THE ECOLOGY OF WRACK: DECOMPOSITION AND USE BY INVERTEBRATES ON NATURAL AND ENGINEERED SHORELINES OF THE HUDSON RIVER

A Final Report of the Tibor T. Polgar Fellowship Program

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ABSTRACT

Organic matter that is washed onto shore, or “wrack,” is an important component of shoreline ecosystems. It provides habitat for invertebrates, which attracts birds and other predators, and provides soil organic matter and nutrients to the upland terrestrial communities. However, wrack along freshwater shorelines has not been studied extensively, and shoreline modification continues without taking into account this essential ecosystem element. The decomposition rates and invertebrate communities of wrack were investigated on four different types of Hudson River shorelines: two natural (sandy and rocky) shorelines and two human-made (riprap and cribbing) shorelines. A significantly faster decay rate and a lower density of invertebrates was observed on cribbing shoreline, while decay and invertebrate density on riprap were similar to that of the rocky shoreline. The sandy shoreline had the highest invertebrate numbers. Invertebrate diversity was higher on sandy, rocky, and riprap shorelines than on cribbing shorelines. As managers seek to restore and protect shorelines from future sea level rise, this study suggests that riprap is a suitable alternative to natural rocky shorelines, cribbing will decrease overall ecological function, and natural sandy shorelines are unique and irreplaceable by cribbing or riprap.

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INTRODUCTION

Organic matter that is washed onto shore, or “wrack,” is an important component of shoreline ecosystems, providing a habitat for invertebrates, attracting birds and other predators, and providing organic matter and nutrients to the upland terrestrial communities (Dugan et al. 2003; Thompson et al. 2002; Strayer and Findlay 2010). Marine wrack has been studied extensively (Brown and McLachlan 2002), but freshwater and estuarine wrack has received much less attention, and little is known about how river wrack functions (Strayer and Findlay 2010). Wrack is often removed because it is deemed unsightly, or it may not be able to accumulate along highly engineered shorelines such as seawalls (Llewellyn and Shackley 1996; Malm et al. 2004; Strayer and Findlay 2010). No research exists about the importance of wrack along the Hudson River’s heterogeneous shorelines, and defining its role is a small step in understanding this critical ecosystem.

Wrack supports high rates of biological productivity on shorelines, as microbes and invertebrates decompose the material (Polis and Hurd 1996; Jedrzejczak 2002b; Strayer and Findlay 2010). The breakdown of organic matter takes place rapidly in marine ecosystems, with high moisture conditions and aeration playing major roles in the speed of decomposition. In a study of marine wrack by Jedrzejczak (2002a), only 22-32% of the original dry mass remained on the shoreline after 27 days. Recent work has found accumulations of as much as 5 kg dry mass per m^2 in the freshwater tidal Hudson River, consisting mainly of *Vallisneria americana* and wood (Strayer et al. unpublished). Decomposition rates on Hudson River shorelines are unknown, but the predominant plant litter (*Vallisneria americana*) has high rates of mass loss in the laboratory (Bianchi et al.

1991), suggesting most wrack should decompose within 30-50 days. In wetlands along the Hudson River, *V. americana* had mass loss of 60-70% within three weeks (Courtwright and Findlay 2010).

Since shorelines are in between aquatic and terrestrial systems, large numbers of invertebrates are able to take advantage of the habitat (Llewellyn and Shackley 1996; Romanuk and Levings 2003). Polis and Hurd (1996) found that production from the ocean subsidized arthropod communities living on the shoreline, which in turn supported communities of birds and mammals (Llewellyn and Shackley 1996; Romanuk and Levings 2003). Invertebrate community type, rate of colonization, and successional changes within the invertebrate fauna change over time, although studies differ on the importance of these changes to the structure and decomposition of wrack (Jedrzejczak 2002a; Bedford and Moore 1984; Griffiths and Stenton-Dozey 1981). No information exists about community structure within wrack or the use of wrack for feeding by fauna along the tidal Hudson River, nor in freshwaters at all (Strayer and Findlay 2010).

Removal of wrack has become common practice along beaches around the world, with debris removed mechanically by large machines in some places, or by hand in others. In Europe, the coveted "Blue Flag Seaside Award" is given to beaches that can prove "no algal or other vegetative materials" are allowed to decay or accumulate, despite evidence that wrack removal eliminates a unique, important habitat (Llewellyn and Shackley 1996; Malm et al. 2004). The Hudson River's shoreline is extremely heterogeneous, with sandy and rocky beaches and various types of constructed, hardened shorelines. According to a shoreline survey, just over half (53%) of the Hudson's shoreline is engineered (Miller 2005). Simplification and hardening of the shoreline has taken place throughout the estuary, which eliminates the natural complexity that helps maintain the biodiversity of these areas (Moschella et al. 2005).

This project is part of a larger effort by Drs. David Strayer and Stuart Findlay from the Cary Institute of Ecosystem Studies in collaboration with the Hudson River National Estuarine Research Reserve to assess the ecological functions of shorelines along the Hudson River. Little information is known about the ecological functions of different shoreline habitats on the Hudson, and thus recommending shoreline restoration methods is difficult (Strayer and Findlay 2010). The goals of this project were to 1) investigate the decomposition of wrack on four different types of Hudson River shorelines and to 2) document the use of wrack by invertebrates on the different shorelines. The null hypothesis for the first question was that there would be no difference in decay rates among shoreline types. Under the second question abundance and diversity of invertebrates would be the same on all shoreline types.

METHODS

Study Sites

Four different types of shoreline (sandy, rocky, riprap, cribbing) were studied along the Hudson River at Beacon, Cruger Island, and Kingston (Fig. 1). The sandy shoreline is defined as small gravel or sandy substrate covering bedrock. The rocky shoreline consisted mainly of cobbles (90%) and some boulders (10%). Riprap is composed of large boulders that are placed along shorelines for stabilization. The term "cribbing" is used to refer to the vertical wooden poles retaining crushed stone that are found throughout the Hudson River estuary. All sites are in the freshwater tidal reach of the Hudson River where daily tides fluctuate 1.2 m (Geyer and Chant 2006). The Beacon shoreline is approximately 70 km south of Cruger Island, and the Kingston site is approximately 19 km south of Cruger Island. At Beacon and Cruger Island three shoreline types could be sampled within 0.5 km of each other, and the sampling sites could be easily accessed by foot. The Kingston site was accessible only by boat.

Sampling locations of 0.6 m, 1.2 m, and 1.5 m above the low tide water mark were identified at each site. Tide predictions from Lamont Doherty Earth Observatory's Tide server were used to determine the low tide on each sampling day (http://xtide.ldeo.columbia.edu/hudson/tides/predictions.html). Both slope and roughness were measured at 0.6, 1 m, and 1.2 m above mean low tide, at three locations along each shoreline type. Slope was measured along each shoreline using a line level and tape measure.

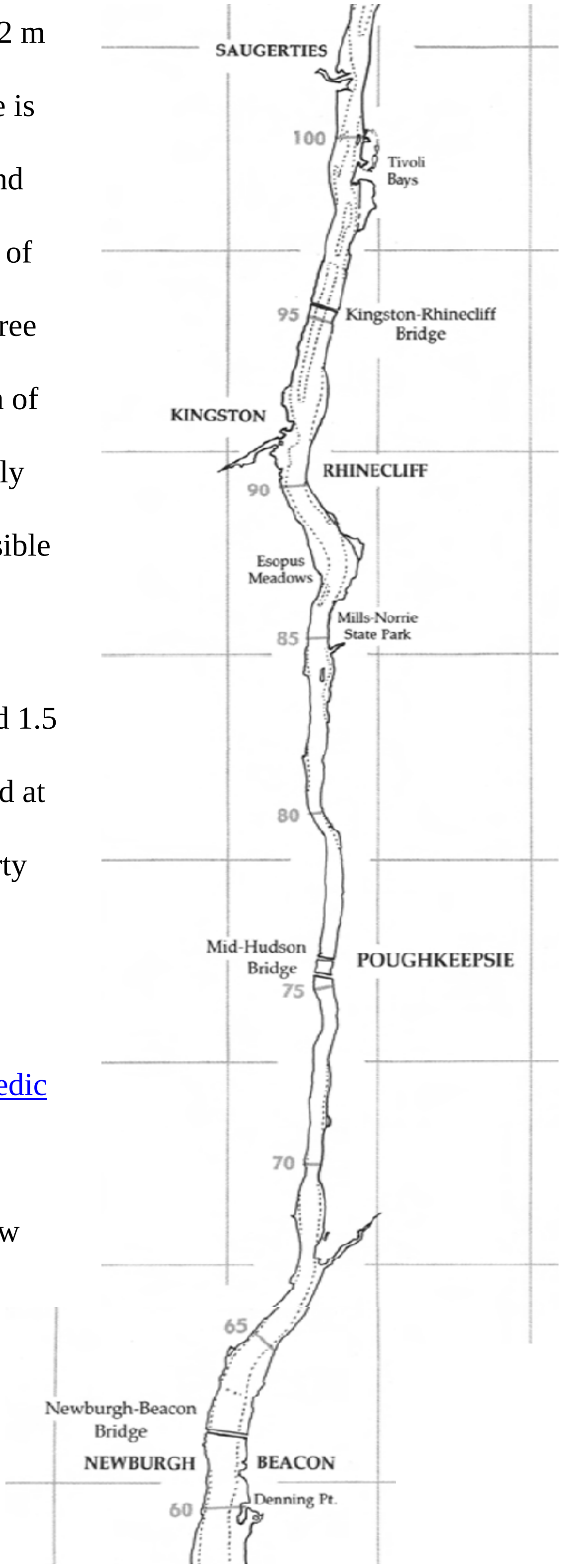


Figure 1: Map of study area

To measure roughness, a 100 cm length of chain (link size of 1cm) was laid parallel and perpendicular to the water line, following the contours of the substrate as closely as possible (US EPA, 2004). The resulting straight-line length between the ends of the chain was measured with a meter stick, and the ratio of chain length to tape length provided a measure of roughness. The particle size class descriptions were used in accordance with the EPA's Environmental Monitoring and Assessment Program, identifying boulders (250 mm to 4000 mm), cobbles (64 mm to 250 mm), coarse gravel (16 mm to 64 mm), fine gravel (2 mm to16 mm), and sand (0.06 mm to 2 mm) (US EPA 2004). Sampling took place in August and October of 2009.

Decay Rates

Decay rates of wrack held in litterbags made from plastic mesh (45.72 cm x 81.28 cm; mesh size 8.5 mm) were measured. At each site, fifteen bags were staked, tied, or anchored on each shoreline at the +1.2 m elevation line, at intervals ranging from 1-3 m. The complexity of the various shorelines did not enable deployment of the bags at exact intervals, and many bags at high-energy sites were lost or suffered severe damage. On the sandy shorelines, bags were tied with fishing line to bricks that were buried beneath the surface at a depth of 0.5 m. During the second sampling interval, the litterbags were enclosed in plastic deer fencing (1.9 cm mesh polypropylene) to protect them from wind and wave abrasion. Each bag was wrapped twice with the deer fencing, creating a litterbag within an envelope of plastic mesh. Each litterbag was filled with 60 grams of oven-dried *Vallisneria americana,* the predominant vegetation found in wrack along Hudson River shorelines. *Vallisneria* wrack collected during the summer of 2008 was used for the first sampling window, and then fresh wrack was collected in August for the second sampling window. The fresh wrack was oven-dried at 60 degrees C for three days before filling the litterbags. Bags were collected at random 7, 14, 21, and 28 days after placement. All bags were placed in individual sealed plastic zip-loc bags and transported to the Cary Institute of Ecosystem Studies.

After collection, the contents of all of the litterbags were dried for three days at 60 degrees C in pre-weighed aluminum pans. Many of the samples had small cobbles embedded in the wrack, so the organic material was combusted in a muffle furnace at 400 degrees C to obtain the ash-free dry weight. The ash was then rinsed from the sample through a 0.5mm sieve and the inorganic remnants were dried at 60 degrees C overnight. The weight of this coarse inorganic material was substracted from the weight of the dried *Vallisneria americana* for each litterbag.

Invertebrates

Invertebrates were collected from bags that were retrieved after 14 and 28 days. The bags were stored in the refrigerator after collection for no more than 48 hours, and then the contents were emptied into a tub of warm water. After agitating the wrack in the water for 1 minute, the mixture was poured onto a coarse-mesh sieve (4.75mm mesh size), which was stacked on top of a fine-mesh sieve (0.5mm mesh size). The material that remained on the fine-mesh sieve was rinsed into a jar with a 70% ethanol solution for counting and identification with a dissecting scope. All individuals were counted, identified to class, and where possible, to order.

Statistical analysis

Decomposition data were expressed as the amount of dry weight remaining and $\log_{10}$ transformed, then analyzed using ANCOVA (SAS 9.2) to determine the effect of shoreline type and time. Time was the continuous variable, shoreline type was the categorical variable, and mass was the dependent variable. Decay rate constants were calculated for each shoreline type using the following single-exponent equation (Weider and Lang, 1982):

$$\ln(M_t/M_o) = -kt + c$$

where M_t is final mass, M_o is initial mass, k is the slope of the regression, c is the intercept of the regression, and t is time in days. The ANCOVA results were analyzed with a post-hoc Tukey test to determine significance between shoreline types.

For invertebrate abundance, the data were $\log_{10}$ transformed and then a 2-way ANOVA was calculated (SAS 9.2). Time was classified into two categories, depending on whether the invertebrates were collected after two weeks or four/six weeks. Due to weather conditions, two cribbing samples were collected after six weeks instead of four. An interaction term and a post-hoc Tukey test was then used to evaluate the interaction and effect of time.

Invertebrate diversity was evaluated by calculating the Gini index,

$$= 1 - \sum_{i=1} n * p_i^2$$

where p_i is the proportion of individuals belonging to a species out of the total number of individuals in that sample. This is a measure of impurity, and it is expected that if all members of the sample are of the same species, the index would be zero. Although this study did not identify to species, the Gini index, as with other indices of biodiversity, are used both at the species level and at the broader taxonomic scale. The closer the index is to 1, the more diverse the sample. The Gini index was chosen because it is relatively insensitive to sample size (Gotelli & Graves, 1996). A two-way ANOVA was calculated to determine the effect of shoreline type on invertebrate diversity.

Non-metric multidimensional scaling (NMDS; PC-ORD) was used to analyze the distribution of macroinvertebrates among shoreline types, as well as the relationship between invertebrate groups across shoreline types. NMDS calculates a distance matrix based on the number of samples and attributes in the data, and identifies the configuration that minimizes the stress of the number and way the axes are arranged (McCune and Grace 2002). The $\log_{10}$ transformed data had the rare species removed prior to ordination, i.e., species found in fewer than three samples.

RESULTS

Decay rates

The *Vallisneria americana* wrack decomposed rapidly, and all shoreline types lost more than 50% of the original mass within each four-week experimental period (Figure 2). Decay constants (k) were calculated for each shoreline type along with an overall decay rate of 3% per day (Figure 3). Decomposition rates were higher on engineered shorelines, with cribbing experiencing both the highest decay rates and the greatest loss of organic matter. After 28 days in the field, less than 10% of the *V. americana* remained in the litter bags on cribbing shorelines.

Figure 2: Changes in ash free dry weight of *Vallisneria americana* in litterbags placed on four different Hudson River shoreline types. Data points are weekly means of 2-3 bags for AFDW on each shoreline type.

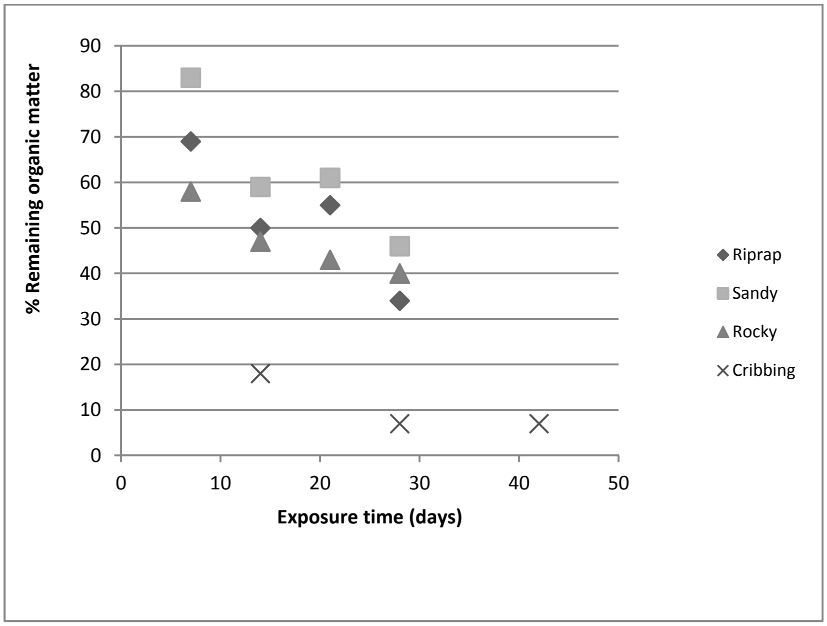
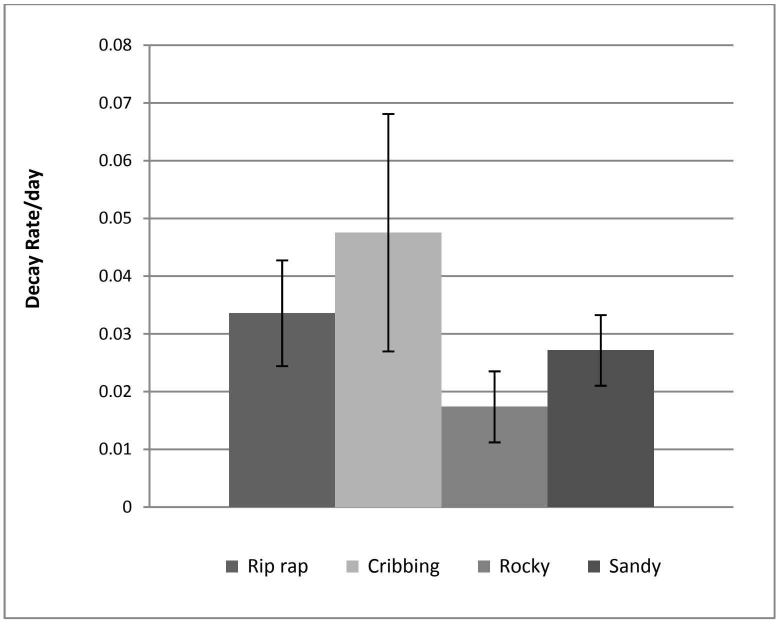


Figure 3: Decay rates of *Vallisneria americana* in litterbags placed on four different Hudson River shoreline types with standard error bars. Average daily decay rates for riprap (3.4%), rocky (1.7%), and sandy (2.7%) were significantly different from decay rates on cribbing (4.8%), according to post-hoc Tukey's which showed significant differences between all shoreline pairs except riprap and rocky shorelines.



Shoreline type ($P<0.0001$) and time ($P<0.0001$) both significantly affected the decay of *Vallisneria americana* (overall ANCOVA, $F=50.76$, $P<0.0001$, $R^2=0.655$). The post-hoc Tukey test showed significant differences ($p<0.05$) between decay rates on all shoreline types except for those on riprap and rocky shorelines (Figure 3).

Invertebrates

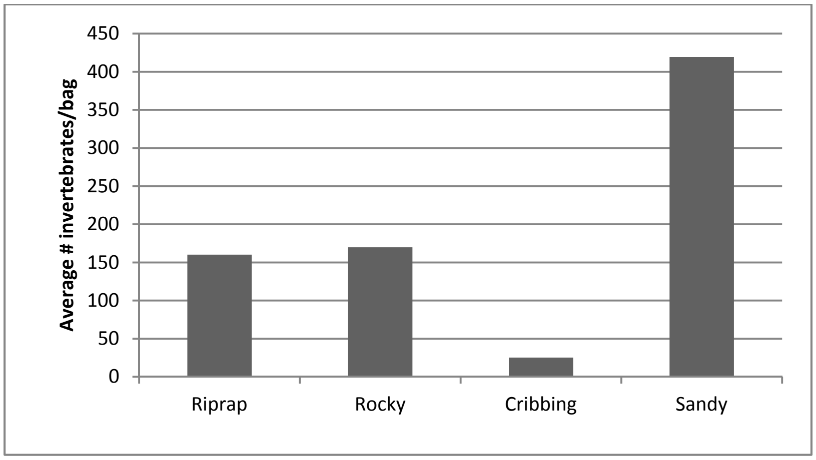
Twenty different taxa were collected during the course of this study. Across all sites, the most abundant taxon observed was Isopoda, followed closely by Collembola and Diptera (Table 1).

Invertebrate abundance was significantly different between shoreline types ($p=0.001$) (Figure 4). There was no significant interaction of time ($p=0.8605$) or main effect of time (0.5268). Tukey post-hoc analysis indicated that cribbing had significantly lower invertebrate numbers when compared to that of the other three shoreline types, but there was no significant difference of invertebrate abundance between the other types of shorelines.

Table 1: Taxa observed on Hudson River Shorelines August/October, 2009, organized by abundance.

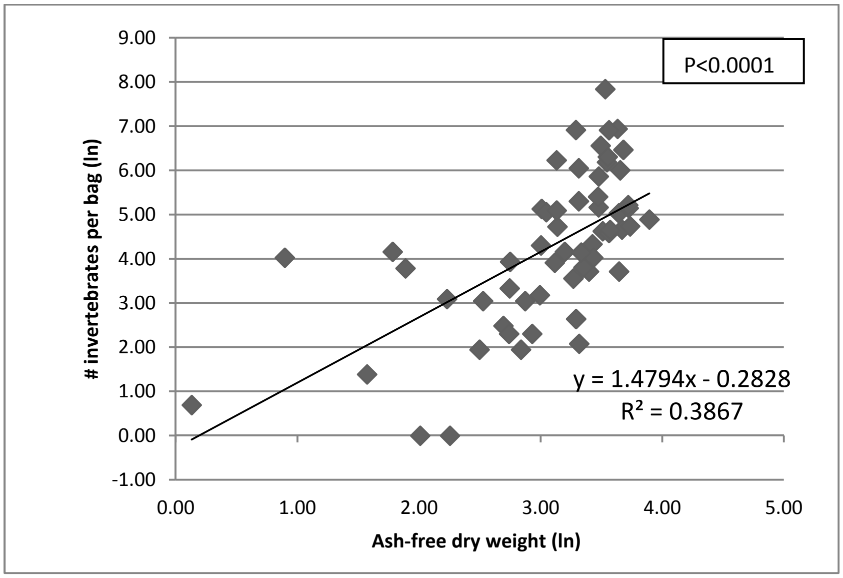
Class	Order	Family	Common Name	Total Number	% community	Average #/bag
Crustacea	Isopoda	-	Pill bugs	3819	29.22%	64.17
Insecta	Diptera	-	Flies	2957	22.63%	50.88
Insecta	Collembola (subclass)	-	Springtails	2636	20.17%	50.07
Gastropoda	-	-	Snails	934	7.15%	15.73
Insecta	Diptera	Chironomidae	Midges	699	5.35%	11.65
Diplopoda	Diplopoda	-	Millipedes	558	4.27%	9.33
Clitellata	Oligochaete (subclass)	-	Earthworms	543	4.15%	9.18
Arachnida	Acari	-	Mites	483	3.70%	9.05
Insecta	Coleoptera	-	Beetles	89	0.68%	1.63
Arachnida	Aranae	-	Spiders	86	0.66%	1.52
Chilopoda	Chilopoda	-	Centipedes	76	0.58%	1.27
Insecta	Hemiptera	-	Shield bugs, aphids	68	0.52%	1.13
Insecta	Hymenoptera	-	Bees, ants	56	0.43%	0.98
Turbellaria	-	-	Flatworms	42	0.32%	0.7
Bivalvia	-	-	Clams, mussels	9	0.07%	0.15
Insecta	Orthoptera	-	Grasshoppers, crickets	5	0.04%	0.083
Phylum Nematoda		-	Nematodes	4	0.03%	0.067
Symphyla	Symphyla	-	Garden centipedes	3	0.02%	0.05
Insecta	Neuroptera	-	Lacewings	1	0.01%	0.017
Insecta	Dermaptera	-	Earwigs	1	0.01%	0.016

Figure 4: Average number of invertebrates per bag. Abundance was significantly different between shoreline types (p=0.001)



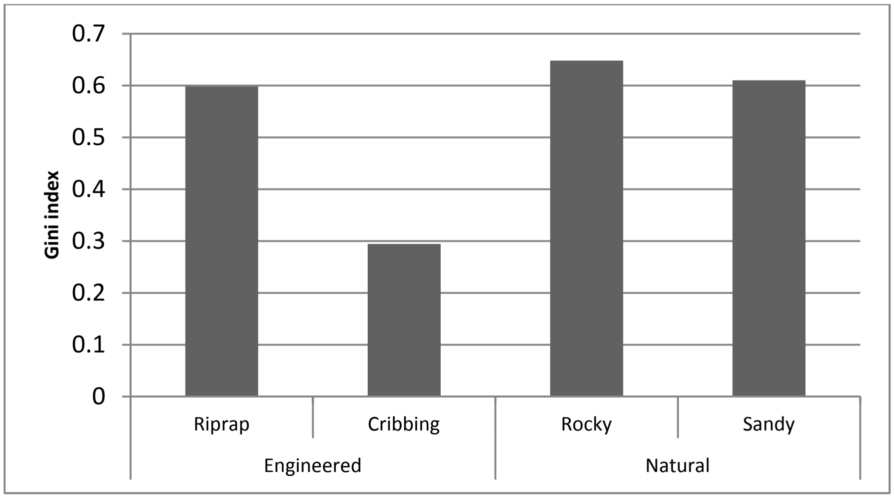
There was a significant relationship (p<0.0001) between the number of invertebrates and the amount of organic matter (Figure 5). As organic matter in the bags decreased, the number of invertebrates declined as well.

Figure 5: The relationship between ash free dry weight and the natural log of the average number of invertebrates per bag.



Invertebrate diversity was significantly different between shorelines (p=0.0031), although there was no significant interaction of time with shoreline type (p=0.3957) or main effect of time (p=0.1629). The highest diversity value occured on the rocky shoreline (Figure 6). Diversity on the riprap shoreline was not significantly different from the rocky or sandy shoreline, but it was significantly different from cribbing. Cribbing was significantly different from all other shoreline types, according to post-hoc Tukey tests.

Figure 6: Gini diversity index for invertebrates on different Hudson River shorelines. Cribbing was significantly different from the other shoreline types.



Invertebrate community structure among shorelines types, with both sampling periods combined, was expressed by NMDS ordination, with a 3-dimensional solution and a stress level of 14, indicating a fairly good ordination. The cribbing sites were clearly separated into a cluster from the other three shoreline types (Figure 7) on Axis 1. A Multi-Response Permutation Procedure showed an overall within-group agreement of A=0.1036, which rejects the null hypothesis that all groups are the same. The relationship between invertebrate groups across shoreline type showed that Chironomidae are more likely to occur on shorelines that also have a lot of Hemipterans, Dipterans, Turbellarians, Oligochaetes, and Bivalvia (Figure 8).

Figure 7: Macroinvertebrate community structure on the four shoreline types; clustering is clear on the cribbing shoreline.

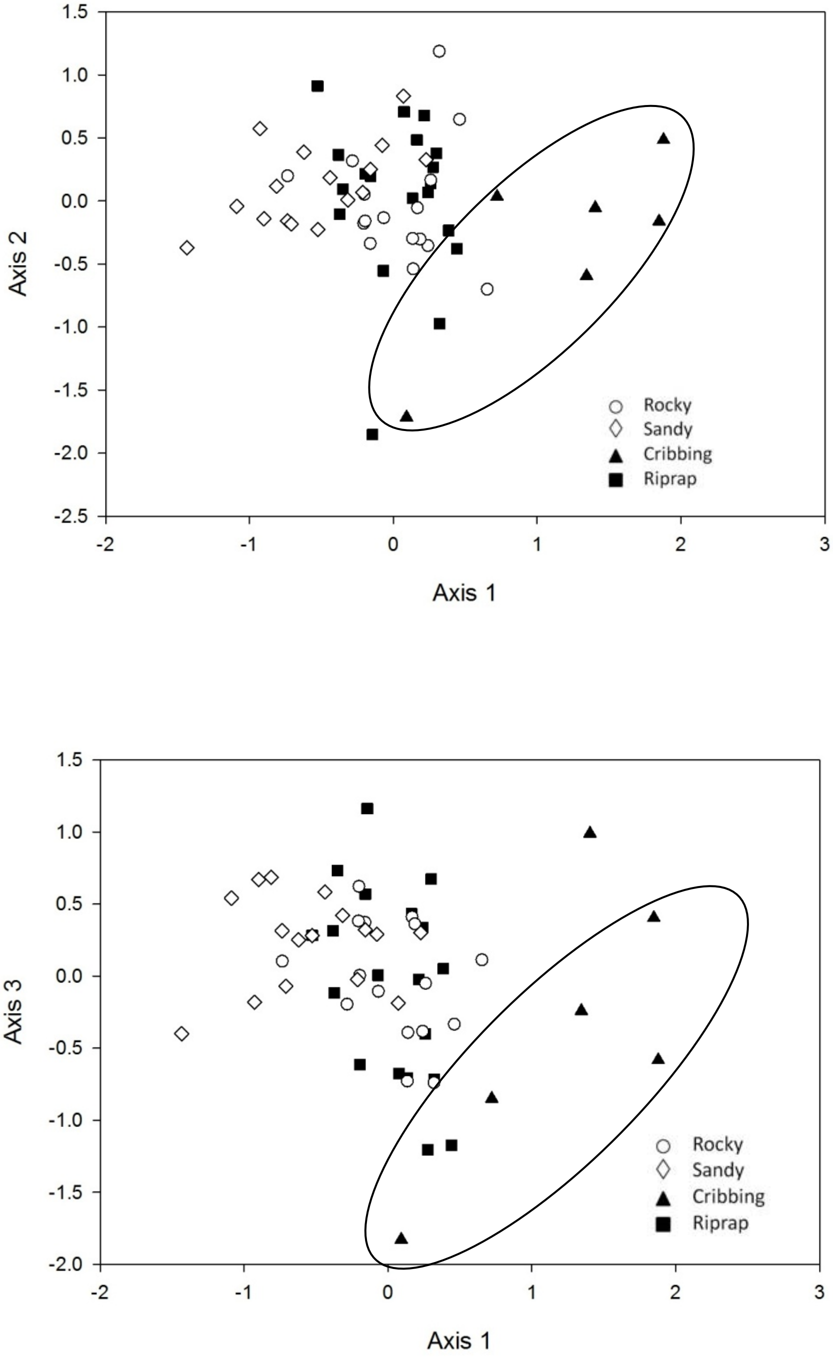
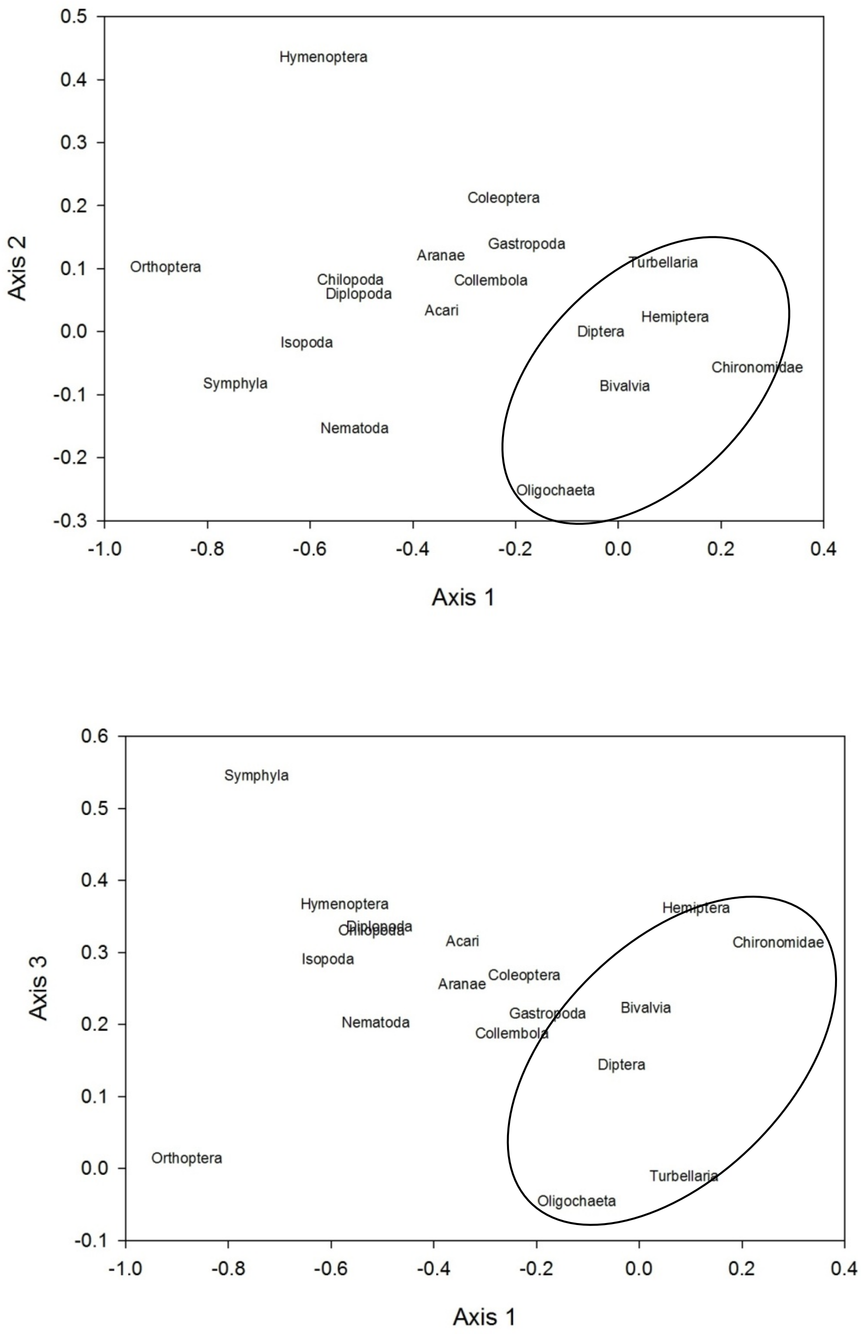


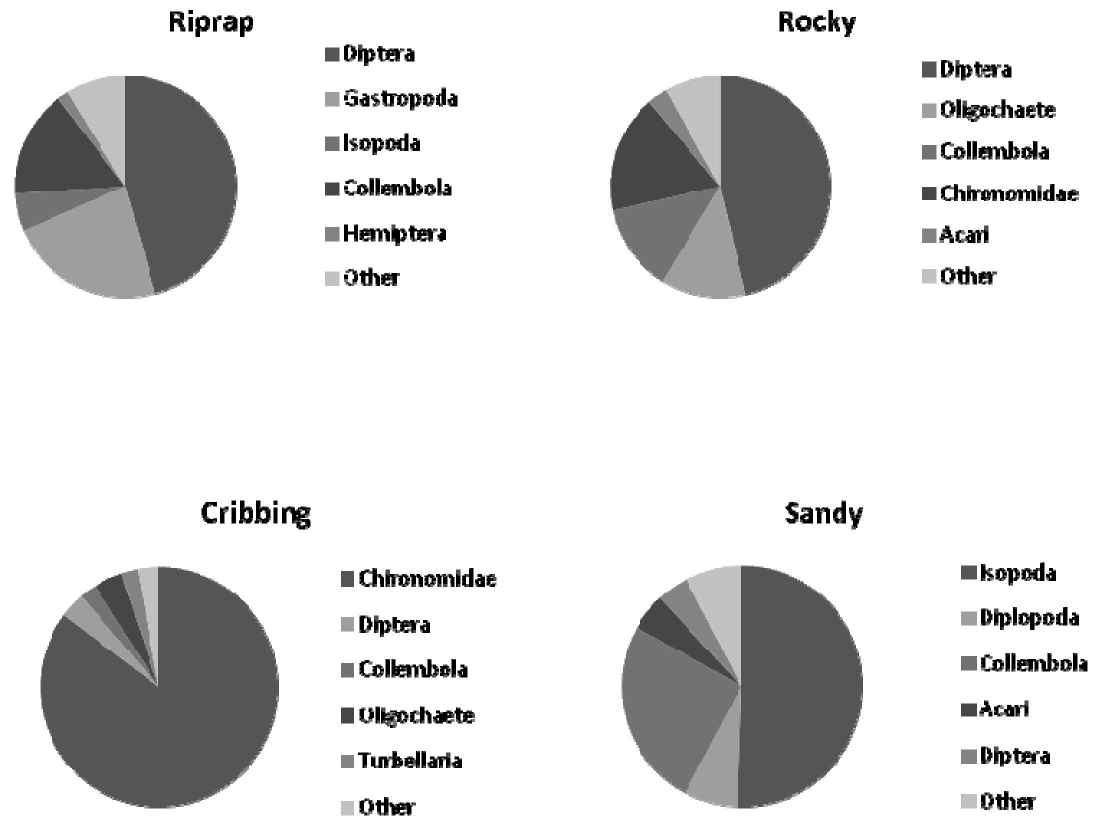
Figure 8: Macroinvertebrate community structure across the four shoreline types; clustering is evident between Chironomidae, Bivalvia, Oligochaete, Diptera, Turbellaria, and Hemiptera.



Isopods were the most common organism found on the sandy shorelines, while the most common taxa found on riprap and rocky shorelines were Dipterans (excluding

Chironomidae). Chironomidae (midges) were the most common organism found on cribbing shorelines, dominating the samples, with only a few other groups present (Figure 9).

Figure 9: Relative amounts of invertebrates organized by shoreline type and grouped by most abundant taxon; the top five groups on each shoreline type are shown, with other taxon groups lumped into the category "other."



The average slope for the riprap shorelines was 21°, while rocky and sandy shorelines had slopes of 7° and 9°, respectively (Table 2). The roughness values were lower on riprap than on the other shoreline types, indicating a more variable shoreline substrate.

Table 2: Physical site data from four shoreline types on the Hudson River, with standard deviation for each variable.

	Slope (°)	SD	Roughness	SD
Sandy	8.85	1.99	88.36	11.55
Rocky	7.32	3.49	76.28	13.29
Riprap	20.69	6.92	60.5	21.48
Cribbing	10.87	1.68	73.2	7.8

DISCUSSION

Wrack found on different shoreline types along the Hudson River had varying decomposition rates, with wrack on cribbing decomposing the fastest, and contained different invertebrate communities, with wrack on cribbing shorelines exhibiting the lowest abundance and diversity. The engineered shorelines, riprap and cribbing, were not similar to each other in decomposition or invertebrate community structure, diversity, or abundance. Decomposition rates, invertebrate abundance, and diversity were similar on riprap and rocky shorelines, but were significantly different between cribbing shoreline other shoreline types.

The cribbing shoreline had the fastest decay rates, and lost the most organic material, which can be expected since cribbing is essentially a vertical seawall with high exposure to the water's movement. Cribbing also had the lowest numbers of invertebrates and the lowest diversity of invertebrates, possibly because the site has little natural vegetation, so few invertebrates would have had the chance to encounter the bag and colonize it. In addition, since cribbing lost organic matter so quickly, there was less material for invertebrates to use, and fewer invertebrates are seen on less organic material

(Figure 9). Prior research has shown cribbing to be a shoreline type that offers little ecological value, enabling no nutrient transformation, little habitat for aquatic invertebrates (mollusks being the exception), and no retention or decomposition of organic matter (Strayer & Findlay 2010; National Research Council 2007). The results of this study support these findings.

One of the largest physical differences between riprap and the rocky and sandy shorelines was slope. Based on the measurements of slope, decay rates were expected to differ between these sites, but this did not turn out to be the case. The roughness values on riprap were lower than on rocky and sandy shorelines, but this also did not contribute to a difference in decay rates between sites. It is possible that the physical variability of the constructed riprap site encouraged the retention of wrack. This would also help explain the high abundance and diversity of invertebrates on riprap, which was expected to offer less beneficial habitat than the natural shorelines. It is well known that structural complexity encourages high densities (Lewin et al. 2004) and species richness of aquatic invertebrates (Chapman & Blockley 2009), so it is possible that the variability of riprap offers sufficient refugia to the invertebrate community along the Hudson River, and thus is of greater ecological value along the shoreline than expected. However, the community composition of the sandy shoreline (Figure 9) was very different from the rocky and riprap shorelines, so replacing a sandy shoreline with riprap would likely result in a large change in the invertebrate community at that site.

Implications for shoreline development

More than 50% of the Hudson River shoreline has been modified or hardened in some way, with many additional development projects currently taking place or scheduled for development (Miller 2005; Squires 1992; personal observation). The most common engineered shoreline type is riprap, making up 52% of engineered shoreline (roughly 25% of total shoreline length) along the Hudson (Miller 2005), and future shoreline modifications can be expected to include a mix of riprap and cribbing. As the climate warms and the sea level continues to rise, the Hudson River shoreline could experience more erosion, which would likely be mitigated by building seawalls or riprap. The sea level at New York City has increased about 40cm since 1850 at a rate of 3cm/decade, and is expected to continue to rise, with low estimates between 11cm-20 cm, and high estimates between 45 cm-77 cm by the end of the century (Permanent Service for Mean Sea Level website; *Climate Change 2001: The Scientific Basis*; draft Sea Level Rise Task Force report 2010).

Adaptation strategies for sea level rise range from 'hard' engineering solutions such as riprap revetments or cribbing seawalls to "soft" engineering solutions or living shoreline techniques that incorporate natural elements along with protective structures such as breakwaters. The current draft report of the New York State's Sea Level Rise Task Force recognizes that hard engineering approaches are likely to continue being used in response to rising sea levels. However, the report suggests that whenever possible, soft engineering or living shoreline techniques should be used to maintain as many of the ecosystem benefits as possible. The report also recommends that local governments begin establishing areas for migration of shorelines as well as large buffers between new development and the shoreline, and "incentivize the use of non-structural shoreline protection measures" (Sea Level Rise Task Force Draft Report 2010). Strayer and Findlay's assessment (2010) of ecosystem services provided by different shoreline types corroborates the Task Force's recommendations, with steel or concrete seawalls providing the fewest benefits.

Prior research has shown cribbing to be a shoreline type that offers little ecological value, enabling no nutrient transformation, little habitat for aquatic invertebrates (mollusks being the exception), and little accumulation of organic matter (Strayer & Findlay 2010; National Research Council 2007). The results of this study support the findings that cribbing offers little habitat for aquatic invertebrates. Cribbing seawalls supported a very different, and less abundant invertebrate community, and demonstrated significantly higher decay rates, and thus should not be used as a restoration strategy if the management goals include increasing the ecological value of the Hudson River shoreline.

These findings support the idea that for invertebrates, riprap shorelines offer similar habitat and decomposition rates to natural rocky shorelines. Thus, riprap could be used to restore shorelines that were previously rocky. However, invertebrate community composition on sandy shorelines was significantly different from the other shoreline types and neither riprap nor cribbing should be used if restoring a shoreline to a "sandy" state. When constructing a riprap shoreline, adding complexity in the form of varying slope and roughness might create refugia for organisms (Chapman & Blockley 2009; Lewin et al. 2004; Way et al. 1995; Scealy et al. 2007; Villamanga et al. 2009). Maintaining upland habitat of good quality is likely also of high importance (Sawyer et al. 2004; Harding et al. 1998; Morgan & Cushman 2005; Strayer 2006). Providing upland vegetation or vegetation interspersed in the boulders could provide habitat for terrestrial invertebrates, as it would likely mimic the natural shoreline more closely.

As society begins to consider adaptation strategies for rising sea levels, those with vested economic interests along the Hudson River will likely advocate for what they perceive to be the most secure and durable forms of protection, namely dikes or seawalls that include cribbing-like features. Creating these types of structures to stabilize shorelines will negatively impact the Hudson River estuary. This study supports the implementation of non-structural solutions such as elevating or relocating important infrastructure, or building shorelines with “soft” engineering in order to improve the overall ecological health of the Hudson River ecosystem.

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