INVESTIGATION OF BENTHIC CONDITIONS UNDER MUSSEL-RAFT FARMS

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2008

Introduction:

After examining the sea floor under several operating mussel-raft farms, Maine Department of Marine Resource Staff questioned the potential nature and extent of environmental degradation caused by organic loading. This project was initiated to evaluate the extent of organic loading under mussel raft farms and the resulting response of the benthic infaunal community.

The Maine Department of Marine Resources conducts leasing of subtidal waters for the culture of marine organisms. The two most commonly used programs are leases that are defined as “limited purpose aquaculture leases” that allow for an area of two acres for a period of three years (12 M.R.S.A §6072A) and a “standard aquaculture lease” that allows for up to 100 acres for a period of ten years (12 M.R.S.A §6072).

Between 2000 and 2005, Department of Marine Resources Staff dove under mussel-raft farms between Casco Bay and Stonington when these farms were making the transition from a limited purpose lease to a standard lease. Underwater video was collected at each of these farm sites as part of the standard lease site review process.

The first farm visited was in Casco Bay (Bangs Island) and we noted substantial mussel shell accumulation on the bottom, grey/black sediments indicative of anoxic conditions, and the presence of the sulfur reducing bacteria *Beggiatoa spp.* The degree of impact to benthic infauna and the surrounding ecological community under these rafts was of concern due to the apparent hypoxic conditions and accumulation of shells and other organic material.

The second farm we visited was in Penobscot Bay. Sediments there were hard sand, shell accumulation was minimal and no organic loading was noted. The third farm we visited was again in Casco Bay (Clapboard Island). Sediments were a mix of sand and mud and little to no impact was observed.

The fourth farm we visited was in the Lamoine area. We noted extraordinarily heavy accumulations of live and dead mussels (a thickness of 4-5 inches) and a very large number of sea stars overlaying the mussels. No anoxia or *Beggiatoa* was noted although, based on the accumulated organic material, we anticipated both conditions might occur in the future. At the time of our visit sea stars were clearly established under the farm while completely absent outside the farm footprint. Additionally, an accumulation of lost dropper ropes was observed on the bottom.

We then dove at a mussel farm in the Stonington area where a covering of a single layer of mostly live mussels were found covering the bottom in approximately 90 feet of water. The mussels appeared to be alive and filtering. A moderate number of sea stars and crabs were interspersed on the mussel bed. Our interpretation of these conditions was that a living mussel bed had been established and organic loading was not impairing ecological functions under the rafts. A viable benthic community appeared to have been established where little had previously existed.

The sixth farm we visited was in Blue Hill Bay. Here, dropped mussel shells on the bottom were very heavy (4-5 inches thick) compared to other farms we had visited, sediments were clearly anoxic based on color and smell, and *Beggiatoa* was heavy in places. Little other fauna such as stars or crabs were present. This farm showed the greatest impact we had observed to date. Here too, netting and dropper ropes were observed on the bottom.

Clearly the extent of impact under mussel rafts was variable. In some locations the epibenthic community appeared enhanced with greater species diversity and abundance. In other locations the epibenthic community appeared unaffected and in others anoxic conditions from organic loading appeared to greatly diminish the epibenthic community. We had at this point accumulated some information about effects to the epibenthic community but had no information regarding benthic infauna responses.

Methods

Phase One - Background

The Aquaculture staff of the Department of Marine Resources conducted an extensive literature review in early 2005, to examine the published effects of suspended mussel aquaculture on the environment.

The majority of scientific literature available on this subject originated in locations outside the U.S and no studies focusing on the benthic impacts of shellfish aquaculture in Maine were found. The search was limited to the suspended culture of oysters and mussels. A great majority of the available literature related to the long-line culture of mussel species. Long-line culture differs from raft culture in that mussel dropper lines are suspended from long support lines instead of rafts. In Maine, the use of a raft concentrates mussels growing on dropper lines within the average 40’X 40’ footprint of the raft. With long-line culture product is spread out over a larger area. The following review is organized by common impacts/changes noted in the literature at suspended shellfish farms.

Sedimentation Rate: Sedimentation rates were commonly reported to be higher under suspended shellfish farms than neighboring reference locations. (Dahlback and Gunnarsson 1981, Grant et al. 1995, Hatcher et al. 1994, Kaspar et al. 1985 and Pietros and Rice 2003). In fact, multiple studies found the sedimentation rates under farms to be more than twice that measured under nearby reference stations (Dahlback and Gunnarsson 1981, Grant et al. 1995 and Hatcher et al. 1994). Seasonal patterns in sedimentation rates were also noted –rates were highest during the warmer spring and summer months and lowest during winter months – suggesting feeding and biodeposition may enhance sedimentation (Gilbert et al. 1995 and Kaspar et al. 1985). Another study found currents within mussel rafts to be significantly reduced compared to currents located between individual rafts, suggesting that inhibition of water flow within a farm may also enhance sedimentation (Stenton-Dozey et al. 2001).

Sediment Organic Matter: There was generally no indication that the organic matter content differed between farms and reference sites (Danovaro et al. 2004 and Grant et al. 1995), which would suggest enrichment A review of the literature suggests that while Total Organic Matter (TOM) has been shown to differ between farm and reference sites – more TOM measured at farm sites versus references (Chivilev and Ivanov 1997, Dahlback and Gunnarsson 1981, Grant et al. 1995 and Hartstein and Rowden 2004) the organic constituents of sedimenting material between culture and non-culture sites is variable and often not distinguishable – especially with regard to organic carbon. Crawford et al. (2003), Dahlback and Gunnarsson (1981), Grant et al. (1995), and Hatcher et al. (1994) reported similar measurements of carbon content in sediments at farms and reference stations, indicating a propensity for greater absolute deposition instead of organic enrichment of the sediments. To the contrary, Chamberlain et al. (2001), Chivilev and Ivanov (1997), Gilbert et al. (1997), Mattsson and Linden (1983) and Stenton-Dozey et al. (2001) found carbon content to be higher under suspended mussel and oyster farms versus at reference locations. Similar variability was found with regard to nitrogen content of sediments at farms versus reference sites (Dahlback and Gunnarsson 1981, Hatcher et al. 1994, Kaspar et al. 1985, Mazouni et al. 1996, Stenton-Dozey et al. 2001 and Chamberlain et al. 2001). Again, hydrodynamic properties of the areas studied may influence sedimentation and accumulation of organics. Hartstein and Rowden (2004) found that TOM was twice as high inside the boundaries of a low current (3-4 cm/s) mussel farm versus outside. Additionally, the carbon to nitrogen ratio was higher in the low current farm versus at the reference. In the same study, no difference in TOM or the carbon to nitrogen ratio was found between a high current (9.7-10.2 cm/s) mussel farm and the reference site.

Sediment Redox Layer: The redox discontinuity layer can be identified from a shift in sediment color from brown through grey to black and is used to identify the depth at which the sediments become anaerobic. The layer is a surrogate measure for redox potential. Generally, the more enriched a location, the shallower the discontinuity layer and smaller the redox potential. When redox falls below zero (or is negative) the greater the reliance on anaerobic breakdown of organic materials. At finfish farms the presence of anoxic surficial sediments is one indicator of organic overload to the benthos. Several studies of the benthic impacts of suspended shellfish aquaculture have measured redox potential in sediment cores. While there was some variability in the effect of suspended shellfish aquaculture on sediment redox potential, the majority of studies found that the addition of cultured mussels or oysters caused localized decreases in sediment redox potential. Dahlback and Gunnarsson (1981) reported redox potentials of ≤ -100 MV at a mussel farm throughout the entire sediment core depth. On the other hand, the reference location became more reduced with increasing sediment depth but was always greater than levels measured at the farm. Currents at the two sites were ~3 cm/s. Mirto et al. (2000) also reported redox layers that were much deeper at a reference location versus a long-line mussel farm site. Similarly, Mattson and Linden (1983) and Chamberlain et al. (2001) found that redox potential increased with increasing distance from a long-line mussel farm. With regard to oysters, Gilbert et al. (1997) found that redox potential was always positive at the reference location but variable within the farm. Seasonal effects were also noted with lowest redox potentials during the summer months (Gilbert et al.

1997). Hydrodynamics also appear to play an important role. In fact, Grant et al (1995) found no difference in redox levels between a long-line mussel farm and a reference site where currents at the stations were 15 cm/s. Chamberlain et al. (2001) found that a shallow mussel farm with low residual currents showed the lowest redox readings closest to the farm whereas another site with higher current speeds was always positive for redox potential.

Sulfides: Sulfate reduction, an indicator of anaerobic metabolism, appears to be stimulated at suspended shellfish aquaculture sites. Grant et al. (1995) found hydrogen sulfide (H_2S) levels increased rapidly with sediment depth at a high current, long-line mussel farm in a semi-enclosed bay. H_2S was not present above 30 cm at the reference station. Hatcher et al. (1994) also found significantly higher levels of H_2S at shallower depths at a mussel farm versus a reference site; Stenton-Dozey (2001) found total reducible sulfides (TRS) to be 3 times greater down to 20 cm at a mussel raft site versus reference, where TRS was constant. Again, sediments were anoxic at the mussel farm resulting in anaerobic metabolism. Dahlback and Gunnarsson (1981) also found sulfate reduction to be enhanced at a long-line mussel farm. They found concentrations of sulfate to be 100 times greater at the farm site than the reference.

Ammonium (NH_4): An increased efflux of ammonium was a commonly observed trait of suspended shellfish farms compared to their counterpart reference stations. At a long-line mussel farm in a semi-enclosed cove, Grant et al. (1995) found that the release of ammonium was an order of magnitude greater than that observed at the reference site. No seasonal effect was noted and the authors concluded that ammonium efflux was a sensitive early indicator of benthic impacts. Additionally, Gilbert et al. (1997) found nitrate reduction to be stimulated at an oyster farm compared to the reference location. In fact, all studies that measured ammonium production found it to be enhanced at farm sites versus references (Hatcher et al 1994, Kaspar et al. 1985, Mazouni et al. 1996), suggesting that the increased deposition at farm sites resulted in a higher rate of nitrogen turnover. Hatcher et al. (1994), Kaspar et al. (1985) and Mazouni et al. (1996) all found ammonium efflux to be always higher at farm versus reference site but also higher during summer months for both farms and reference locations.

Chlorophyll/Phaeopigment: The presence of increased amounts of sediment chlorophyll-a and phaeopigment (product from the breakdown of chlorophyll-a) has been noted at suspended mussel farms (Dahlback and Gunnarsson 1981, Hatcher et al. 1994, Kaspar et al. 1985 and Mirto et al. 2000). Chlorophyll-a is the photosynthetic pigment found in algae. Its presence, in higher concentrations at mussel farms versus reference sites suggests that filtered phytoplankton by mussels and deposition through pseudofeces enhances sedimentation (Hatcher et al. 1994).

Benthic Infauna: Several reviewed studies investigated the impacts of suspended mussel and oyster culture on benthic infauna. The general conclusion that can be drawn from such studies is: increased biodeposition occurring at these farms has the potential to cause eutrophication and a successional shift in benthic infaunal communities – towards smaller, opportunistic species such as polychaetes. Impacts were found to be localized and the severity of impacts was site specific. Harstein and Rowden (2004) found that polychaetes were more abundant within the boundaries of a slow current (3-4 cm/s) long-line mussel farm versus outside the farm. On the other hand, the same study found no difference in infaunal community structure within and outside a fast current (10 cm/s) long-line mussel farm. Danovaro et al. (2004), having found no other indications of benthic impact from a long-line mussel farm, reported no difference in community structure between farm and reference. Unfortunately, current speeds were not provided. On the other hand, several studies documented alterations to infaunal diversity, abundance, biomass, and community structure at suspended shellfish farms. Infaunal diversity was commonly found to be reduced at farm sites (Kaspar et al. 1985, Mattson and Linden 1983, Mazouni et al. 1996 and Chamberlain et al. 2001). When compared to reference stations, suspended mussel and oyster farms were also found to exhibit increased abundance of infaunal organisms yet decreased biomass (Stenton-Dozey et al. 1999 and Stenton-Dozey et al. 2001). These observed reductions in benthic infaunal diversity and biomass accompanied by an increase in abundance can be explained by the propensity of shellfish farms to be dominated by small opportunistic species such as the polychaete *Capitella capitata* (Chamberlain et al. 2001, Chivilev and Ivanov 1997, De Casabianca et al. 1997, Hartstein and Rowden 2004, Kaspar et al. 1985, Mattsson and Linden 1983, Mazouni et al. 1996, Stenton-Dozey et al. 1999 and Stenton-Dozey et al. 2001).

The results of this literature review suggest that, while they type of impacts from suspended shellfish farms are similar to those noted at marine finfish farms, the severity of impacts are generally less than what one might observe at a fish farm. Additionally, benthic impacts from shellfish farms appear to be localized to within the basic footprint of the farm and are generally site specific. A number of studies indicate that hydrodynamic regimes at shellfish farms play an important role in the resultant impact to the benthos. Overall, the increased biodeposition that occurs at suspended shellfish farms has the potential to cause some level of eutrophication. In response to this eutrophication, opportunistic deposit feeders move in and there is more reliance on detritus based food chains. Additionally, the increased organic inputs may result in enhanced recycling rates with increased ammonium efflux and more reliance on anaerobic metabolism.

Phase Two

While a number of changes have been documented in published literature we decided to focus on changes to community structure (or benthic infauna) in phase two of this project. Though changes to the environment can be documented, our concern was did it ultimately affect life surrounding the farms? (e.g. how did the community respond to potential changes?)

To investigate the response of benthic communities under Maine mussel rafts we revisited two farms that in our experience represented moderate and severe impact (Bangs I., Casco Bay; and Long Island, Blue Hill Bay, respectively). At the Bangs Island farm underwater video was collected by SCUBA diver under the rafts and along transects extending 60 meters beyond the raft edge and in line with the prevailing currents. At Long Island in Blue Hill Bay, due to water depths, a drop camera was used along the raft edges and out to 60 meters. Benthic infauna samples were collected under the rafts and at five and thirty meters from the upstream and downstream edges. We also collected sediment samples from a reference location where bottom conditions appeared similar to beneath the rafts and thought to be outside of farm influences. Sediment samples were collected by hand in 4 inch PVC cores or by grab. Three replicate samples were taken at each benthic sampling station along with a fourth sample used for granulometry.

Sediment samples were passed through a 1 mm. sieve, and all material retained was jarred, fixed in 10% buffered formalin, and subsequently stained with 1% Rose Bengal to aid in the sorting of organisms for species identification. After approximately five days of fixing in the 10% formalin, the solution was decanted and replaced with 70% ethanol to ensure preservation of the organism's integrity; particularly bivalves and other calcareous forms. MER Inc., a Brunswick, Maine consulting firm, identified all organisms found in each replicate sample.

Sediment granulometry cores were collected at each station in the same manner as the benthic infauna samples. The contents of the cores were transferred into doubled Zip-loc bags. Granulometric analyses were performed by S.W. Cole Engineering, Inc. in Gray Maine using standard wash methods through nested sieves.

Results

Summary of station benthic metric means

Station	Total organisms	Abundance (orgs/0.1 m^2)	Richness Sp./Fam.	Distance (m)	Rel. Diversity	% Capitella
Blue Hill 30m South	**8.0**	**98.8**	**4.0/3.7**	**30**	**0.852/0.839**	**0.0**
Blue Hill 5m South	**1.3**	**16.5**	**1.3/1.3**	**5**	**0.333/0.333**	**0.0**
Blue Hill 0m South	**49.7**	**613.1**	**5.0/5.0**	**0**	**0.555/0.555**	**73.1**
Blue Hill Reference	**4.7**	**57.6**	**3.7/3.7**	**>100**	**0.654/0.654**	**0.0**
Bangs 30m North	**3.7**	**45.3**	**1.0/1.0**	**30**	**0.000/0.000**	**0.0**
Bangs 5m North	**0.7**	**8.2**	**0.7/0.7**	**5**	**0.000/0.000**	**33.3**
Bangs 0m North	**1.0**	**12.3**	**1.0/1.0**	**0**	**0.333/0.333**	**0.0**
Bangs 0m South	**2.3**	**28.8**	**2.3/2.3**	**0**	**0.667/0.667**	**0.0**
Bangs 5m South	**1.0**	**12.3**	**0.7/0.7**	**5**	**0.306/0.306**	**0.0**
Bangs 30m South	**3.0**	**37.0**	**2.0/1.3**	**30**	**0.594/0.241**	**0.0**
Bangs Reference	**12.3**	**152.3**	**3.7/3.3**	**>100**	**0.847/0.844**	**6.7**

Relative diversity for each sample is calculated where n is the total number of organisms in the sample, k is the number of species in the sample, and f_i is the number of individuals in each species i.

$$H = \frac{n \log n - \sum_{i=1}^{k} f_i \log f_i}{n}$$

Results generally showed very low diversity in the vicinity of and under the rafts and no clear pattern of lowered diversity under or near the rafts compared to 30 meters away. Few benthic infauna were found under rafts and at the severely impacted site, sediments were clearly anoxic by odor. The moderately impacted site (Bangs Island) did not exhibit anoxic conditions.

At the farm in Blue Hill Bay, the samples collected under the rafts showed a higher number of organisms than at the reference location,(49.7 versus 4.7) however 73% of these organisms consisted of *Capitella* worms, a pollution tolerant species. *Capitella* worms would have been expected in this sample based on sediment odor and color. This location directly under the rafts was clearly impacted by the organic loading as evidenced by these *Capitella* worms. Species richness was low throughout the Blue Hill farm and reference samples (ranging from 1.3 to 5.0.).

Bangs Island samples also contained few benthic infauna. Samples from under the rafts showed little infaunal life. Total numbers of organisms ranged from 0.7 to 3.7. With these values a difference of one organism represented more than a 25% overall change. All other measured parameters would also differ greatly with only the absence or presence of a single organism. By way of example, Bangs Island 5m North samples showed 33.3% *Capitella* worms. While this might appear significantly different than the 0% *Capitella* at all other sampling stations the results were driven by finding only a single *Capitella* worm in one of the three replicate samples.

Please see the Appendix for individual sampling results.

Conclusions

Here is where reference sites became extremely important and informative. Reference stations also had little infauna, and therefore low diversity, in each sample. While differences were apparent, these differences were the result of very small sample sizes in terms of organisms identified. Life at the reference stations sampled was minimal just as it was under the rafts.

What did this sampling tell us? It appears that siting of these mussel rafts is appropriate in that they have not been located over sensitive or naturally rich environments. While samples under the rafts showed some impact, there was little there to affect in the first place. Organic buildup under the rafts, while clearly visible to the eye, has essentially made a depauperate bottom potentially less hospitable; but with little or nothing there to be affected, is it of concern?

We know that organic buildup under mussel rafts can be "remediated" through biological consumption and degradation over time. The effect is not permanent. Hence, where buildup has been documented a rational and practical response is to shift the rafts over a new footprint where possible. At both farms sampled, lease holders were able to identify past practices that might have contributed to organic buildup and changes that they could employ to reduce future drop-off. These practices included careless handling of mussels during seeding and harvest, and allowing multiple wild-sets of mussels to attach to the seeded mussels leading to slippage of product from the lines due to excess weight.

Finally, nets and ropes dropped to the bottom continue to be of concern both from an ecological perspective and from a diver safety perspective. Nets act as a trap for organic sedimentation and represent a dangerous entanglement risk to divers.

Recommendations

The use of benthic infaunal analyses to document changes under mussel rafts may be misleading due to small changes in individual samples driving the results. Small changes can lead to drastic differences in species richness, diversity, and percent *Capitella* worms.

For example, if there are only three organisms in a sample, but each represents a different species, the species diversity is 1.00; perfect... but the bottom might not be. "Might not" is key, in that ambient, unaffected soft bottoms often support very few organisms. Reference samples become important to interpret this example. The reference samples collected at the two farms discussed here also contained very few organisms. This latter case is an example of a "False-positive" where the numbers indicate an unimpacted condition when it is likely not. An example of a "False-negative is an 80% *Capitella* value from a sample that contains 30 other species; the 80% *Capitella* value seemingly indicates organic loading problems and the relative diversity values will likely be low. This implies a highly enriched bottom condition, but the fact that the bottom can support 30 other species suggests that the bottom condition is likely acceptable and not nearly as bad as percent *Capitella* would imply.

One of our observations was the large number of mussel shells in the samples with comparatively little or no sediment. Shells alone will support very few infauna (only in the sediment trapped in selected shells), since infauna are "in" the sediment, but may not necessarily preclude colonization of the underlying sediment as long as the shells do not promote anoxic conditions below. Mussel shells that land with the concave surface down, however, do tend to promote anoxia, as the shell forms a capsule in which oxygen exchange is prohibited or severely limited.

Benthic conditions under a mussel farm are determined by a combination of factors; many of which are neither predictable nor static. For instance, storms can dislodge mussels from the ropes causing "drop-off" to the bottom. How the mussels are seeded and harvested can affect the amount of drop-off. Sloppily handled product will fall to the bottom. Predation by Eider ducks will also cause uneaten mussels and empty shells to fall to the bottom. Finally, the Blue Hill Bay farmer attributed the substantial impact to the bottom at his site to multiple wild sets of mussels attaching to the socked mussels thereby creating too much weight on the lines and subsequent stripping of the socked mussels off the lines. Any, none, or all of the above conditions can occur in any given year at a mussel farm.

To date we have observed a gamut of impacts from the mussel farms we have visited. Those two farms where we have observed the heaviest impacts were located over soft bottom habitats that are naturally depauperate in infauna. The appropriate sitting of farms may be the key to minimizing harm from even the most poorly run farm in that with a relative absence of epibenthic fauna and benthic infauna to affect, even the most severely impacted farm represents little change to the environment in terms of space and ecological function.

Acknowledgements

This work was partially supported by the Coastal Zone Management 309 Program through the Maine Coastal Program.

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Apppendix

Sediment granulometry testing results

Blue Hill Bay 08/31/06

	Station 30m S		Station 5m S		Station 0m S		Reference	
	Passing	Retained	Passing	Retained	Passing	Retained	Passing	Retained
2"	100		100		100		100	
1-1/2"	100	0	100	0	100	0	100	0
1"	100	0	100	0	100	0	100	0
3/4"	100	0	100	0	100	0	100	0
1/2"	100	0	100	0	21	79	100	0
1/4"	100	0	99	1	15	6	100	0
#4	100	0	97	2	15	0	100	0
#10	100	0	81	16	12	3	91	9
#20	100	0	67	14	11	1	77	14
#40	100	0	61	6	10	1	67	10
#60	100	0	58	3	10	0	61	6
#100	99	1	55	3	10	0	55	6
#230	99	0	49	6	10	0	49	6
<#230		99		49		10		49
		100		100		100		100

Sediment granulometry testing results (Continued)

Bangs Island 10/17/2006

	Station 30m N1		Station 5m N		Station 0m N1		Station 0m N2		Station 30S1		Station 30S2	
	Passing	Retained	Passing	Retained	Passing	Retained	Passing	Retained	Passing	Retained	Passing	Retained
1-1/2”	100		100		100		100		100		100	
1”	100	0	100	0	100	0	100	0	100	0	100	0
¾”	100	0	95	5	100	0	100	0	100	0	100	0
½”	100	0	92	3	100	0	100	0	100	0	100	0
¼”	100	0	86	6	90	10	100	0	100	0	100	0
#4	100	0	80	6	71	19	100	0	100	0	100	0
#10	100	0	79	1	65	6	100	0	100	0	100	0
#20	96	4	71	8	46	19	100	0	99	1	99	1
#40	89	7	65	6	35	11	100	0	98	1	92	7
#60	82	7	62	3	29	6	100	0	97	1	82	10
#100	78	4	60	2	27	2	99	1	95	2	77	5
#230	72	6	54	6	24	3	98	1	91	4	71	6
<#230	56	16	27	27	18	6	95	3	71	20	53	18
		56		27		18		95		71		53

Bangs Island 10/17/2006

	Station 0mS		Station 5m N		Station 30m S		Station 30m S		Reference		Station 30m S	
	Passing	Retained	Passing	Retained	Passing	Retained	Passing	Retained	Passing	Retained	Passing	Retained
1-1/2”	100		100		100		100		100			
1”	100	0	100	0	100	0	100	0	100	0		
¾”	100	0	100	0	100	0	100	0	100	0		
½”	100	0	100	0	100	0	100	0	100	0		
¼”	94	6	95	5	100	0	100	0	100	0		
#4	71	23	87	8	100	0	100	0	100	0		
#10	62	9	80	7	100	0	100	0	100	0		
#20	43	19	59	21	99	1	99	1	97	3		
#40	31	12	45	14	98	1	92	7	92	5		
#60	25	6	39	6	97	1	82	10	87	5		
#100	22	3	34	5	95	2	77	5	83	4		
#230	18	4	27	7	91	4	71	6	74	9		
<#230	12	6	13	14	71	20	53	18	37	37		
		12		13		71		53		37		

Benthic data

Blue Hill Bay 08/31/2006
30m South

SPECIES level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	6	13	5	24	8.0	12.7
Abundance (organisms/0.1 m²)	74	160	62	296.3	98.8	1930.4
Species richness (No. species)	4	5	3	8	4.0	0.7
Distance in meters	30	30	30		30	
Rel. Diversity	0.959	0.732	0.865		0.852	0.009
% CAPITELLA	0.0	0.0	0.0		0.0	0.0

FAMILY level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	6	13	5	24	8.0	12.7
Abundance (organisms/0.1 m²)	74	160	62	296.3	98.8	1930.4
Family richness (No. families)	3	5	3	7	3.7	0.9
Distance in meters	30	30	30		30	
Rel. Diversity	0.921	0.732	0.865		0.839	0.006
% CAPITELLIDAE	0.0	0.0	0.0		0.0	0.0

5m South

SPECIES level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	2	1	1	4	1.3	0.2
Abundance (organisms/0.1 m²)	25	12	12	49.4	16.5	33.9
Species richness (No. species)	2	1	1	4	1.3	0.2
Distance in meters	5	5	5		5	
Rel. Diversity	1.000	0.000	0.000		0.333	0.222
% CAPITELLA	0.0	0.0	0.0		0.0	0.0

FAMILY level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	2	1	1	4	1.3	0.2
Abundance (organisms/0.1 m²)	25	12	12	49.4	16.5	33.9
Family richness (No. families)	2	1	1	4	1.3	0.2
Distance in meters	5	5	5		5	
Rel. Diversity	1.000	0.000	0.000		0.333	0.222
% CAPITELLIDAE	0.0	0.0	0.0		0.0	0.0

Benthic data (Continued)

0m South

SPECIES level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	29	59	61	149	49.7	214.2
Abundance (organisms/0.1 m²)	358	728	753	1839.4	613.1	32647
Species richness (No. species)	4	6	5	8	5.0	0.7
Distance in meters	0	0	0		0	
Rel. Diversity	0.619	0.482	0.563		0.555	0.003
% CAPITELLA	72.4	76.3	70.5		73.1	5.8

FAMILY level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	29	59	61	149	49.7	214.2
Abundance (organisms/0.1 m²)	358	728	753	1839.4	613.1	32647
Family richness (No. families)	4	6	5	8	5.0	0.7
Distance in meters	0	0	0		0	
Rel. Diversity	0.619	0.482	0.563		0.555	0.003
% CAPITELLIDAE	72.4	76.3	70.5		73.1	5.8

Reference

SPECIES level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	5	6	3	14	4.7	1.6
Abundance (organisms/0.1 m²)	62	74	37	172.8	57.6	237.1
Species richness (No. species)	4	6	1	8	3.7	4.2
Distance in meters	>100	>100	>100		>100	
Rel. Diversity	0.961	1.000	0.000		0.654	0.214
% CAPITELLA	0.0	0.0	0.0		0.0	0.0

FAMILY level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	5	6	3	14	4.7	1.6
Abundance (organisms/0.1 m²)	62	74	37	172.8	57.6	237.1
Family richness (No. families)	4	6	1	8	3.7	4.2
Distance in meters	>100	>100	>100		>100	
Rel. Diversity	0.961	1.000	0.000		0.654	0.214
% CAPITELLIDAE	0.0	0.0	0.0		0.0	0.0

Benthic data (Continued)

Bangs Island Farm 10/17/2006
30m North

SPECIES level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	4	2	5	11	3.7	1.6
Abundance (organisms/0.1 m²)	49	25	62	135.8	45.3	237.1
Species richness (No. species)	1	1	1	1	1.0	0.0
Distance in meters	30	30	30		30	
Rel. Diversity	0.000	0.000	0.000		0.000	0.000
% CAPITELLA	0.0	0.0	0.0		0.0	0.0

FAMILY level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	4	2	5	11	3.7	1.6
Abundance (organisms/0.1 m²)	49	25	62	135.8	45.3	237.1
Family richness (No. families)	1	1	1	1	1.0	0.0
Distance in meters	30	30	30		30	
Rel. Diversity	0.000	0.000	0.000		0.000	0.000
% CAPITELLIDAE	0.0	0.0	0.0		0.0	0.0

5m North

SPECIES level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	1	1	0	2	0.7	0.2
Abundance (organisms/0.1 m²)	12	12	0	24.7	8.2	33.9
Species richness (No. species)	1	1	0	2	0.7	0.2
Distance in meters	5	5	5		5	
Rel. Diversity	0.000	0.000	0.000		0.000	0.000
% CAPITELLA	100.0	0.0	0.0		33.3	2222.2

FAMILY level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	1	1	0	2	0.7	0.2
Abundance (organisms/0.1 m²)	12	12	0	24.7	8.2	33.9
Family richness (No. families)	1	1	0	2	0.7	0.2
Distance in meters	5	5	5		5	
Rel. Diversity	0.000	0.000	0.000		0.000	0.000
% CAPITELLIDAE	100.0	0.0	0.0		33.3	2222.2

Benthic data (Continued)

0m North

SPECIES level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	2	0	1	3	1.0	0.7
Abundance (organisms/0.1 m²)	25	0	12	37.0	12.3	101.6
Species richness (No. species)	2	0	1	3	1.0	0.7
Distance in meters	0	0	0		0	
Rel. Diversity	1.000	0.000	0.000		0.333	0.222
% CAPITELLA	0.0	0.0	0.0		0.0	0.0

FAMILY level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	2	0	1	3	1.0	1.0
Abundance (organisms/0.1 m²)	25	0	12	37.0	12.3	12.3
Family richness (No. families)	2	0	1	3	1.0	1.0
Distance in meters	0	0	0		0	0
Rel. Diversity	1.000	0.000	0.000		0.333	0.333
% CAPITELLIDAE	0.0	0.0	0.0		0.0	0.0

0m South

SPECIES level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	3	0	4	7	2.3	2.9
Abundance (organisms/0.1 m²)	37	0	49	86.4	28.8	440.3
Species richness (No. species)	3	0	4	6	2.3	2.9
Distance in meters	0	0	0		0	
Rel. Diversity	1.000	0.000	1.000		0.667	0.222
% CAPITELLA	0.0	0.0	25.0		8.3	138.9

FAMILY level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	3	0	4	7	2.3	2.9
Abundance (organisms/0.1 m²)	37	0	49	86.4	28.8	440.3
Family richness (No. families)	3	0	4	5	2.3	2.9
Distance in meters	0	0	0		0	
Rel. Diversity	1.000	0.000	1.000		0.667	0.222
% CAPITELLIDAE	0.0	0.0	25.0		8.3	138.9

Benthic data (Continued)

5m South

SPECIES level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	0	3	0	3	1.0	2.0
Abundance (organisms/0.1 m²)	0	37	0	37.0	12.3	304.8
Species richness (No. species)	0	2	0	2	0.7	0.9
Distance in meters	5	5	5		5	
Rel. Diversity	0.000	0.918	0.000		0.306	0.187
% CAPITELLA	0.0	0.0	0.0		0.0	0.0

FAMILY level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	0	3	0	3	1.0	2.0
Abundance (organisms/0.1 m²)	0	37	0	37.0	12.3	304.8
Family richness (No. families)	0	2	0	2	0.7	0.9
Distance in meters	5	5	5		5	
Rel. Diversity	0.000	0.918	0.000		0.306	0.187
% CAPITELLIDAE	0.0	0.0	0.0		0.0	0.0

30m South

SPECIES level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	5	3	1	9	3.0	2.7
Abundance (organisms/0.1 m²)	62	37	12	111.1	37.0	406.4
Species richness (No. species)	3	2	1	4	2.0	0.7
Distance in meters	30	30	30		30	
Rel. Diversity	0.865	0.918	0.000		0.594	0.177
% CAPITELLA	0.0	0.0	0.0		0.0	0.0

FAMILY level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	5	3	1	9	3.0	2.7
Abundance (organisms/0.1 m²)	62	37	12	111.1	37.0	406.4
Family richness (No. families)	2	1	1	3	1.3	0.2
Distance in meters	30	30	30		30	
Rel. Diversity	0.722	0.000	0.000		0.241	0.116
% CAPITELLIDAE	0.0	0.0	0.0		0.0	0.0

Benthic data (Continued)

Reference

SPECIES level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	8	24	5	37	12.3	69.6
Abundance (organisms/0.1 m²)	99	296	62	456.8	152.3	10600
Species richness (No. species)	3	4	4	8	3.7	0.2
Distance in meters	>100	>100	>100		>100	
Rel. Diversity	0.819	0.760	0.961		0.847	0.007
% CAPITELLA	0.0	0.0	20.0		6.7	88.9

FAMILY level analysis	Rep 1	Rep 2	Rep 3	Total	Mean	Var.
Total organisms	8	24	5	37	12.3	69.6
Abundance (organisms/0.1 m²)	99	296	62	456.8	152.3	10600
Family richness (No. families)	2	4	4	6	3.3	0.9
Distance in meters	>100	>100	>100		>100	
Rel. Diversity	0.811	0.760	0.961		0.844	0.007
% CAPITELLIDAE	0.0	0.0	20.0		6.7	88.9