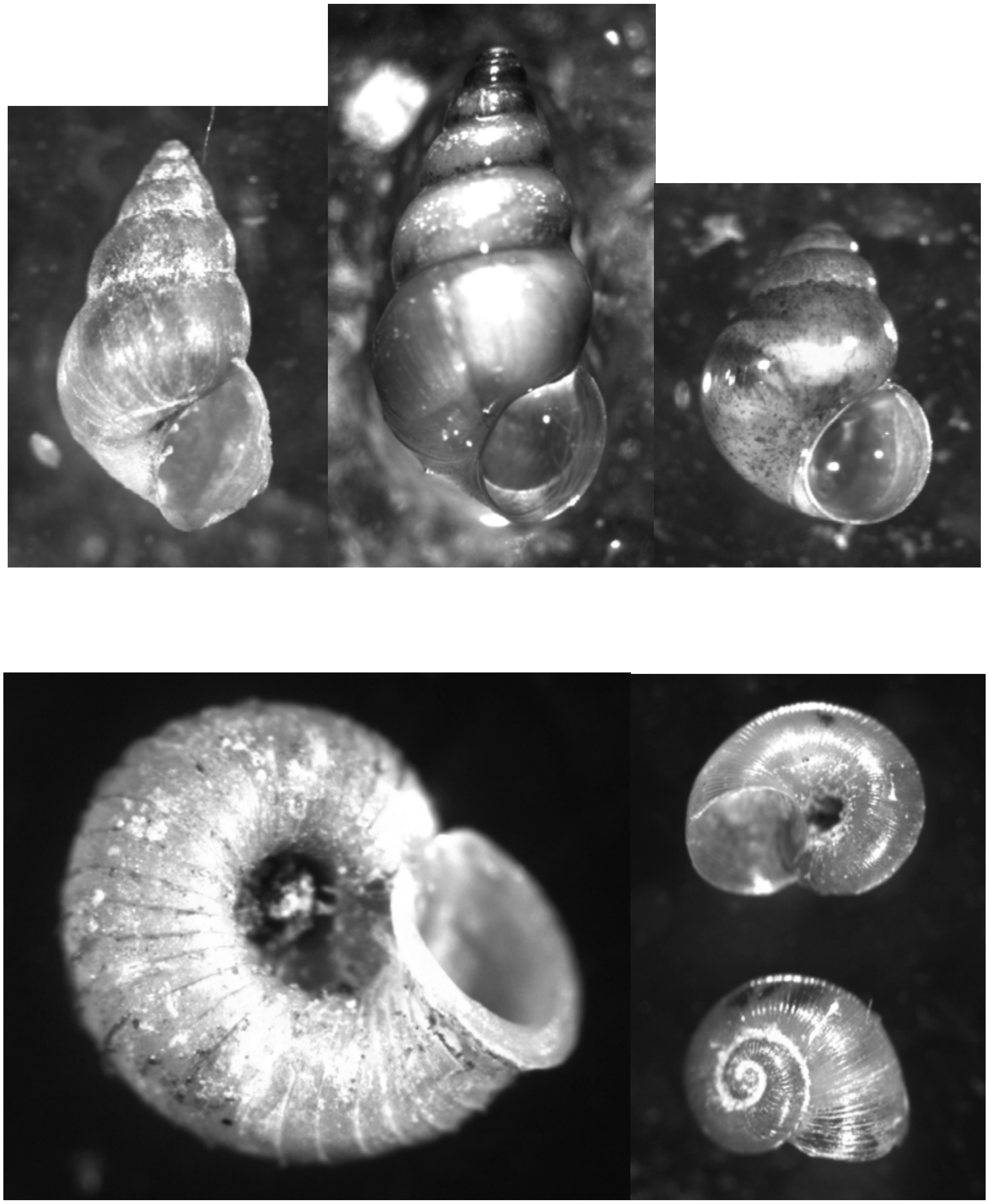

Figure 3. Selected photographs of some snails found during this study. Clockwise starting from the top: *Littoridinops tenuipes*, *Pomatiopsis lapidaria*, *Floridobia winkleyi*, *Vallonia costata*, and *Valvata lewisi*. Scale bar is approximately 1.0 mm: ------------

Two upland species not previously reported in Hudson River surveys were collected below the high-tide mark. *Vallonia costata* was represented by one specimen, and was found on bricks in timber cribbing in the inter-tidal elevation. *Pomatiopsis* *lapidaria*, known to be amphibious, was found at several sites in the mid and upper river sections, was represented by several specimens, and was found both in the upland and inter-tidal elevations. Due to its amphibious nature, *P. lapidaria* has rarely been reported in New York (Strayer, pers. comm.), with only a handful of records. No specimens were reported by Strayer (1987) or Harman and Berg (1971), and Jokinen only reported one live population in her survey of New York (Jokinen 1992).

The results for land snails overall are disappointing. The upland elevations yielded fewer species and lower numbers than what was expected (Table 2). The two genera of slugs found, Arionidae and *Deroceras*, are invasives, and are common throughout the northeast United States. While sampling in the upland elevations at each of the sites was extensive, it appears that relatively dry weather resulted in low incidence during the primary upland sampling trip in early June. This is evident when comparing the fifteen upland sites surveyed in early June to an additional three sites sampled in late June (Figure 4), which followed rain events throughout the month. Due to logistical constraints, additional sampling of the upland sites was not feasible.

Prosobranch snails	1867-1900	1936	1972-1985	2008
Valvata lewisi				x
Valvata piscinalis[1]			x	
Valvata sincera			x	
Valvata tricarinata	x	x	x	
Viviparus georgianus[1]		x	x	
Campeloma decisum	x	x		
Lioplax subcarinata	x	x		
Bithynia tentaculata[1]	x	x	x	x
Probythinella lacustris	x	x	x	x
Gillia altilis	x	x		
Birgella subglobosa[2]		x		
Littoridinops tenuipes[3]				x
Marstonia lustrica	x			
Amnicola limosa	x		x	x
Amnicola pupoidea			x	
Goniobasis (=Elimia) livescens[2]	x	x	x	
Goniobasis (=Elimia) virginica	x	x	x	x
Pleurocera acuta[2]			x	E
Floridobia winkleyi				x
Pulmonate snails				
Pseudosuccinea columella			x	
Lymnaeidae	x	x	x	x
Physidae *(Physella)*	x	x	x	x
Gyraulus deflectus	x		x	
Gyraulus parvus	x	x	x	x
Helisoma anceps	x	x	x	
Micromenetus (Menetus) dilatetus			x	E
Planorbella trivolvis	x	x	x	
Promenetus exacuous		x	x	x
Ferrissia rivularis			x	E
Laevapex fuscus		x		
Land snails found below high tide in 2008				
Pomatiopsis lapidaria				x
Vallonia costata				x

Table 1. Historical survey results of gastropods in the Hudson Valley (Strayer 1987) combined with this study’s findings. (E=recent empty shells, 1=Exotic, 2=Suspected Invasive, 3=First reported in 2001 (Strayer & Smith 2001))

Upland Gastropods	Abundance
Stenotrema hirsutum	1
Euchemotrema fraternum	1
Deroceras sp. [1]	7
Arionidae *sp.* [1]	6
Novisuccinea ovalis	21
Helicodiscus parallelus	1
Retinella rhoadsi	1
Vallonia costata [2]	2
Pomatiopsis lapidaria [2]	13

Table 2. List of land snails found in this study. (1. exotic   2. inter-tidal)

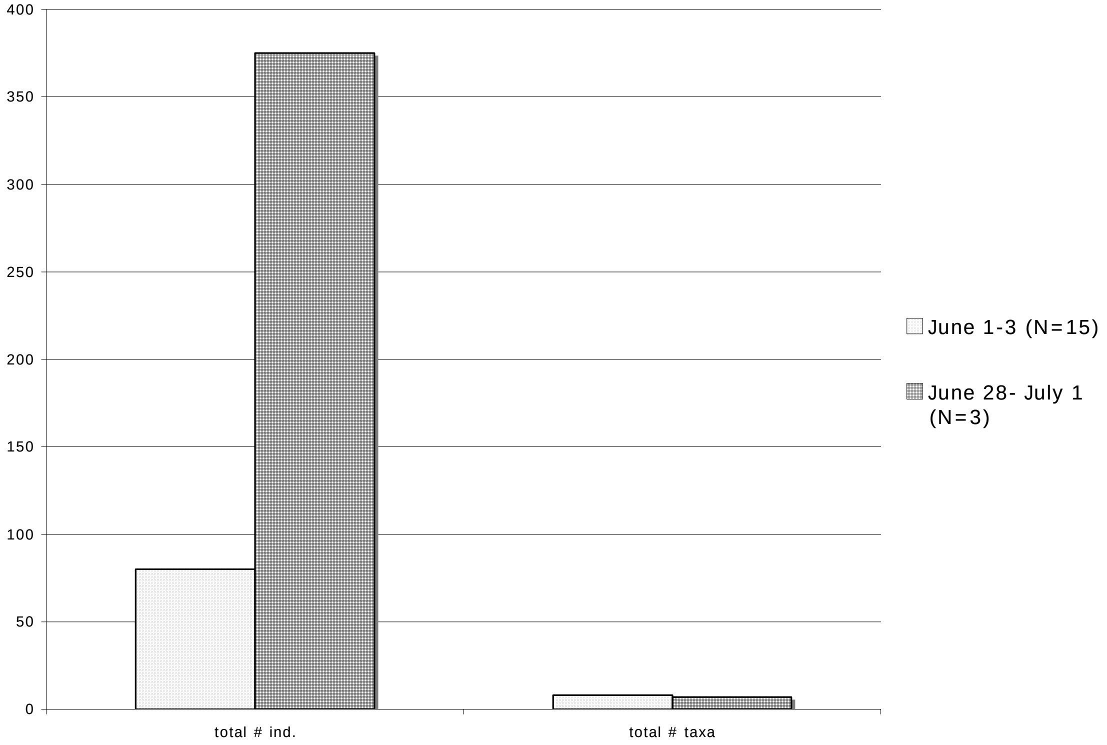

Figure. 4. Incidence of land snails in the beginning of June and the end of June. 15 upland sites were surveyed from June 1-3 and 3 sites were sampled from June 28-July 1.

Quantitative Analysis

The distribution of snail counts in the samples deviated significantly from normal (*Shapiro-Wilk* = 0.29) and so the data were subjected to a $\log_{10}$ transformation. Following this transformation, the distribution of the data still deviated from normal, but less so (*Shapiro-Wilk* = 0.78). Species richness distributed more closely to normal (*Shapiro-Wilk* = 0.78) and $\log_{10}$ transformation did not result in any improvement, so these data were not transformed for analyses. The transformed snail count data were subjected to a 3-way ANOVA, examining the effects of the three independent variables: elevation, shore type and river section.

For abundance, the ANOVA revealed significant main effects of elevation, shore type and river section (Table 3). Tukey post-hoc comparisons indicated that across shore types, sand and sea wall contained significantly lower numbers of snails, while unconsolidated and riprap contain significantly higher numbers. The mean snail abundances are also higher in the lower and mid river sections than at the upper river section. Post-hoc tests also indicated the highest snail count at the inter-tidal elevation, as expected due to sampling efficiency.

All of these main effects were qualified, however, by a significant three-way interaction (Table 3). Examination of the means across the 54 cells revealed higher snail counts in the riprap and unconsolidated rock river sections, and highest at the intertidal elevation (Table 4).

ANOVA

total_snails_log$_{10}$		Experimental Method				
		Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	40.805	9	4.534	23.893	.000
	elevation	24.843	2	12.421	65.459	.000
	shore type	13.811	5	2.762	14.557	.000
	river section	2.151	2	1.076	5.668	.005
2-Way Interactions	(Combined)	24.730	24	1.030	5.430	.000
	elevation * shore type	13.948	10	1.395	7.351	.000
	elevation * river section	2.569	4	.642	3.389	.012
	shore type * river section	8.212	10	.821	4.328	.000
3-Way Interactions	elevation * shore type * river section	14.239	20	.712	3.752	.000
Model		79.774	53	1.505	7.932	.000
Residual		20.494	108	.190		
Total		100.268	161	.623		

Table 3. Three-way ANOVA summary table for log$_{10}$ transformed snail abundance.

Elevation	upland			intertidal			subtidal		
Riversection	lower	mid	upper	lower	mid	upper	lower	mid	upper
bedrock	0.33	0.00	0.00	8.67	89.33	16.33	7.33	3.33	0.33
cribbing	2.00	0.00	0.33	23.67	184.00	23.00	0.00	1.33	2.33
unconsolidated	18.67	83.33	10.67	**267.33**	**224.00**	0.00	5.00	5.00	0.00
riprap	0.00	0.00	0.00	12.33	**582.67**	**154.00**	30.67	7.00	1.67
sand	1.33	5.00	2.00	0.00	0.00	3.67	0.00	4.00	2.33
seawall	0.00	0.00	0.00	0.00	0.00	98.00	0.00	0.67	0.00

Table 4. Raw mean snail counts by cell (cell n’s = 3). Bold indicates significantly (p=.05) higher counts.

The ANOVA on the number of species (richness) indicated significant main effects of elevation, shore type and river section (Table 5). Tukey post-hoc analysis indicates that across shore types, sea wall contains significantly lower numbers than riprap, unconsolidated rock and bedrock; across elevation, species richness was significantly lower at the upland sites.

These main effects were again qualified, however, by a significant three-way interaction (Table 5). Examination of the mean total species counts across the 54 cells again revealed higher counts in riprap and unconsolidated rock, and again at the intertidal, but also sub-tidal, elevations (Table 6).

To test for possible effects of upland and subtidal elevations on the inter-tidal elevation, an additional ANOVA was run on the inter-tidal elevation only. There was a highly significant effect for shore type on total species richness, F (5,36) = 5.48, p<.001, and a marginal effect of river section, F (2,36) = 2.38, p=.109. Post-hoc analysis indicates there was no effect for shore type in the lower or upper river sections, but species richness was significantly greater for riprap in the middle river section versus sand and seawall.

ANOVA

total_species		Experimental Method				
		Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	62.352	9	6.928	7.687	.000
	elevation	26.012	2	13.006	14.432	.000
	shore type	32.994	5	6.599	7.322	.000
	river section	6.272	2	3.136	3.429	.034
2-Way Interactions	(Combined)	76.926	24	3.205	3.557	.000
	elevation * shore type	45.395	10	4.540	5.037	.000
	elevation * river section	7.284	4	1.821	2.021	.097
	shore type * river section	24.297	10	2.425	2.690	.006
3-Way Interactions	elevation * shore type * river section	37.309	20	1.865	2.070	.009
	Model	179.512	53	3.387	3.758	.000
	Residual	97.333	108	.901		
	Total	276.846	161	1.720		

Table 5. Three-way ANOVA summary table for species totals.

Elevation	upland			intertidal			subtidal		
River section	lower	mid	Upper	lower	mid	Upper	lower	mid	upper
Bedrock	0.33	0.00	0.00	2.67	**3.33**	1.00	2.33	1.33	0.33
Cribbing	1.33	0.00	0.33	0.67	2.67	1.33	0.00	1.00	1.00
Unconsolidated	1.00	1.00	1.67	**3.33**	**3.00**	0.00	1.00	2.33	0.00
Riprap	0.00	0.00	0.00	1.67	**3.00**	2.33	**3.00**	2.67	1.00
Sand	1.00	1.33	1.67	0.00	0.00	0.67	0.00	1.00	1.33
Seawall	0.00	0.00	0.00	0.00	0.00	1.67	0.00	0.33	0.00

Table 6. Mean species counts (cell n's = 3). Bold indicates significantly (p=.05) higher species counts.

There was also a significant effect for shore type on $\log_{10}$ abundance, F(5,36)= 14.53, p<0.001, and for river section, F(2,36)= 6.17, p=0.005. Post-hoc analysis indicates that there was a significant difference between sand (low abundance) and unconsolidated rock (high abundance) in the lower river section, a significant difference for sand and seawall (low) versus unconsolidated rock, riprap, bedrock and cribbing (high) in the middle river section, and a significant difference for unconsolidated rock (low) versus riprap (high) in the upper river section.

Regressions of $\log_{10}$ slope, complexity and rugosity on the transformed snail abundance data and H′ (Shannon Index) revealed no significant relationship between slope, complexity or rugosity on snail count or H′ (Table 7).

NMS ordination was attempted on all samples ($\log_{10}$) but was unsuccessful. Ordinations were then completed without species that occurred in fewer than three samples, resulting in no significant ordination (stress=29.76). Additional analysis was completed without species that occurred in fewer than 3 samples, as well as all samples with fewer than 2 species. This resulted in a reasonable (stress =12.72), 3-axis ordination for both samples and species (Figures 5 & 6).

Correlation analysis for the three ordination axis for samples, along with slope, rugosity, complexity, elevation, river section and shore type were completed (Figure 5). The results indicate that 17.6% (r^2) of axis one can be explained by slope, 20.1% can be explained by rugosity, and 34.5% by elevation. For axis 2, only elevation has any explanatory power accounting for 21.2% of the results, and for axis 3, elevation and river section explain 19.8% and 14.8% of the data respectively. The clusters of species in Figure 6 coincide with the clustering of samples in Figure 6, showing that the ordination has grouped the data according to the dominant species for each sample. Despite low numbers (less than 10 individuals), the upland species are clearly clustered together where no other species occurred. Samples that were dominated by Physidae and Lymnaeidae are clustered at the top of axis 3. *F. winkleyi* and *P. lapidaria* are clustered with Physidae and Lymnaeidae because they are present in those same samples at relatively high numbers. Of the 22 samples represented by the cluster of Physidae, Lymnaeidae, *F. winkleyi* and *P. lapidaria*, 19 are inter-tidal, two are upland and three are sub-tidal. Samples that were dominated by *A. limosa* and *L. tenuipes*, and had only one or two individuals from other species, are clustered at the bottom of axis 1 and 2. Three of these samples are inter-tidal and 16 are sub-tidal. Overall, the patterns of snail occurrences are relatively weak, but do indicate that there is some effect of environmental variables on the distribution of gastropods, particularly elevation.

		slope	rugosity	abundance	complexity	H
slope	Pearson Correlation	1	.477	-.238	-.368	.179
	Sig. (2-tailed)		.045	.341	.133	.476
	N	18	18	18	18	18
rugosity	Pearson Correlation		1	-.461	-.098	.163
	Sig. (2-tailed)			.054	.698	.518
	N		18	18	18	18
abundance	Pearson Correlation			1	.435	.232
	Sig. (2-tailed)				.071	.354
	N			18	18	18
complexity	Pearson Correlation				1	.117
	Sig. (2-tailed)					.642
	N				18	18
H	Pearson Correlation					1
	Sig. (2-tailed)					
	N					18

Table 7. Correlations between slope, complexity, and rugosity on H’ and snail abundances (N). Slope and abundances were non-normal and subjected to $\log_{10}$ transformation.

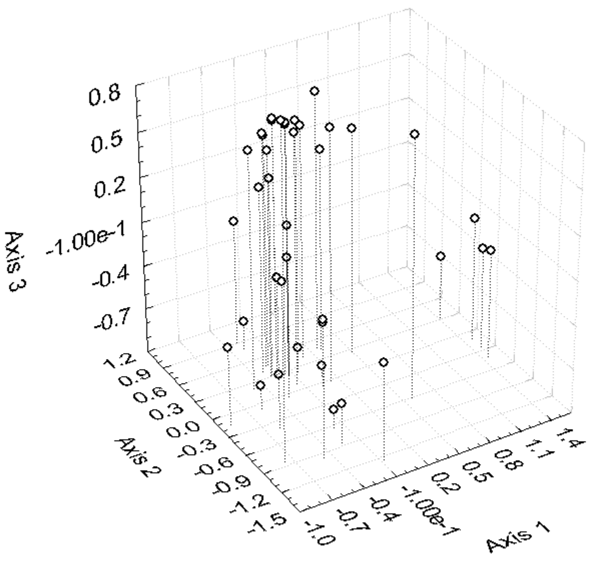

Figure 5. NMS ordination of samples.

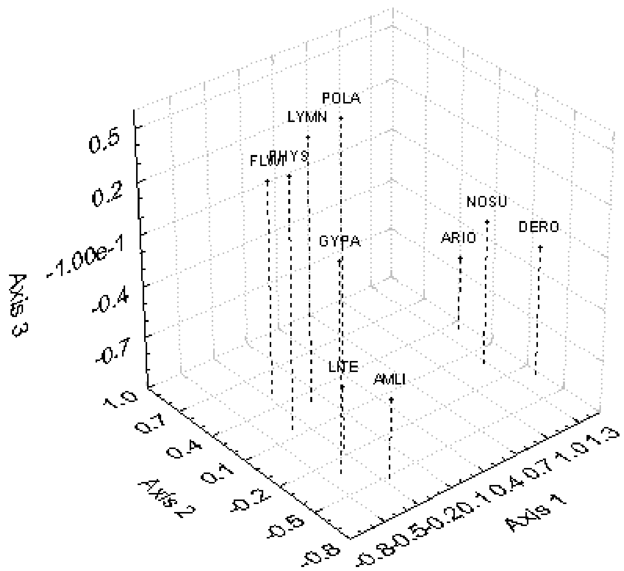

Figure 6. NMS ordination for species.

DISCUSSION

The goal of this project was to survey gastropods across the six different shore types, and to draw some conclusions on how the various assemblages correlated with the various ecological and physical structures. It is clear from the analysis that the inter-tidal elevations supported the majority of snails, although the data on the upland and sub-tidal elevations are relatively weak. At the inter-tidal elevation, the unconsolidated rock and riprap habitats supported the most snails and the most species, although bedrock also supported a high number of species. Sand beaches and seawall structures were the most depauperate.

Generally speaking this study suggests that stable, medium scale structure (brick, small rock, timber cribbing) may be beneficial to gastropod communities, whereas unstable, fine scale (sand and unconsolidated rock), or stable large smooth structures (seawall and large exposed basalt surfaces) are not as supportive. An issue for management of shorelines then may be not so much a question of natural versus man-made, but rather which type of structure is best suited to protect the shoreline while simultaneously promoting aquatic life.

The environmental variables tested in this paper did not provide explanatory power for the gastropod communities. This agrees with field observations, specifically that there are a plethora of microhabitats in each of the major shoreline types, precluding any distinct larger-scale pattern from emerging. For example, within the timber cribbing sites, the variability in habitat structure ranged from large smooth faced basalt, to small rough bricks, to the wood support structure, with each type of habitat supporting different abundances and different species. This type of variability existed at most of the sites. However, NMS ordination does support elevation as a potential selecting factor, distinguishing samples dominated by *L. tenuipes* and *A. limosa* as occurring primarily in sub-tidal elevations, as opposed to Physidae, Lymnaeidae, *F. winkleyi*, and *P. lapidaria* as dominating inter-tidal elevations.

Table 1 highlights several interesting results. First is the incidence of the relatively rare and state-listed snail *Valvata lewisi*, which has no previous record in the Hudson Valley. In this study, two live individuals were collected from mid-river cribbing habitat, in the sub-tidal elevation. There are only two records for this species in New York, one from a ditch in Onondaga County, in the St. Lawrence River watershed, and one from Oneida Lake in central New York (Jokinen 1992).

Floridobia winkleyi is one of the most surprising finds. This species is new to New York State, and represents a substantial increase in its known range. It is of particular interest because of its close similarity morphologically to *Marstonia lustrica*, which has been recorded occasionally in the Hudson River, but was not found during this survey. The identification of *F. winkleyi* came about after initial identification as *M. lustrica* based on morphology. Several specimens were then submitted for genetic analysis as part of another project on *M. lustrica*, with the surprising result that they were *F. winkleyi.* Further work needs to be completed to check historical lots and records to determine if *F. winkleyi* is indeed new to the river, or if it has been mistakenly identified as *M. lustrica*, or if both species are present and *M. lustrica* was simply not found during this survey.

Another species only recently reported for the upper Hudson River is *Littoridinops tenuipes*. It is generally considered an Atlantic seaboard species, extending from Florida to the northeastern shore of Massachusetts, with records only for the lower Hudson River (below Poughkeepsie) (Smith 1987; Strayer pers. comm). This species was a common occurrence throughout the lower and mid-river sections in this study (both above Poughkeepsie), but was not represented in the upper river section. It is possible that this species is a relatively recent introduction to the river and is moving upstream.

Pomatiopsis lapidaria is a species that is also considered rare in New York, yet it occurred at four locations, in all three river sections. The land snail *Vallonia costata* was found attached to bricks in timber cribbing in the inter-tidal elevation, raising the possibility that it is amphibious. Only one specimen of the exotic *Bithynia tentaculata* was found, which is in stark contrast to Strayer's (1987) findings in 1985 when they covered the rocks of the inter-tidal zone of the shoreline. While this study is not conclusive, it does appear that this species has declined significantly.

The results of this project highlight the great variety of habitats and community structures, and variety of gastropods that inhabit those environments, the multiple scales of interest, and the dynamic nature of the Hudson River shoreline. It also highlights how little is understood about gastropods and their relationship to the environment, while highlighting that such understanding is not beyond grasp, and that this information is critical for appropriate management. Recommendations for further study include repeating the work attempted here in the upland elevations, as well as looking closer at the potential differentiation of species occurrence in the inter-tidal and sub-tidal elevations.

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LITERATURE CITED

Burch, J.B. 1962. How to know the eastern land snails. W.C. Brown, Dubuque, IA.

Burch, J. B. 1989. North American freshwater snails: introduction, systematics, nomenclature, identification, morphology, habitats, distribution. Ann Arbor, MI: Museum of Zoology, The University of Michigan.

Cao, Y., D. D. Williams, and N. Williams. 1998. How important are rare species in aquatic community ecology and bioassessment? Limnology and Oceanography, 43: 1403-1409.

Daniels, R., K. Limburg, R. Schmidt, D. Strayer, and R. Chambers. 2005. Changes in fish assemblages in the tidal Hudson River, New York. American Fisheries Society Symposium 45:471-503.

Davis, G.M., and M. Mazurkiewicz. 1985. Systematics of *Cincinnatia winkleyi* (Gastropoda: Hydrobiidae). Proceedings of the Academy of Natural Sciences of Philadelphia 137: 28-47.

Dillon, R.T. 2000. The ecology of freshwater molluscs. Cambridge University Press.

Dillon, R. 2005. Freshwater Gastropoda. Pages 251-259 in C. F. Sturm, T. Pearce, and A. Valdés, editors. The mollusks: a guide to their study, collection, and preservation. American Malacological Society.

Harman, W. and C. Berg. 1971. The freshwater snails of central New York. Search (Cornell University Agricultural Experiment Station, Ithaca, New York) 1 (4): 1-68.

IUCN. 2004. The IUCN Red List of Threatened Species. http://www.iucnredlist.org/documents/2008RL_stats_table_3a_v1223294385.pdf (accessed January 22, 2009)

Jokinen, E. H. 1992. The freshwater snails (Mollusca: Gastropoda) of New York State. New York State Museum Bulletin 482.

Kabat, A. and R. Hershler. 1993. The prosobranch snail family Hydrobiidae (Gastropoda:Rissooidea): Review of classification and supraspecific taxa. Smithsonian Contributions to Zoology 547: 1-94.

Limburg, K. and R. Schmidt. 1990. Patterns of fish spawning in Hudson River tributaries: response to an urban radient. Ecology 7: 1238-1245.

Lodge, D. M., K. M. Brown, S. P. Klosiewski, R. A. Stein, A. P. Covich, B. K. Leathers, and C. Brönmark. 1987. Distribution of freshwater snails: spatial scale and the relative importance of physicochemical and biotic factors. American Malacological Bulletin 5: 73-84.

Loo, S.E., R.P. Keller, and B. Leung. 2007. Freshwater invasions: using historical data to analyse spread. Diversity and Distributions 13: 23-32.

Lydeard, C., R. H. Cowie, W. F. Ponder, A. E. Bogan, P. Bouchet, S. A. Clark, K. S. Cummings, T. J. Frest, O. Gargominy, D. G. Herbert, R. Hershler, K. E. Perez, B. Roth, M. Seddon, E. E. Strong, and F. G. Thompson. 2004. The global decline of nonmarine mollusks. BioScience 54: 321-330.

McCollough, M. 1997. Conservation of invertebrates in Maine and New England: perspectives and prognoses. Northeastern Naturalist 4: 261-278.

McCune, B., and J.B. Grace. 2002. Analysis of ecological communities. MjM Software Design, Gleneden Beach, OR.

Mills, E. L., D. Strayer, M. Scheuerell, and J. Carlton. 1996. Exotic species in the Hudson River basin: a history of invasives and introductions. Estuaries 19: 814-823.

Nekola, J. 2005. Geographic Variation in Richness and Shell Size of Eastern North American Land Snail Communities. Records of the Western Australian Museum 68: 39-51.

New York State Department of Conservation. 2008. http://www.dec.ny.gov/docs/wildlife_pdf/2007_animal_list.pdf, (accessed January 22, 2009)

Pilsbry, H. 1939-1948. Land Mollusca of North America (north of Mexico). Academy of Natural Sciences at Philadelphia, Monograph 3, Volumes 1 and 2.

Sauer, J.S., Cole, R.A., and Nissen, J.M., 2007. Finding the exotic faucet snail (*Bithynia tentaculata*): Investigation of waterbird die-offs on the Upper Mississippi River National Wildlife and Fish Refuge. U.S. Geological Survey Open-File Report 2007–1065, 3 p.

Smith, D. G. 1987. The Genus *Littoridinops* (Mesogastropoda: Hydrobiidae) in New England. The Veliger 29:442-44.

Smith, D.G. 1994. On some Connecticut, U.S.A., Snails reported by J.H. Linsley. Malacological Review 27:1-4.

Strayer, D. 1987. Ecology and zoogeography of the freshwater mollusks of the Hudson River basin. Malacological Review 20:1-68.

Strayer, D. and L. Smith. 2000. Macroinvertebrates of a rocky shore in the freshwater tidal Hudson River. Estuaries 23: 359-366.

Strayer, D. and L. Smith. 2001. The zoobenthos of the freshwater tidal Hudson River and its response to the zebra mussel (*Dreissena polymorpha*) invasion. Archivfür Hydrobiologie Supplementband 139, 1-52.

Thorp, A., R. Jones, and D. Kelso. 1997. A comparison of water-column macroinvertebrate communities in beds of differing submersed aquatic vegetation in the tidal freshwater Potomac River. Estuaries 20: 86-95.