FINAL REPORT (Research Results)

Assessment of Population Levels, Biodiversity, and Design of Substrates that Maximize Colonization in NY Harbor: Experimental Study

Hudson River Foundation grant number: 00202A
SUNY Research Foundation award number: 26015

5/1/2002-5/30/2006

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Report Date: 11/13/2006

Abstract:

Over two seasons in 2002 and 2003, we performed a colonization study of hard substrates at Pier 26, which faces the Hudson River in lower Manhattan. Using a stratified design our objective was to measure the biodiversity and amount of coverage of experimental colonization tiles. We used a point count method, assigning randomly located points, at which species or open space was identified. We used several frames with replicate panels, which allowed a study of microspatial variation when necessary.

The most detailed data set was collected from tiles set in from late spring 2003 and followed into the fall. The number of taxa increased linearly with time, so biodiversity increased steadily. We identified 31 taxa on the tiles, but more taxa were found on the frame edges. Occupation of space was very high, but in the early part of the season tiles were covered to an extent by soft sediment, which was later replaced by sessile invertebrates such as colonial tunicates.

INTRODUCTION

Throughout most of the past century, untreated sewage has been discharged directly into the Hudson River estuary. Combined with additional factors such as industrial effluents, overfishing and agricultural run-off, the negative impact on the river's biodiversity has been severe. Between 1887 and 1996, the total landings of the estuary's most important commercial fish an bivalve fisheries decreased approximately 90%, attributed in large part to depleted dissolved oxygen (DO) levels caused by pollution (Reviewed in Tetra Tech and Andrew Stoddard & Associates, 2000). Recognition of this problem and legislation such as the Clean Water Act of 1972 has led to improved water quality and environmental management and has resulted in the marked rebound of DO from critically low levels averaging below 3.0 mg/l through the 1970's to average summer surface levels of 6.1-6.5 mg/l in 2002 (NYCDEP 2002). The return of many organisms previously missing from the river's subtidal communities demonstrates the positive effect such legislation has had. (Cerrato 2005).

Three species with particularly conspicuous recent increases have been the shipworm, *Teredo navalis* and the gribbles *Limnoria lignorum* and *L. tripunctata*. These are marine borers that are slowly destroying all wooden structures in New York Harbor (Abood et al 1995). They are capable of destroying untreated wooden pilings in under a decade; as a result, most of these structures will need to be replaced in the near future (Tetra Tech and Andrew Stoddard & Associates 2000). When one considers the estimated hundreds of acres of potential habitat that will be replaced, the importance of understanding how colonization of new structures is likely to proceed becomes evident.

Apart from the intrinsic aesthetic appeal of restoring a productive, functioning ecosystem to a long-polluted, depauperate harbor, such improvement is also likely to have a positive financial impact on the region. For example, in the mid-1990s, despite the severe depletion of sport fish populations, recreational fishing in the New York Harbor, New York Bight and Long Island Sound is estimated to have contributed over $1 billion annually to the New York-New Jersey regional economy (Schwartz and Porter 1994). The Hudson River is a wintering ground for the young-of-the-year of one of these sport fish, the striped bass, *Morone saxatilis*. Due to their small size, they are more susceptible to starvation during severe winters than older, larger individuals. About 95% of their winter diet consists of benthic invertebrates (Conover and Hurst 2002); understanding the factors that influence larval recruitment of these potential invertebrate prey and designing a plan for the harbor that maximizes their recruitment should have a positive effect on the population of the striped bass as well as other commercially and recreationally important fisheries.

Many factors can potentially interact to influence colonization of hard substrata in marine ecosystems. Initial colonization depends on the arrival of larvae, which, in turn, can depend on the presence and location of a colonizing pool of adults and the large-scale flow patterns of the region (Alexander and Roughgarden, 1996, Sammarco and Andrews 1988, Achambault and Bourget, 1999).

The patterns of larval dispersal vary greatly from species to species in the Hudson River Estuary and New York Bight, with some species remaining in the estuary, some migrating from the estuary to the continental shelf, and others making the opposite trip (Morgan 2005). In many instances it appears that larvae accomplish this by varying their vertical position in the water column and exploiting differential flow in the river and in the Hudson River plume in New York Bight. Lighter, fresher water from upstream inputs may flow downstream while denser, saline water travels upstream in a distinct lower level; this salt wedge is most evident in the summer and during neap tides when turbulence is lowest, coinciding with the spawning of many invertebrates (Peters et al, 2005). Thus, by modifying their behavior, the larvae of many Hudson River estuary/New York Bight species can apparently travel quite far not only downstream, but also upstream, against the net flow of water, from their source populations. They appear to migrate with a much higher level of control over where they eventually settle than might be expected from simple current patterns (Morgan 2005)

However, despite this apparent level of behavioral control over their dispersal, larvae may still be subject to more localized flow patterns influenced by the geometry of the shoreline and structures in the lower estuary and Harbor. Density and diversity of larval recruitment has been shown to be higher in bay areas than along straight coastlines in the St. Lawrence estuary (Archambault and Bourget, 1999).

On a yet smaller scale, variation in flow over a surface can also differentially affect larval settlement depending on the species investigated, impacting it negatively in some instances while having no effect at all in others (Harii and Kayanne, 2002, Fonseca and Hart, 2001, Tamburri and Zimmer-Faust 1996). Crimaldi et. al (2002) demonstrated a correlation between the density of adults in a clam bed, the effect of the density on the turbulence structure of flow over the bed, and the resulting variation in the ability of larvae to anchor to the substrate.

Physical factors such as depth may also shape recruitment patterns For example, Smith and Witman (1990) showed that the lowest subtidal epifaunal diversity in a New Zealand fjord occurred at the shallowest depths, due perhaps to salinity levels and predation pressure and recruitment by large numbers of mussel larvae. In deeper depths, high diversity patches were maintained by short-distance dispersal of a number of colonial invertebrate species. Light seems to have a positive effect on the growth of some photosynthetic epiphytes 1999), while shade can positively influence the recruitment of some organisms such as zebra mussels (Kobak 2001) and polychaetes (Glasby 1999). Wave swash – the constant action typical of waves contacting a substrate attached to a floating structure – can significantly affect the settlement of several animal taxa, including the blue mussel *Mytilus edulis* and the tubeworm *Hydroides sp*. (Holloway and Connell, 2002).

Also important is the nature of the substrate itself. Calcium hydroxide, $Ca(OH)_2$, which leaches out of concrete in seawater, has been shown to enhance settlement by some oysters (Anderson 1996), while on the other end of the spectrum multiple varieties of anti-fouling treatments and materials such as jacketed steel and creosote impregnated wood serve successfully as intentionally poor settlement sites. Additionally, the degree of relief of the substrate can affect recruitment by various species, for example, some species like the eastern oyster, *Crassostrea virginica*, require a certain amount of interstitial space to provide protection from predation for newly settled recruits (O'Beirn et. al. 2000).

Conspecifics can also create spatial refugia, which might enhance recruitment (Walters and Wethey 1996), however, larvae attempting to settle near adults can also be subject to potentially higher levels of conspecific predation (e.g. *Molgula manhattensis*, Osman and Whitlatch 1995, *Crepidula fornicata*, Pechenik et al. 2004) and competition for resources such as space. Depending on the species, it appears that the presence of conspecific adults can also serve to attract larvae (e.g. *Crepidula onyx*, Zhao and Qian 2002) or have no effect at all (e.g. *Chamaesipho tasmanica*, Jeffrey, 2002). Similarly, the presence of adults of other species can also have a negative effect on settlement of new colonizers, for example, *Schizoporella unicornis* and *Hydractinia echinata* were found to prevent colonization by other species on pilings (Sutherland 1974).

The timing of when an area becomes available for settlement can also have significant effects on the nature of the community that subsequently develops; Zajac and Whitlatch (1982a) found that succession in an estuary following a disturbance in the spring led to higher species number and density than a disturbance in the summer or fall. However, they also found that the species number and diversity were similar to those in surrounding sediment, indicating that the estuarine community was stable and resilient; i.e. it returned to levels typical for ambient sediments. (Zajac and Whitlatch 1982b) This is similar in this respect to the findings of Bertness et al (???) that rocky intertidal communities in Maine recover to their previous states following disturbances, but differs in that recovery in Maine seems to follow a very deterministic succession. By contrast, Sutherland (1974) found that the time of year that open space was available might have long-term consequences for the nature of the species that came to dominate the space.

A final factor to consider is the scale of a disturbance; depending on its size, it has been proposed that a given disturbance may or may not be severe enough to initiate a switch from one stable state to another (Petraitis and Latham 1999). It may be that in New York Harbor we will not be able to accurately predict how succession will occur and what the resultant community profile will be like if the bulk of the wooden structures are replaced in a short time span from only examining how colonization progresses on smaller scales.

GOALS OF THIS STUDY

The goal of our study is to examine the following questions:

(1) What species are present in a site in the lower Hudson River Estuary? How will they colonize new substrates?

(2) How quickly will colonization progress?

(3) How will colonization proceed? Which species, if any, will be dominant?

(4) What is the pattern of diversity change with time?

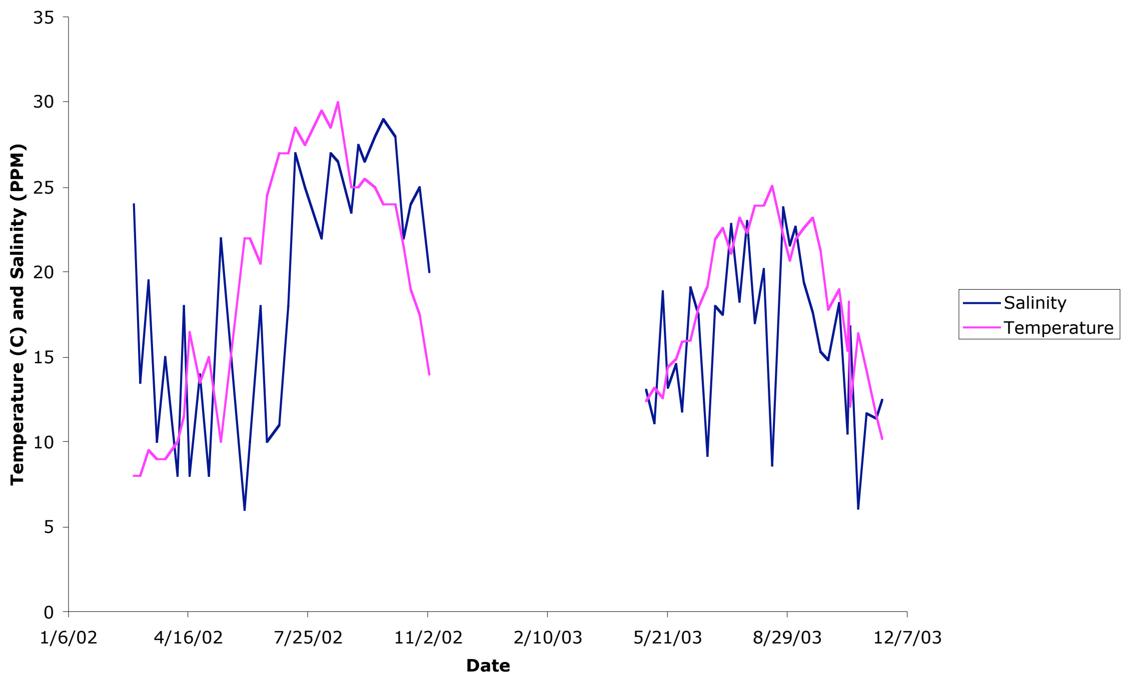
METHODS

Species diversity and rate of hard substratum colonization was measured on Pier 26 on the Hudson River, located on the southwestern shore of Manhattan and managed by The River Project, an environmental research organization. The site, at 40° 46' longitude and 74° 01' latitude comprises a concrete and wood dock extending about 20m, north to south along the shore, and a field of wooden pilings extending approximately 200m westwards into the river just seaward (south) of the inner dock. The depth of the river off of the bulkhead is 3-4m with a silty bottom. Light transmission through the water is quite poor due to a heavy load of suspended particulates.

The Hudson River is a partially mixed estuary, whose tidal exchange is with the Atlantic Ocean via New York Bay. It exhibits mixing patterns of salt and fresh water that vary depending on the flow velocities of the river; low velocities during neap tides result in a well defined salt wedge structure, while high flow during spring tides cause a transition to well mixed conditions (Peters et al, 2005). Additionally, the degree of intrusion of salt water upstream varies seasonally, extending as far as 90-120 km north of the entrance to New York Bay in the summer when flow velocities are lowest, while reaching as low as 30 km upriver in the spring when snowmelt and rain introduce a high discharge of fresh water to the river and peak flow levels as high as ten times those in the summer (Geyer and Chant, 2005). During the late spring and summer, when the majority of invertebrates spawn, flow in the river is at its lowest and salinity at its highest, thereby creating a distinctly stratified vertical profile that may be exploited by larvae to influence their dispersal (Morgan 2005). At Pier 26, surface salinity and temperature varied weekly over the course of the study as seen in Fig. 1, reaching maximum levels in late July/early

August. The river is tidal, with a mean tidal range of 1.34 m, and a mean spring range of 1.62 m at Pier 26 (NOAA).

Figure 1. Temperature and Salinity 2002-2003



Six frames were constructed out of 3/4" PVC tubing, and were drilled with holes for air/water drainage to allow nearly neutral buoyancy. Three 3/8" thick stainless steel rods were threaded horizontally through holes drilled in each frame. Twelve 6" x 6" terra cotta tiles, used as settling plates, were attached to each frame via cable ties strung through aluminum and stainless steel holders made for each tile, and were secured to the stainless steel rods on the frames. Each frame consisted of four horizontal rows of three tiles each, with a difference in height between the top and bottom rows of approximately 0.75 meters.

Two vertical nylon guidelines per frame were anchored off of the dock with cinderblocks; each frame was equipped with two eyebolts attached to each vertical side that allowed them to slide up and down these guidelines. The guidelines prevented the frames from twisting in the current, such that the same face of each tile was always exposed to the river and any sunlight, while the opposite face always faced the shore and the shade under the dock. The frames were suspended from the dock at a fixed depth approximately 0.5 meters below mean low tide. This configuration attempted to minimize the effects of short-term differences in depth, wave swash/floating, and light on colonization.

This set-up could not, however, homogenize variation in local current patterns caused by pre-existing structures such as pilings and the concrete supports of the bulkhead. The frames were suspended with respect to these structures.

The frames were deployed in May of 2003. The riverward face of each tile was subsequently photographed with an Olympus 3.2 megapixel digital camera approximately once a week through October 2003. In order to prevent desiccation during photography, each frame was lifted out of the river and transferred to a shallow plastic pool filled with river water. To minimize disturbance to colonizing organisms, representative samples were collected throughout the course of the study from the shoreward face of the tiles and identified by microscopy, usually at 6X.

To account for slight variations in the sizes and angles of photographs taken, all photos were digitally manipulated with Adobe Photoshop 7.0 to a consistent size and shape and were subsequently analyzed with a point-counting software method developed by Thad Murdoch (personal communication 2003) to quantify how colonization varied between tiles and over time. A plot of 50 random points was generated to overlay on each photograph of a tile; each point was classified either as an organism, sediment, or bare substratum. "Sediment" is a category that includes the polychaete *Polydora ligni* as the tube-building worm could not be reliably distinguished from the mud itself. Therefore, although *P. ligni* was often quite abundant on the tiles and covered a significant amount of space, it does not appear in any records of percentage coverage by various taxa. Some hydroids and the bryozoan *Bugula simplex* are also potentially represented in the category "sediment", although to a much lesser degree than *Polydora,* as they were also difficult to distinguish from the sediment in photographs. *B. simplex* and hydroids also tended to have a small point of attachment on the tiles that was difficult to quantify in a count, a similar problem reported by Sutherland (1974). However, they did not seem to attach to the riverward face of the tiles to any significant extent, being limited mostly to the top and side edges of the tiles.

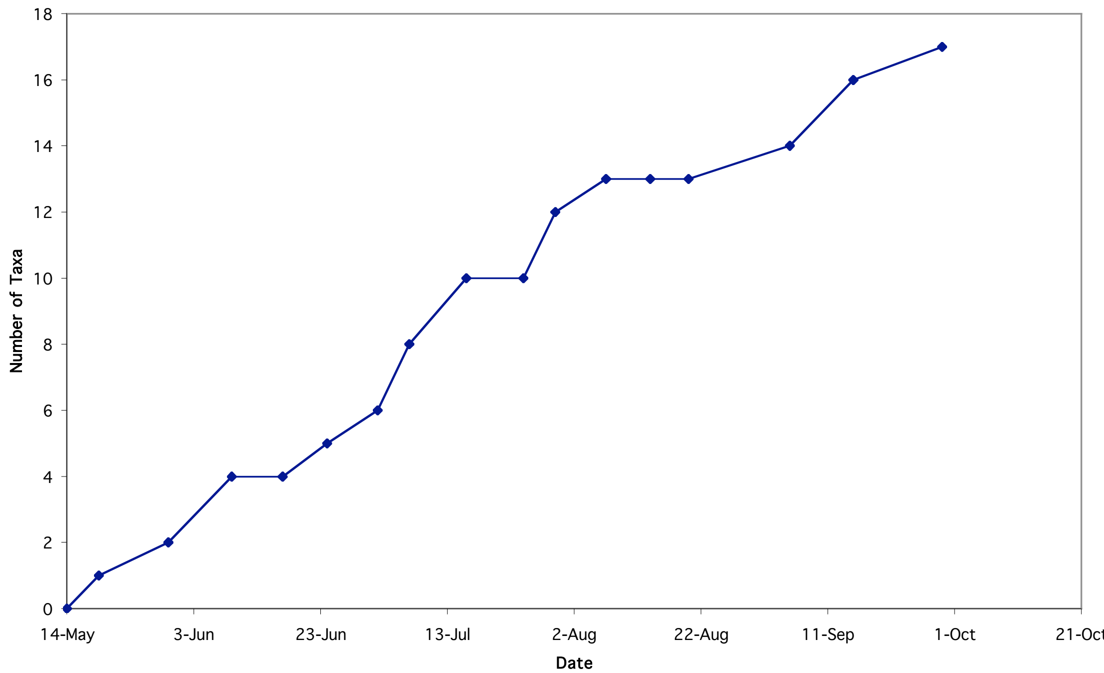
A preliminary pilot study was done in 2002 in a similar fashion, however, it was limited to 2 frames of 8 tiles each, and was started on 7/14/02. Sampling by photograph was conducted approximately once every 2 weeks subsequent to that, however, the method for photographing tiles had not yet been optimized and many of the photos were unusable. The limited data from this study are also presented in the results section.

RESULTS

Species

A total of 31 identified taxa were collected from the settling plates over the course of this study. Of these, 19 were sessile, with the remainder being mobile species. There were several unidentified species of gammarid amphipods that are not included in this count. Species are listed in Table 1 along with approximate dates of presence. The total number of sessile taxa present over time on the settling plates increased steadily over the course of the summer and into the autumn, without any apparent upper limit. (Fig. 2)

Figure 2. Number of Taxa Over Time



Colonization dynamics

Total percentage cover in 2003 rose to 80-90% within approximately one month and subsequently stayed constant, although the composition of this cover varied over time. Until the beginning of June, the primary cover was sediment and the bryozoan *B. simplex*, housing mostly *P. ligni* and unidentified amphipods. As barnacles (primarily *Balanus improvisus* interspersed with a few members of *Balanus eburneus*) settled in late May and grew in body size, they eventually covered approximately 60% of available space while there was a concurrent drop in the amount of sediment. Although barnacles remained the primary cover through October, other species also showed changes in cover over time. In particular, *Molgula manhattensis* first appeared in mid July and subsequently increased steadily in number, eventually covering approximately 5% of total area by late September/early October. Although *Botryllus schlosseri* and *Membranipora membranacea* both settled, neither was successful at colonizing tiles already colonized by barnacles to any significant extent; neither persisted for more than a few weeks. (Fig. 3b)

Figure 3a. Percentage Cover By Taxa Over Time, 2002

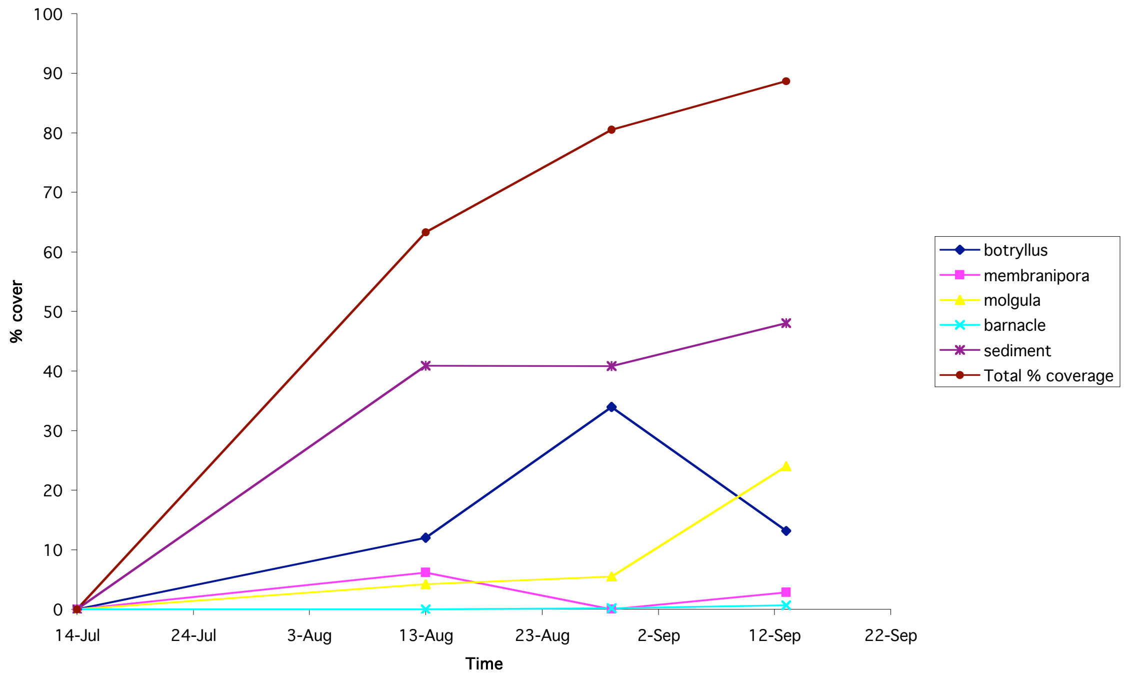
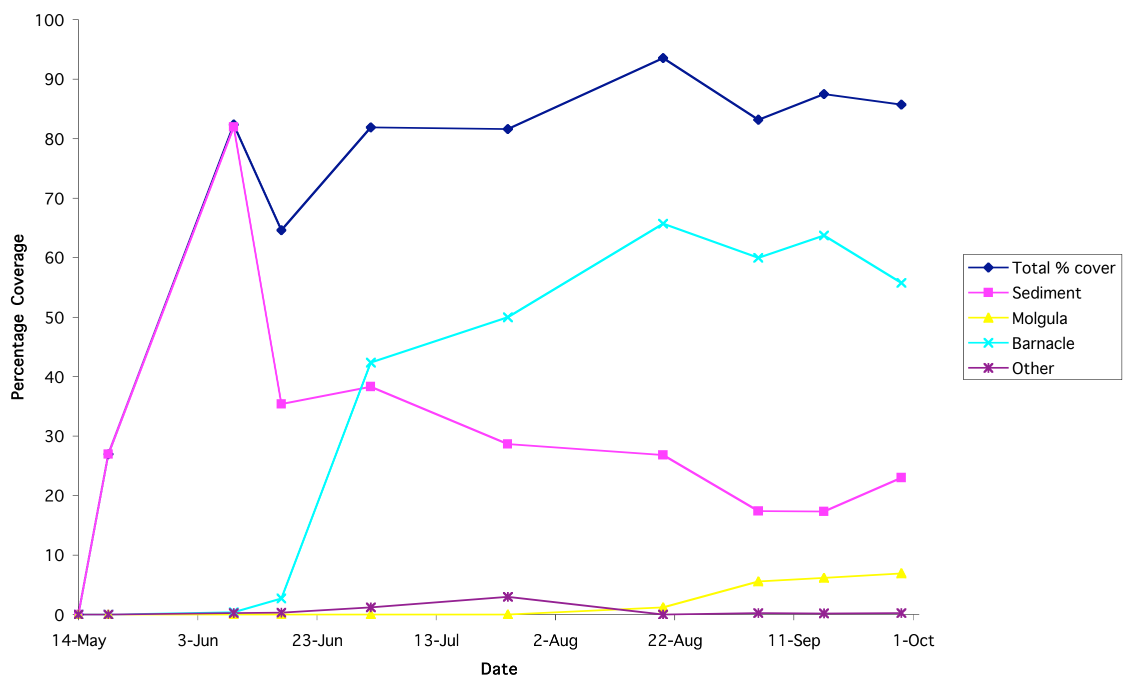


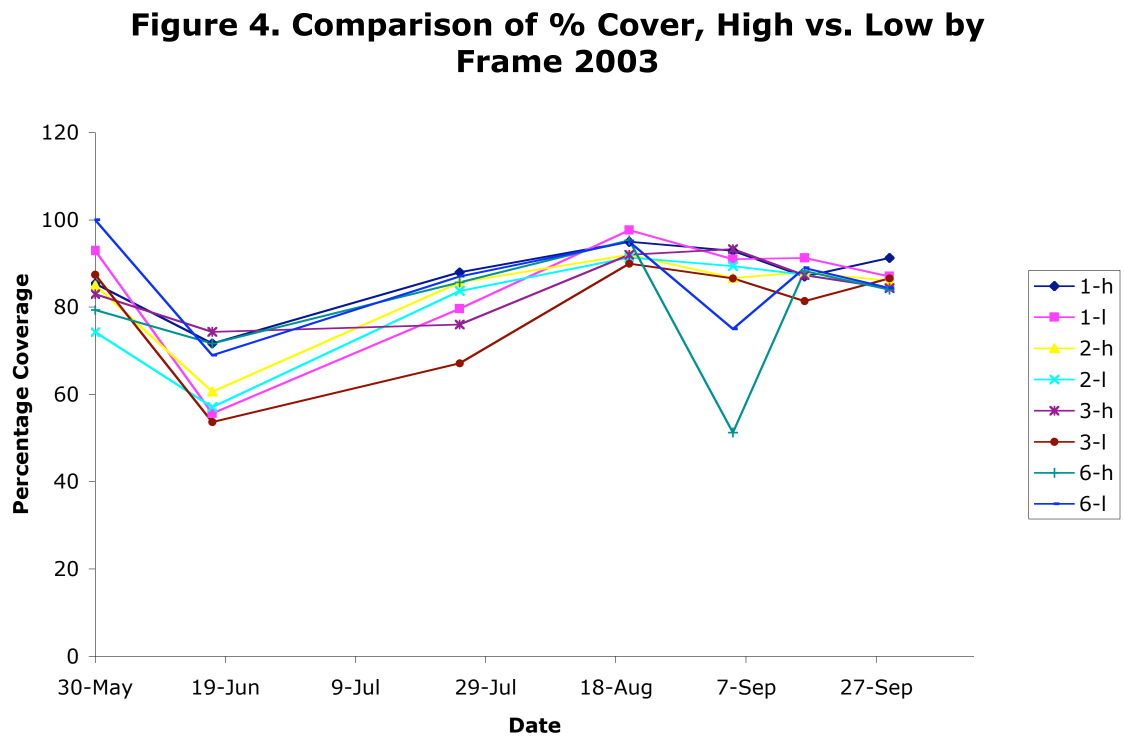
Figure 3b. Percentage Cover Over Time By Taxa, 2003



In 2002 (Fig. 3a), the total percentage cover was similar to that in 2003, rising to approximately 90% between 7/14 and 9/12. However, the dominant species were different; the tiles were apparently deployed after *B. improvisus* had spawned as none settled, with only a few individuals of *B. eburneus* settling. As shown in Fig. 3 and reinforced by observation, *B. schlosseri* and *M. membranacea* were the primary colonizers, with many colonies settling within the first week and then expanding until many of the colonies abutted each other. Eventually, *B. schlosseri* overgrew the *M. membranacea* colonies, and the space that was not covered by *B. schlosseri*, including the crevices between colonies, was filled in by sediment containing primarily *P. ligni* and two unidentified species of gammarid amphipods. Starting in early September there was a steep decline in the number and size of *B. schlosseri* colonies and a corresponding increase in the number of individuals of the species *M. manhattensis*. This continued until late October/early November, when *P. ligni* started to disappear and *B. schlosseri* began to reappear. Over the winter, most of the organisms disappeared, until the following April when the only organisms remaining were a few individuals of *P. ligni*. The numbers of both *M. membranacea* and *M. manhattensis* were higher than in 2003, the latter reaching as high as nearly 25% coverage by late summer, 2002.

In 2003 there was no significant difference between 4 of the frames in terms of total percentage coverage (p = 0.0802, Table 2). One of the remaining frames was situated next to a submerged piling that apparently shifted enough in the current to make contact with the frame; the constant bumping jarred 7 of the 12 plates on the frame loose over the course of the experiment, and although they were replaced as they were loosened, the difference in time was apparently enough to cause a significant difference from the other frames. Frame number 5 was not included in analysis because in August, most of the barnacles on 8 out of 12 of the tiles were accidentally scraped off by construction equipment installing a floating dock nearby.

When the tiles were divided into two groups based on their mounted height on the frames, there was a significant within-subjects interaction effect between height and frame on percentage coverage over time (p = <0.001, Table 2). With the exception of one frame, the tiles mounted closer to the surface of the water had higher percentage cover over time than did the lower tiles (Fig. 4).



DISCUSSION

Comparison to prior survey

In a 1986 colonization study conducted at Pier 76 on the Hudson River, (several miles north of Pier 26) for the New York City Public Development Corporation (EEA, 1988), the most consistently abundant species found colonizing submerged cinder blocks were *Polydora ligni*, *Balanus improvisus, Mytilus edulis* and *Molgula manhattensis*. Although our study used percentage coverage rather than mean density as a method to quantify colonization, we found these species, with the exception of *M. edulis*, to be the most abundant as well. In the case of *P. ligni,* although its coverage was not directly measured, it was present in varying densities in nearly all sediment from the time of its first appearance in early June through the course of the study.

The 1986 survey also found relatively high levels of the soft-shell clam *Mya arenaria*, which might be considered unusual as it generally burrows in soft sediments, rather than growing on a hard substratum such as the concrete of a cinder block. We did not find any specimens of *M. arenaria* in our study, however, in 2003 we recorded instances of several other epifaunal bivalves and gastropods, including *Mytilus edulis, Crassostrea virginica, Crepidula fornicata* and *Crepidula plana*. *M. edulis* is relatively common on the pilings around Pier 26, growing in dense beds especially in crevices in the large concrete blocks that form part of the base of the pier. The only specimen of *M. edulis* found in our study had settled at the very edge of a settling plate, protected to a certain extent by an overhang provided by the aluminum frame holding the tile. It did not survive to the end of the study. Similarly, only three specimens of *C. virginica* were found. Two of the individuals were on the exposed surfaces of the plates among barnacles, and grew to a length of about 25mm before dying for undetermined reasons. The remaining individual, similar to the mussel, had settled in the protected crevice between the plate and the frame.

O'Beirn (2000) found that settling oyster larvae and juveniles require some degree of interstitial space to serve as a refuge from predators; adult oyster shells served this purpose quite well in his study. It seems likely that, particularly in the case of *M. edulis*, which is quite common around Pier 26, the lack of recruitment by *M. edulis* and *C. virginica* was due at least in part to a lack of adequate relief on the surface of the tiles to provide predation protection for new recruits. Hence, the only individuals to survive were those protected by the pre-existing structure of the tiles and frames themselves. Barnacles do not seem to require the same protection from predation; from our data it is not possible to predict whether in future seasons the barnacles will provide enough surface complexity to allow viable populations of *Mytilus* and *Crassostrea* to grow among them. It is, however, encouraging to simply note individuals of *Crassostrea* settling and growing; prior to 1998 they had not been seen in the Hudson River for at least 3 decades. Bivalves such as the mussel and the oyster, in addition to filtering sediment out of large quantities of water and attracting many species of fish, can also be commercially important when harvested from clean waters.

Comparison between years

In 2002, the settling plates were deployed in mid-July, after the barnacle *B. improvisus* had settled (in the 2003 series), while in 2003 they were deployed in late May. It is no surprise that the pattern of colonization was quite different between these two years. In 2002, it would seem reasonable to assume that *B. schlosseri*, being so dominant during the summer, decreased so dramatically in the autumn due to the change in temperature. However, this does not explain why it would then make a return in late October/early November, unless at a certain density *P. ligni* was somehow able to inhibit its growth until the temperatures cooled enough to lower *P. ligni* levels to a point where *B. schlosseri* was able to recolonize. Indeed, evidence suggests that *B. schlosseri* requires a relatively silt-free environment to flourish, as it tends to settle on downward facing surfaces that do not accumulate silt (Chadwick-Furman and Weissman, 1995), while *Polydora* clearly requires a silty substrate from which to build its tubes. The rapid colonization by *B. schlosseri* in 2002 begs the question of the source of larvae. Its larvae, due to their lecithotrophic nature, must settle within approximately 36 hours. Therefore, they are largely dependent on currents to disperse to suitable colonization sites that are relatively close by; generally this range is between 1 and 10 km (Berrill, 1950), and perhaps often less than one km.

Resistance to invasion

One encouraging result of the 2003 study is that the number of colonizing species present on the tiles increased linearly over time (Fig. 2), while the total percentage coverage of the tiles remained constant between 80-90% (Fig. 3). This suggests high levels of biodiversity were not limited by space but apparently only by time of exposure to recruits. Such a community is more likely to be resistant to invasion by introduced species (Stachowicz et al. 2002a), although we do not currently know very much about how invasive species such as *Botryllus schlosseri* and *Membranipora membranacea* are affecting communities in the Hudson River. *M. Membranacea* was first introduced to the east coast in the Gulf of Maine in 1987 (Lambert et al. 1992), while *Botryllus*, originally introduced to Newfoundland from Europe in the early 1800s, has since spread to both coasts of the United States. Both of these species have been shown to have detrimental effects in other ecosystems such as the kelp beds of Nova Scotia, Canada (e.g. Berman et al. 1992). Since invasive species can have dramatic effects on ecosystems, often with severe financial repercussions (see for example, the effect of the zebra mussel, *Dreissena polymorpha*, on the ecosystem of the Great Lakes and Hudson River), there is interest in understanding what factors allow species to invade successfully, and how invasions can be prevented or stopped. One hypothesis that has been supported by several studies is that communities that are more diverse should be less susceptible to invasion. Particularly in marine communities, which tend to be space limited, having a diverse assemblage of organisms should assure that fluctuations in populations of individual species do not cause an overall fluctuation in coverage of the substratum. Any fluctuations that create open space could potentially open the door for invaders to settle. Stachowicz et al. (2002a) found support for this hypothesis; they experimentally manipulated the availability of space while keeping species richness of a marine community constant and found that invasion success increased as space increased.

In the case of New York harbor, it seems conceivable that the timing of reconstruction could affect the species profile of the resulting community, although given the seasonal nature of the river this may not be the case. For example, if the timing of recruitment for *Balanus* is such that it recruits before *Botryllus* does every year, it may be that it will become the dominant species in the assemblage every year regardless of the presence of *Botryllus* the previous year, as *Botryllus* colonies do not grow very quickly and may in fact cease reproducing entirely when the temperature is too cold (Millar 1971), therefore not maintaining their cover of space from year to year. Additionally, the Hudson River freezes to some extent during the winter, and the action of floating ice on fixed surfaces could remove the majority of organisms each year, effectively “resetting” the colonization clock. Another way that the time at which the substrate becomes available could influence the resulting community profile is suggested by Stachowicz et al., (2002b). They found that the recruitment of native and non-native species of ascidians in Long Island Sound varied in opposing directions with the climate. For example, if the winter was particularly cold, recruitment by invasive species was negatively impacted, while recruitment by native species was positively impacted.

Looking to the future

It seems evident that every effort should be made to assure maximum biodiversity when New York Harbor's bulkheads, docks, piers and platforms are rebuilt. In addition to creating a community that will be more likely to resist invasion by detrimental aliens, it is also probable that it will provide significant financial benefits to the region. By attempting to maximize biodiversity, we should also be maximizing the likelihood that commercially important species such as the eastern oyster will flourish, since we are creating multiple sources of larvae. Oysters can serve not only as a valuable fishery to be exploited, but also as an important habitat to be cultivated and protected. Oyster beds provide many ecological benefits to estuaries: they effectively filter particulate matter, decreasing turbidity, increasing light penetration and thereby increasing primary productivity. They are also long-lived, surviving winters. They are therefore able to effectively control phytoplankton populations in the spring when zooplankton biomass is still low; this control is thought to prevent the creation of an anoxic state when phytoplankton go un-grazed and serve as a nutrient source for bacterial communities. Their feces and pseudofeces serve as both nutrient and substrate to other invertebrates. Their shells serve as settling points for other sessile organisms such as barnacles and provide protection from predation for other invertebrates. Clearly their potential positive impact on an estuarine ecosystem is great (reviewed in Newell, 1988).

Percentage cover was negatively influenced by depth (fig. 6); one factor that is likely to be influencing this is light transmission. The high particulate load in the river causes transmission to be quite poor; one impact that increased filtering provided by oyster beds could have is to clear some of the suspended particulates and increase the depth to which light penetrates. This could potentially increase the amount of substrate eventually covered by communities.

One aspect of the reconstruction that is unknown is what materials will be used in building. The most probable options are either concrete or, less expensively, a polymer-coated steel. Although a proper study was not conducted on this matter, a few sets of settling plates made from representative materials were deployed in 2003: concrete, recycled plastic, polymer-coated steel and terra cotta. These plates were only in the water for several weeks, but from qualitative observation it was evident that the most growth took place on the concrete. This is not surprising given the diversity of organisms reported on the concrete used by the EEA in 1986, as opposed to the anti-fouling nature of the polymer-coated steel. It seems useful therefore to maximize the deployment of concrete substratum, as opposed to those surfaces that are not likely to attract epibenthic species.

SUMMARY

Given the diversity of organisms observed, particularly those sensitive to pollution and DO levels not recorded in previous studies such as *C. virginica*, we can conclude that the water quality of the Hudson River has improved in the past several decades. Colonization of the tiles occurred fairly rapidly, and *Balanus improvisus* was the dominant cover species at around 60% by early August. However, the total number of species present increased at a steady rate even after *B. improvisus* had reached its highest percentage cover, suggesting that recruitment was not limited by space. Recruitment did, however, appear to be limited by depth, although further research is needed to determine influencing factors in this pattern.

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Table 1. Species

SPECIES	COMMON NAME	Sessile Y/N	PRESENT FROM/COLLECTED ON	PRESENT TO
Polydora ligni	Mud Worm	Y	30-Jul	29-Sep
Amphitrite ornata	Ornate Terebellid Worm	Y	30-Jul	29-Sep
Spirorbis spp.	Hard Tube Worm	Y		29-Sep
Jassa marmorata	Tube-building Amphipod	Y	24-Jun	7-Jul
Obelia geniculata	Knotted Thread Hydroid	Y		
Gonothyrea loveni	Hydroid	Y		
Campanularia flexuosa	Hydroid	Y		
Microciona prolifera	Read Beard Sponge	Y		
Haliclona loosanoffi	Loosanoff's Haliclona	Y	15-Sep	
Bugula simplex	Bushy Bryozoan	Y		
Membranipora membranacea	Lacy Bryozoan	Y	30-Jul	
Balanus improvisus	Bay Barnacle	Y	10-May	29-Sep
Balanus eburneus	Ivory Barnacle	Y	10-May	29-Sep
Botryllus schlosseri	Golden Star Tunicate	Y	29-Sep	
Molgugla manhattensis	Common Sea Grape	Y	16-Jul	29-Sep
Crepidula fornicata	Slipper Limpet	Y	7-Aug	
Crepidula plana	Eastern White Slipper Shell	Y	7-Aug	
Mytilus edulis	Blue Mussel	Y	16-Jul	29-Sep
Crassostrea virginica	Eastern Oyster	Y	29-Sep	
Nereis virens	Clam Worm	N	16-May	
Nereis pelagica	Clam Worm	N	24-Jul	
Nephtys incisa	Common Painted worm	N		
Hydroides dianthus	Carnation Worm	N		
Euplana gracilis	Flatworm	N	24-Jul	
Gammarus spp.	Scuds	N	10-May	
Caprella penantis	Skeleton Shrimp	N	30-May	
Phloxichilidium femoratum	Sea Spider	N		
Mnemiopsis leidyi	Comb Jelly	N		
Aurelia aurita	Moon Jelly	N		
Idotea metallica	Isopod	N	15-Sep	
Palaemonetes pugio	Daggerblade Grass Shrimp	N	14-May	29-Sep
Rithropanopeus harrisii	Harris Mud Crap	N	24-Jul	
Libinia emarginata	Spider Crab	N	14-Aug	
Callinectes sapidus	Blue Crab	N	24-Jul	
Opsanus tau	Oyster Toadfish	N	29-Sep	

Table 2. ANOVA results, Repeated Measure Analysis of Variance Tests of Hypotheses for Between Subjects Effects

Source	DF	Type III SS	Mean Square	F Value	Pr > F	G-G	H-F
Time	4	20902.1	5225.525	43.32	<.001	<.0001	<.0001
Time*Height	4	2626.56667	656.64167	5.44	0.0048	0.0048	0.0023
Time*Frame	12	8028.56667	669.04722	5.55	<.001	<.0001	<.0001
Time*Frame*Height	12	1308.9	109.075	0.9	0.5441	0.5016	0.5166
Error(time)	160	19298.6667	120.61667				