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Variability in Growth and Age Structure Among Populations of Ribbed Mussels, Geukensia demissa (Dillwyn) (Bivalvia: Mytilidae), in Jamacia Bay, New York (Gateway NRA)

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Variability in Growth and Age Structure Among Populations of Ribbed Mussels, *Geukensia demissa* (Dillwyn) (Bivalvia: Mytilidae), in Jamaica Bay, New York (Gateway NRA)

by

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Abstract. Growth rates, body weight, density and biomass of ribbed mussels, *Geukensia demissa* (Dillwyn), were determined at *Spartina alterniflora* marsh-flat sites in Jamaica Bay, New York (Lower Hudson Estuary). Cumulative growth and annual growth increments varied but rates were lower at sites within the central bay relative to peripheral sites. Local variability both in size at Ring-1 and size-specific annual growth rates probably account for the variability in cumulative length. No patterns were noted in frequency distributions of shell size but congruence in age structure was observed among neighboring sites in some areas of the bay. Length-specific dry body weights were lower in the central bay. Mussel densities were greater within Jamaica Bay than at most other locations reported in the literature and estimated biomass values were lower. Growth rates of Jamaica Bay mussels were lower than other populations in the northeastern American coast. Four hypotheses that may account for observed *Geukensia* growth rates in Jamaica Bay are presented and discussed: higher population density, higher vertical marsh levels, variability in phytoplankton quality and/or quantity, long-term sublethal chemical pollution.

INTRODUCTION

Jamaica Bay is an urban estuary located at the southwestern end of Long Island and comprises the easternmost component of the Lower Hudson River estuarine system. Bounded on the north by the New York City boroughs of Brooklyn and Queens, and on the east by Long Island's Nassau County, most of the bay at present is included within the Gateway National Recreation Area. In spite of severe human impacts from pollution, development, and population pressure, Jamaica Bay remains a critical local resource for migrating shorebirds and waterfowl and provides nesting sites for several endangered wildlife species.

The intertidal zone of much of Jamaica Bay is bordered by *Spartina* salt marshes. A ubiquitous inhabitant of this community is the Atlantic ribbed mussel, *Geukensia demissa* (Dillwyn, 1817) (BERTNESS, 1984). This bivalve may prove useful as a candidate for long-term monitoring of environmental quality in Jamaica Bay. Its advantages include: (1) Mussels are relatively long-lived (>10 yr at many places) and moderately large (>1 g dry weight); (2) Mussels are relatively immobile (after a post-settlement period of active movement) and accessible year round; (3) The age of individual mussels can be determined by enumeration of external annuli (LUTZ & CASTAGNA, 1980; BROUSSEAU, 1984); and (4) As long-lived filter feeders,

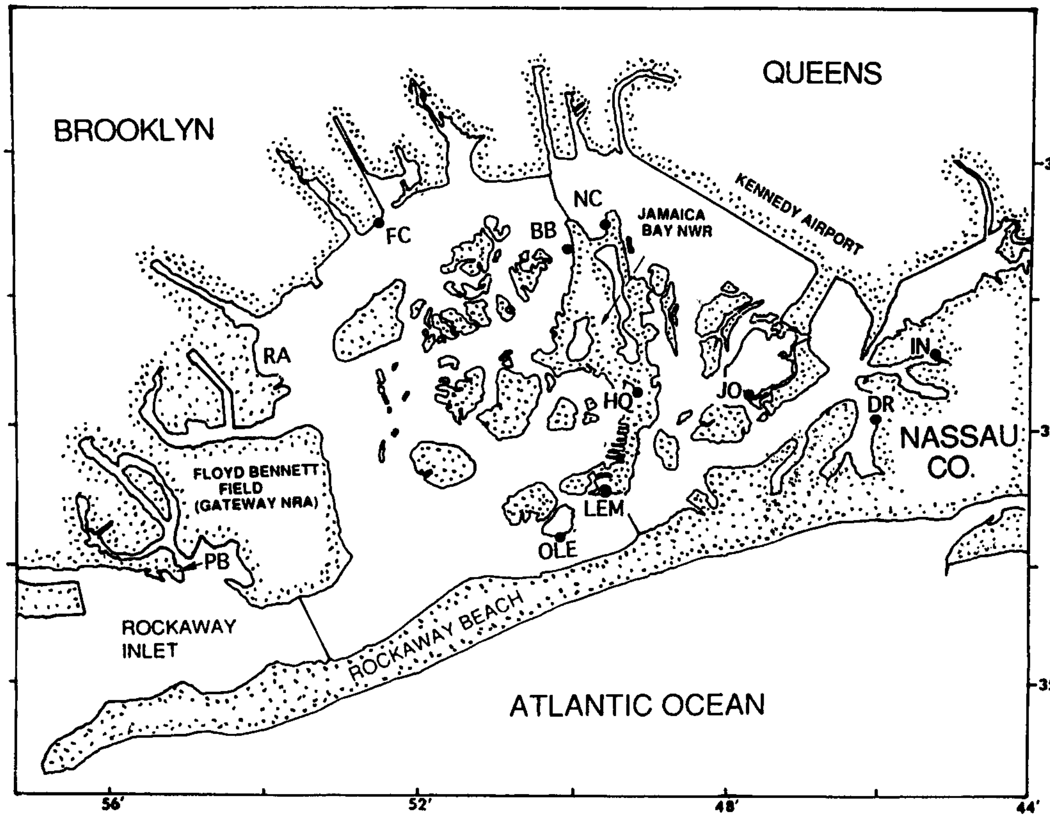

Figure 1

Map of Jamaica Bay (New York City) showing location of mussel sampling sites. W, water; PB, Plum Beach; RA, Riding Academy; FC, Fresh Creek; BB, Black Bank; NC, North Channel; JO, Joco; In, Inwood; DR, Drucker; HQ, Headquarters; LEM, Inner Little Egg; OLE, Outer Little Egg.

mussels may integrate the effects of low concentrations of suspended or dissolved toxic materials, which may be measurable as sublethal modifications of physiological functions such as growth or reproduction. The prerequisite for the use of mussels for this purpose is an adequate understanding of their ecology, particularly the role of natural variables in affecting these physiological functions. The purposes of the research reported here were to determine the variability in *Geukensia* growth rates among sites within Jamaica Bay, and to compare growth with data from other locations.

MATERIALS AND METHODS

Study Sites

Mussel populations (Figure 1) were selected to include a range of habitats within Jamaica Bay as well as a site just outside of the Bay proper (Plum Beach). At all sites, mean tidal range is close to 1.5 m. Sites were visited between June and September 1991. At all locations, collections came from the marsh flat, which is the section of the "tall" *Spartina alterniflora* salt marsh immediately upshore of the marsh edge, and characterized by the presence of *Spartina* culms. All marsh-flat samples were collected approximately 1 m from the marsh edge.

Analyses

For analyses of growth, entire sections of turf containing mussels were cut by spade and brought to the laboratory, where larger mussels were removed by hand, and small mussels were washed into a 1-mm sieve. Barnacles and epiphytic growth were scraped from larger mussels, which were scrubbed with a metal brush. Mussels used for age determination were steamed open, the flesh was removed, and the paired valves were numbered. Age was determined by counting external growth annuli following the methods of LUTZ & CASTAGNA (1980) and BROUSSEAU (1984). The growth annulus appears at the time of new growth beginning in May. Transmitted light was used to identify annuli in smaller mussels. Annuli were then confirmed by examination of the outer shell surface under the dissecting microscope. Shells of larger, older mussels were soaked in Clorox to remove the periostracum. The shell length corresponding to each annulus was measured with vernier calipers.

Mussel density (m^{-2}) was estimated at eight sites. Mus-

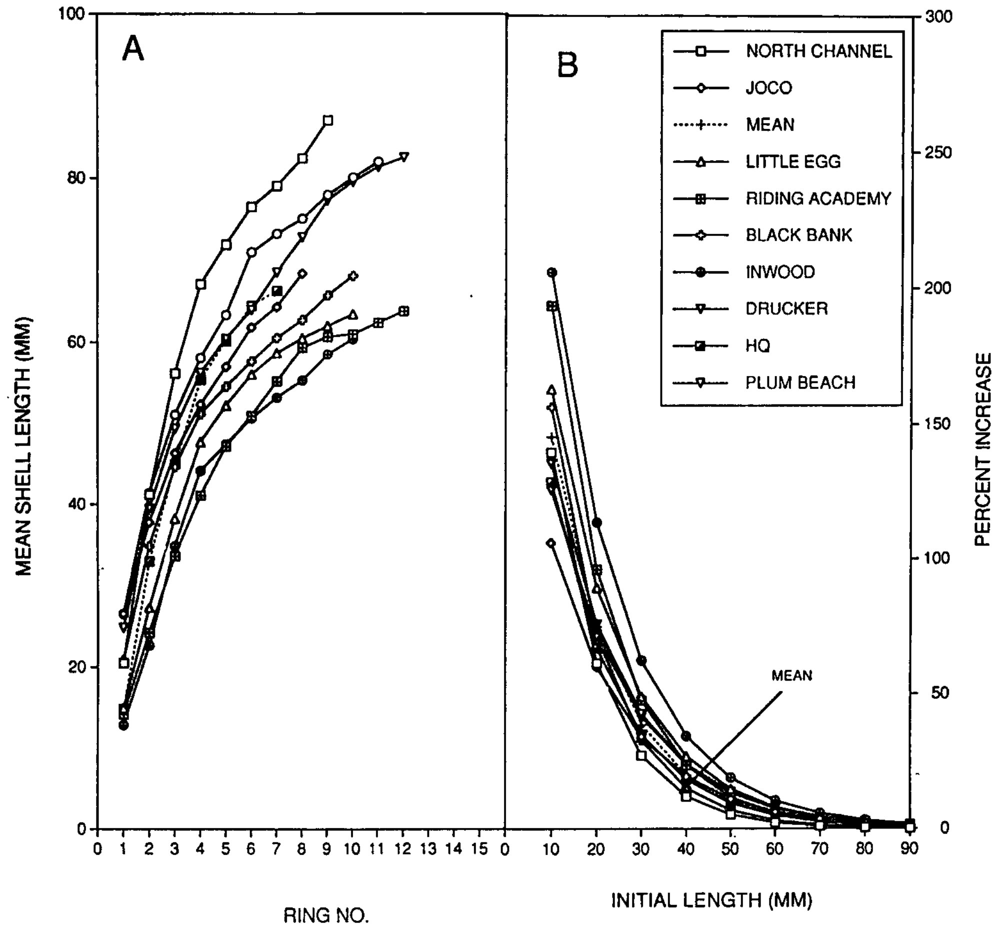

Figure 2

A. Cumulative growth curves of nine mussel populations. B. Fitted size-specific relative growth curves. The y-axis is the log(mean percent annual length increase); x-axis is the initial length of a mussel at the beginning of a growth season. The curve labelled "mean" is generated using regression coefficients averaged for all populations, and may be considered as an average relative growth curve for Jamaica Bay mussels.

sels were counted in 18 circular quadrats (area = 346 cm^2) which were located randomly along a line stretched parallel to the marsh edge.

Dry body weight/shell length relationships were determined for six populations in July 1991. For each population, 25 mussels spanning the available size range were selected. After measuring shell length, bodies including fluids were removed by dissection into pre-weighed pans. Tissues were dried at 70°C for 48 hr and re-weighed using a Metler Microbalance. Log-linear regressions of dry weight vs. shell length were used in conjunction with density and size-frequency distributions of mussels to estimate biomass.

RESULTS

Cumulative and Relative Growth

Cumulative growth curves for nine marsh-flat mussel populations from a range of sites within Jamaica Bay (Figure 2A) show that higher growth rates occurred at sites located away from the central core of the bay (*e.g.*, Inwood, Little Egg Marsh, Plum Beach, and Riding Academy). Lower growth occurred at sites within the central core of the bay (*e.g.*, Drucker Marsh, North Channel Marsh and Black Bank Marsh). Mussel length at year-1 was a poor predictor of size at age-8 ($R^2 = 0.31$, $P = 0.07$) but probably is a factor of importance in determining asymptotic future size. Another factor is the geographical position of the population within the bay.

In order to distinguish between these factors, data from the growth curves in Figure 2A are rearranged in Figure 2B as size-specific relative growth curves—*i.e.*, the annual growth increment as a percentage of length at the initiation of growth for each year. These are fitted curves based on linear regressions of the log[(annual growth/initial length) × 100] vs. initial length. Initial length is the mean length of an age cohort at the start of any growing season; annual growth is the mean increment in length for the cohort by

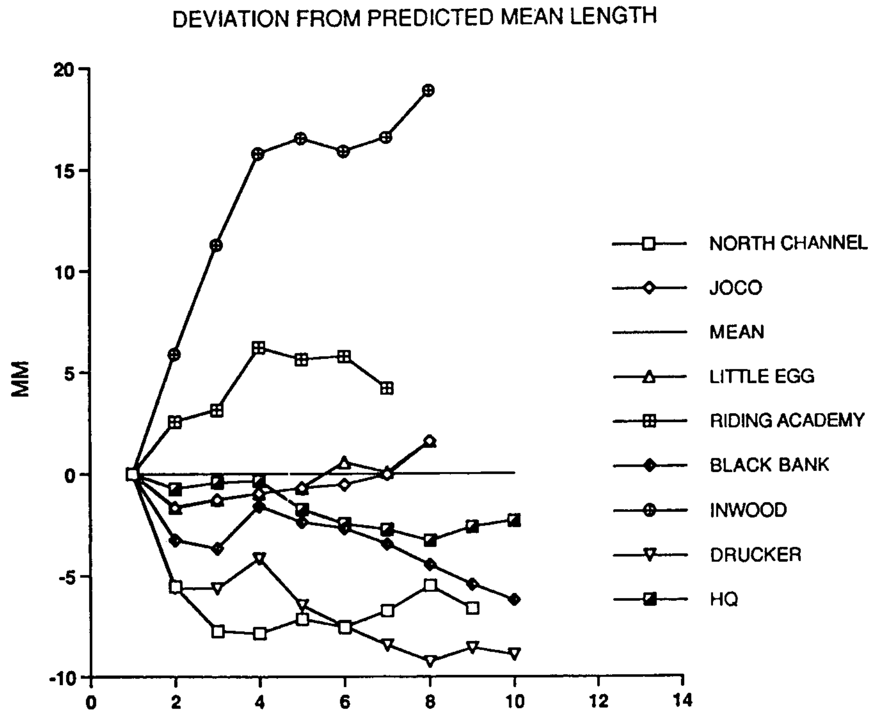

Figure 3

Predicted growth curves for Jamaica Bay populations are generated using observed initial (Ring-1) mean lengths in combination with the "mean" growth coefficients for Jamaica Bay from Figure 2B. If the mean curve accurately portrays growth for Jamaica Bay mussels, observed and predicted growth curves would be identical. Note that observed growth tends to be lower than predicted at sites in the central bay but higher at sites distant from the central core and outside of the bay.

the end of the growing season. Linear regression coefficients used to generate these curves and regression statistics are summarized in Table 1. An average growth curve for all populations (Figure 2B) has been used to reconstruct the cumulative growth curves. The average curve is based on the mean regression coefficients of all populations. These coefficients can then be used to simulate a cumulative growth curve for any site by using the observed mean year-1 length for that site as a starting point. To the extent that the average curve in Figure 2B accurately portrays a generalized growth strategy for Jamaica Bay mussel populations, the resulting "predicted" growth curves should be equivalent to the observed curves. Deviations between the observed and predicted growth curves in relation to age are shown in Figure 3 for each site.

Frequency Distributions of Size and Age

Frequency distributions of age and shell length for all populations are shown in Figure 4. Shell-length distributions are polymodal and variable, with no pattern of similarity among sites. The absence of small mussels at sites such as North Channel and Inwood may indicate scarcity of 1991 and, possibly, 1990 year classes.

Mussel Body Weights, Density, and Biomass

Regression coefficients [log(dry weight, g) = a + b log(shell length, mm)] for six populations, and fitted curves reflecting these coefficients are shown in Table 1 and Figure 5. Note that length-specific dry body weight (DW) is highest outside of Jamaica Bay (Plum Beach) and is lower at sites within the central core of the bay (Black Bank, Fresh Creek, Drucker). Mussel density at eight marsh-flat sites (Table 2) ranged between 600 and 1900 m^{-2}.

Estimates of biomass (g DW $\cdot$ m^{-2}) for eight marsh-flat populations (Table 2) show that biomass ranged from 0.21 kg (Drucker) up to 0.46 kg (Plum Beach). At sites within Jamaica Bay, biomass ranged from 0.21 to 0.42 kg.

DISCUSSION

Mussel populations in the central core of Jamaica Bay exhibit lower growth in comparison with more distant sites within the bay and with other locations in the northeastern American coast. This can be seen most clearly in the comparison between observed relative growth curves and predicted curves based on average growth statistics for all populations (Figure 3). Although the observed and pre-

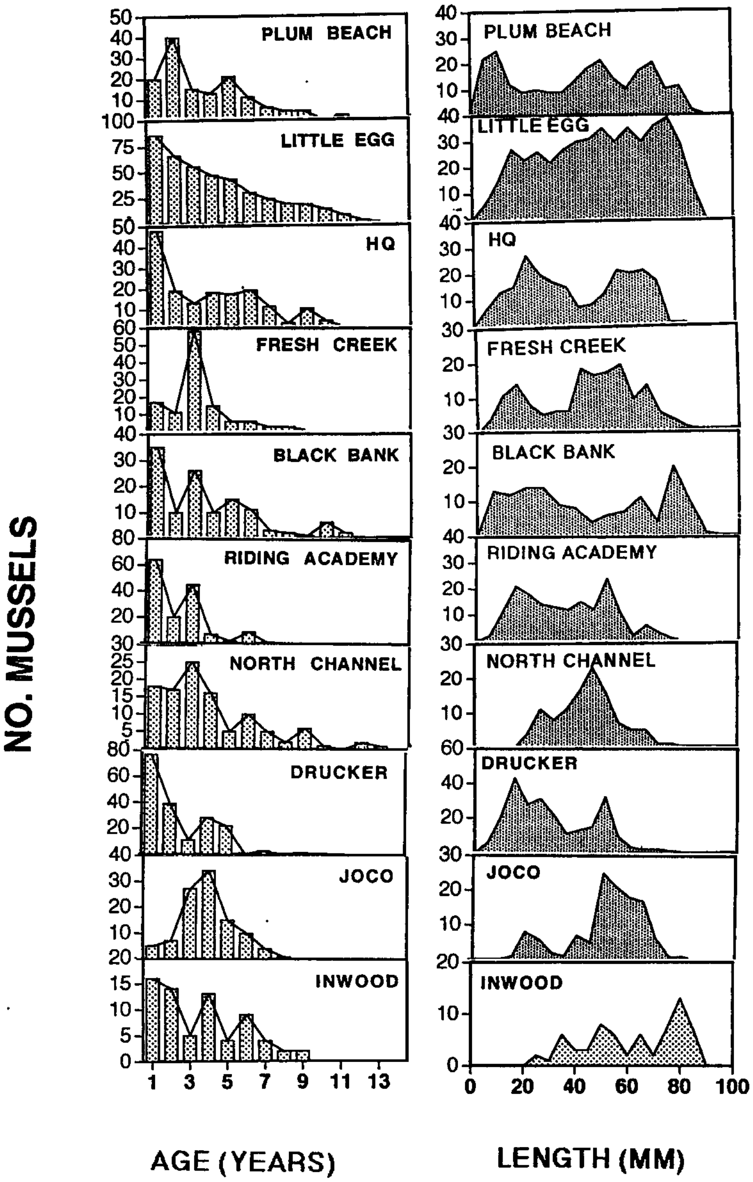

Figure 4

Left panel shows age structure of each population (excluding 1991-class mussels). Right panel shows shell length-frequency distributions at all sites based on collections taken between June and September 1991.

dicted curves are similar at some sites (HQ, Little Egg, Joco), the predicted curves deviate from the observed curves at others. If cumulative growth curves were determined primarily by size at year-1, then the pattern of deviation relative to geographical location should be random. However, this clearly is not the case (Figure 3). At sites closer to the entrance to Jamaica Bay (Plum Beach, Riding Academy) the observed growth curves exceed the predicted. At sites in the central bay (HQ, North Channel, Drucker, Black Bank) the observed growth is lower than the predicted. Growth rates at the Inwood site are anomalously high. However, this population is located within the warm-water plume of an electric generating station. These data suggest that mussel populations in the central bay may be more stressed than populations located peripherally, as reflected by a smaller annual proportional allocation to growth—*i.e.*, mussels of any given size in the central bay increase in size by a smaller percentage of starting size per year than other populations.

Although no patterns in population size structure were discernible, there was congruence in age composition between some sites. For example, all of the northern sites

Table 1

Regression statistics for *Geukensia demissa.*

A. Regression statistics: log(annual length increment/initial length) vs. initial length.

Site	b	a	r^2
North Channel	−0.035	0.499	0.83
Little Egg	−0.026	0.473	0.94
Black Bank	−0.034	0.532	0.97
Drucker	−0.032	0.382	0.96
Inwood	−0.025	0.572	0.98
Joco	−0.025	0.271	0.94
Riding Academy	−0.03	0.591	0.96
HQ	−0.028	0.39	0.88
Plum Beach	−0.024	0.338	0.93

B. Regression statistics: log(dry weight, g) vs. log(length, mm)

Site	b	a	r^2
Black Bank	2.837	−5.342	0.99
Drucker	3.177	−5.947	0.97
Joco	2.557	−4.805	0.97
HQ	2.43	−4.416	0.95
Plum Beach	2.893	−5.189	0.98
Fresh Creek	2.742	−5.168	0.99

(Riding Academy, Fresh Creek, North Channel, and Black Bank) show a pulse of 3-year mussels, suggesting that all received relatively large numbers of recruits in the 1989 season. Since these sites are fairly distant from the entrance to the bay (Rockaway Inlet), which is the only external source of larvae, these recruits probably originated within Jamaica Bay. At Plum Beach (outside of Jamaica Bay) and at the Little Egg and HQ sites, more age classes are represented with less year-to-year fluctuation in numbers over time than at other sites within Jamaica Bay. These sites, located nearer the inlet, are more likely to receive larvae brought into the bay with tidal currents and may be less dependent on localized recruitment than sites in the central and eastern bay.

Table 2

Mussel density and biomass at eight sites.

Site	Density (m^{-2}) Mean	SE	No. quad-rats	CV†	ID‡	Biomass (g/m^2)
North Channel	919	159	18	73.5	496	226.7
Little Egg	622	72	18	49.4	151	308.4
Black Bank	1888	173	16	36.5	252	379.5
Drucker	1955	138	18	30	176	214.7
HQ	1545	85	15	21.4	71	418.7
Plum Beach	735	111	8	42.8	135	463.1
Outer Little Egg	1215	93	18	32.4	127	379.8
Fresh Creek	802	109	18	57.8	268	218.2

† CV = Coefficient of variation = (SD/mean) × 100.
‡ Index of dispersion = variance/mean.

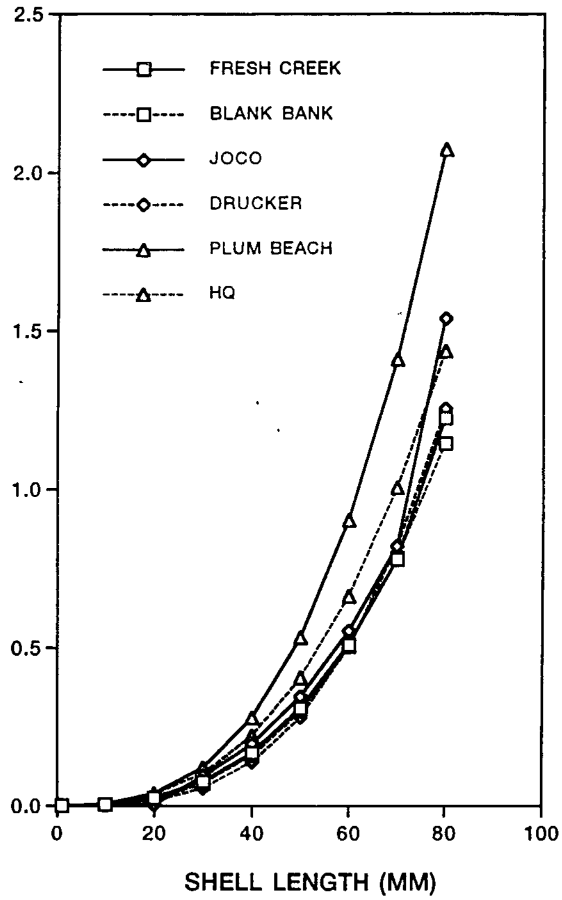

Figure 5

Fitted curves showing the relation between dry body weight (g) and shell length (mm) for six sites in July 1991. Note that body weights tend to be lower in populations from central Jamaica Bay. Curves are produced using linear regression coefficients for the equation: log(DW) = a + b(log length).

Population density (Table 2) was variable and all populations were highly clumped. Coefficients of variability (CV = SD/mean × 100) ranged from 21 to 73% and coefficients of dispersion (CD = s^2/mean) ranged from 71 to 496. Densities were statistically different among Jamaica Bay sites (Kruskall-Wallis statistic = 48.91, P = <0.001) and fell within the range of maximum *Geukensia* densities reported by others working in the New England to northern Middle-Atlantic region (FELL *et al.*, 1982; BERTNESS, 1984; BERTNESS & GROSHOLZ, 1985). Comparing density data between studies is problematic; however, the Jamaica Bay marsh flat densities seem much greater than those in the eastern Long Island Sound marshes investigated by FELL *et al.* (1982) but similar to the western Long Island Sound marshes (and to the Narragansett Bay site studied by BERTNESS, 1984).

Estimates of biomass for Jamaica Bay mussel populations were lower than those reported by FELL *et al.* (1982) for the the Great Meadows and Branford marshes in west-

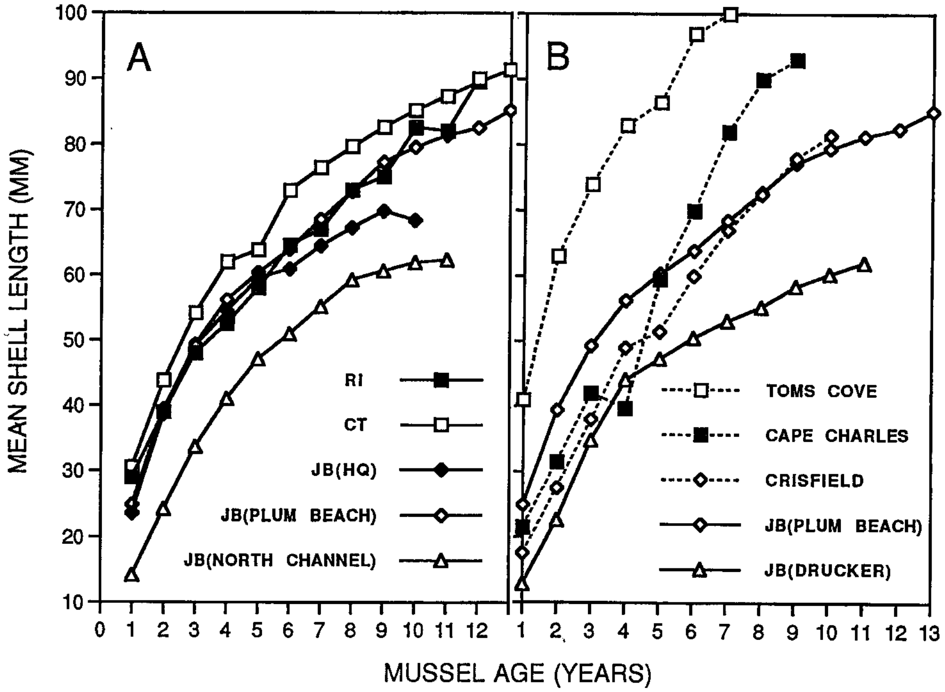

Figure 6

A. Cumulative growth curves for two within-bay sites (HQ, North Channel) and a site from the Rockaway Inlet outside Jamaica Bay (Plum Beach) compared with literature data for Rhode Island (BERTNESS & GROSHOLZ, 1985) and Connecticut (BROUSSEAU, 1984). Note that within-bay sites show lower growth rates.

B. Similar data comparing Jamaica Bay and Rockaway Inlet sites with published growth curves for three sites inside and outside of Chesapeake Bay (curves redrawn from BERTNESS, 1980). Note that the within-bay site (represented here by Drucker) is lower than all Chesapeake sites, but that growth at Plum Beach (outside of Jamaica Bay) is similar to the Crisfield site (within Chesapeake Bay).

ern Long Island Sound. There was no statistically significant correlation between mussel density and biomass in Jamaica Bay, whereas these appear to be positively correlated in the Connecticut marshes studied by FELL *et al.* (1982). This suggests that environmental factors in addition to crowding determine mussel biomass in Jamaica Bay.

There are few appropriate data on the growth rates of *Geukensia demissa* that can be compared with Jamaica Bay. In Figure 6, growth curves of Jamaica Bay mussels are superimposed on published growth curves for mussels from Connecticut (BROUSSEAU, 1984), Rhode Island (BERTNESS & GROSHOLZ, 1985), and the Chesapeake Bay area (BERTNESS, 1980). The New England mussel populations (Connecticut, Rhode Island) have higher growth rates than all inter-Jamaica Bay populations, but are similar to Plum Beach (Figure 6a). However, all of the Chesapeake Bay area populations exceed Jamaica Bay growth rates, including the Crisfield site, located well within Chesapeake Bay. BERTNESS (1980) suggested that differences in growth rates in his study reflected habitat-related physical differences among sites, including food quantity and quality.

Our results indicate that the mussels at Plum Beach (outside of Jamaica Bay) grew at rates comparable to those in other northeastern American populations. However, mussels within Jamaica Bay grew more slowly, and size-specific body weights of mussels in central bay populations were depressed relative to mussels in populations in the Rockaway Inlet (Plum Beach).

We propose and briefly discuss four hypotheses which, either singly or in combination, may account for depressed growth rates within Jamaica Bay: (1) Mussels in the central core of Jamaica Bay may be more crowded than in populations outside of the bay; (2) The vertical shore level of the marsh flat at sites within Jamaica Bay may be higher than at sites outside of Jamaica Bay; (3) Mussel populations within Jamaica Bay may utilize a qualitatively and/or quantitatively different phytoplankton population from mussels populations outside of Jamaica Bay; (4) Mussel populations in Jamaica Bay may be stressed as a result of long-term exposure to toxic heavy metals, polyaromatic hydrocarbons, or other chemical pollutants.

By experimentally manipulating mussels in the size range of 30 to 100 mm, BERTNESS & GROSHOLZ (1985) were able to show that mussels at high experimental densities (1600 m^{-2}) grew more slowly than mussels at low density (400 m^{-2}). However, the crowding effect on growth was smaller than the effect of shore level—*i.e.*, in spite of greater crowding, mussels at the marsh edge, which could filter for longer periods on each tidal cycle, grew faster than marsh flat mussels in the low density treatment. These results indicate that crowding will negatively affect growth, but that the crowding effect may be relatively small compared to the effect of shore level. As noted above, Jamaica Bay sites support relatively dense populations. Moreover, there is a statistically significant inverse correlation between mussel length at year-7 and mean density ($r = -0.71$, $P = <0.05$). These results are consistent with the hypothesis of density-dependent depression of growth rates in Jamaica Bay. However, neither the sampling methods used in this study nor the numbers of samples collected were appropriate to test adequately this hypothesis.

During this study, we observed that the vertical level of the marsh edge varies significantly among sites owing to differences in erosion and sediment deposition. On the basis of work by BERTNESS & GROSHOLZ (1985), noted above, as well as other unpublished data from Jamaica Bay, we suggest that this factor could account for some of the variability in mussel growth rates among sites, although this might not explain the general depression of growth rates within the central bay.

Available evidence on the species composition and productivity of phytoplankton in Jamaica Bay (PETERSON & DAM, 1986) is consistent with similar investigations in the Lower New York Harbor and New York Bight (MALONE, 1977), and indicates that plankton populations shift from diatom-dominated assemblages in early spring to nannoplankton (especially phytoflagellate)-dominated assemblages in summer. Other studies (PETERSON *et al.,* 1985) indicate that *Geukensia* populations located deeper within marsh-dominated estuaries may utilize greater amounts of detrital material than populations associated with the major marsh creeks and inlets, which consume larger amounts of phytoplankton. Accumulating evidence (*e.g.,* STIVEN & KUENZLER, 1979; FRECHETTE & BOURGET, 1985) supports a conclusion that some mussel populations may be food limited. Although there is no evidence at present that site differences in potential food quality in Jamaica Bay account for differences either in growth or individual body weight, this topic requires further study. Spatial variability in current velocities also may relate to food abundance and quality. However, tidal current velocities are high in Jamaica Bay, and at present we have no evidence suggesting a correlation between flow rates and mussel growth.

Jamaica Bay receives relatively large loadings of nutrients, heavy metals, PAHs, and other chemicals from many point and non-point sources, including two sewage treatment plants, large volumes of combined sewer overflows, run-off from Kennedy International Airport, and chemical leachates from three inactive municipal landfills (FRANZ & HARRIS, 1988). Mussels (*Mytilus edulis*) sampled from Jamaica Bay in the Mussel Watch Program (NOAA, 1989) exhibited high tissue concentrations of several toxic metals, PAHs and PCBs, some of which may induce sublethal stress in mussels.The possibility that depressed growth of *Geukensia* may be caused by chemical pollutants needs further investigation.

ACKNOWLEDGMENTS

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