An Analysis of the Relationship between Sediment Physical-Chemical Characteristics and the Abundance of the Mud Shrimp, *Corophium volutator*

Prepared By

M. Brylinsky
Acadia Centre for Estuarine Research
Acadia University
Wolfville, Nova Scotia
B4P 2R6

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SUMMARY

The mud shrimp, *Corophium volutator*, is a major component of the fauna of intertidal mudflats in northern areas of the Atlantic Ocean. Numerous studies have been carried out to define the physical-chemical characteristics of intertidal sediments necessary for colonization and support of *C. volutator* populations. The factors currently thought to be most important are sediment particle size, water content and organic content. To determine if *C. volutator* density could be predicted from these and other related factors, data obtained from the existing literature was collated into a database and used to explore the relationships between these sediment parameters and the density of *C. volutator*.

The results of the analysis indicated that *C. volutator* densities could not be predicted with any degree of confidence using multivariate regression procedures based on the sediment parameters included in the database. It is not clear if this is a result of the quality or comparability of the data, lack of consideration of other important sediment characteristics, or that factors other than sediment characteristics are as, or perhaps more, important in determining *C. volutator* densities.

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1. Background

Recent observations on the distribution of migratory shorebirds within the Minas Basin have revealed that changes are taking place. Areas known to once have an abundance of shorebirds have become devoid of shorebirds, and there is some evidence that these areas have experienced changes in the physical characteristics of the mudflats on which the shorebirds feed. The reasons for these changes are not well understood, but may be related to changes in the distribution and abundance of *C. volutator*, the major prey item of migratory shorebirds. A hypothesis often used to explain these observations is that the mudflats have changed in a manner that makes them unsuitable as a habitat for *C. volutator*. This raises the question as to what factors may be responsible for these changes, and whether the changes are natural or anthropogenic.

Numerous studies have attempted to determine the habitat requirements of *C. volutator*. Most have focused on the physical characteristics of sediments. Although the existing literature contains considerable discussion and data on the physical, chemical and biological factors thought to be necessary to support a productive *C. volutator* population, there have been no attempts to collate and/or analyse this information.

The objective of this study was to determine what physical-chemical factors have been suggested to be most important in determining suitable habitat for *C. volutator*, and to determine if the abundance of *C. volutator* could be predicted, using data available in the scientific literature, from quantitative measurements of these factors.

Relevant information contained in the literature was assimilated into one database that was analysed to determine if the distribution and abundance of *C. volutator* can be related to those factors. Particular attention was placed on developing a predictive model based on sediment characteristics that are easily measured, and for which considerable data exists. Examples include sediment particle size, water content, organic content and chlorophyll content

2. Habitat Requirements of *C. volutator*

C. volutator is commonly found in intertidal and shallow subtidal muds of brackish bays and estuaries. It is boreal in distribution and, on the east coast of North America, is limited to the Bay of Fundy-Gulf of Maine region. It lives in a U-shaped burrow constructed to depths of about 4 cm, but in some cases as deep as 12 cm, and can be found at densities of more than 50,000 m^{-2}. Sediment characteristics suggested to be important in determining its distribution include water content, organic content, sediment particle size, and sediment stability. Other factors suggested to be important include water salinity and the degree of winter ice cover and scour.

Gee (1961) was among the first to suggest that sediment water content is the most important factor in determining the distribution of *C. volutator*. In a study carried out at a small tidal inlet of the River Thames, it was found that *C. volutator* occurred only at sites having water contents between 29-39 %. Gee also indicated, however, that water content is partly a function of sediment grain size and that the silt/clay fraction where *C. volutator* was present ranged between 37.1-38.4 %, a range much narrower than that of water content. He also indicated that some of the variation in both distribution and abundance of *C. volutator* could be related to tidal current velocity and the stability of sediments, and that *C. volutator* can not live in an erosional environment. Turk et al. (1980) studied the abundance of *C. volutator* on the Windsor mudflat in Nova Scotia at a time when sediments were accumulating rapidly as a result of the construction of a causeway across the Avon River. Sediment water contents were quite high, generally about 50 %, and *C. volutator* abundance was very low. This was attributed to the inability of *C. volutator* to maintain burrows in the highly fluid muds.

Early field observations and laboratory experiments by Meadows (1965a; 1965b; 1965c) on substrate selection by *C. volutator* indicated it prefers fine to coarse sand, but that it showed no selection for anaerobic or aerobic substrates. The results of laboratory studies suggested that a combination of particle size and organic matter content are the most important factors, and that the preference is for silt sized particles that are high in organic content (Meadows and Campbell 1972). Anderson (1972), in a study of the factors affecting the distribution of intertidal invertebrates in Morecambe Bay, U.K., found maximum densities of *C. volutator* to occur on high, level flats having silt contents of 30-66 %, and on which micro-organisms (presumably diatoms) were most abundant.

Some of the earliest studies on the habitat requirements of *C. volutator* attempted to relate its distribution to salinity (Nicol 1935), but it is now believed that *C. volutator* is truly euryhaline and, although its preferred salinity is between 10-30 ppt, it can live at salinities ranging from as low as 5 ppt to as high as 35 ppt, (McLusky 1970).

Meadows and Raugh (1981) carried out a series of multifactorial experiments on the behavioural responses of *C. volutator* to combinations of salinity and temperature. The results were complex and difficult to interpret, but suggested that, overall, temperature discrimination decreased with increasing salinity and that salinity discrimination was unaffected by temperature. The ecological implication of this with respect to the distribution of *C. volutator* is that variations in water temperature are unlikely to affect salinity preferences.

There is some evidence that, under certain conditions, the distribution and abundance of *C. volutator* may be more strongly influenced by their dispersal behaviour than by sediment characteristics. Dense populations are often observed on the banks of tidal creeks and in bays. Based on observations made at two estuaries in Great Britain, Hughes and Verdol (1993) suggested this may be a result of a dispersal behaviour pattern exhibited by *C. volutator* in which it enters and swims within the water column on flood tides. This results in it being swept into areas, such as tidal creeks, where the tide rises but does not flow laterally. As they appear to swim only on flood tides, the reverse does not occur on ebb tides with, the result that they tend to become concentrated in the upper areas of bays and along the banks of tidal channels.

There are, of course, a number of other biological factors, aside from those related to behaviour, such as predation and competition, that influence the abundance of *C. volutator***.** Figure 2.1 summarizes the factors suggested to be most important.

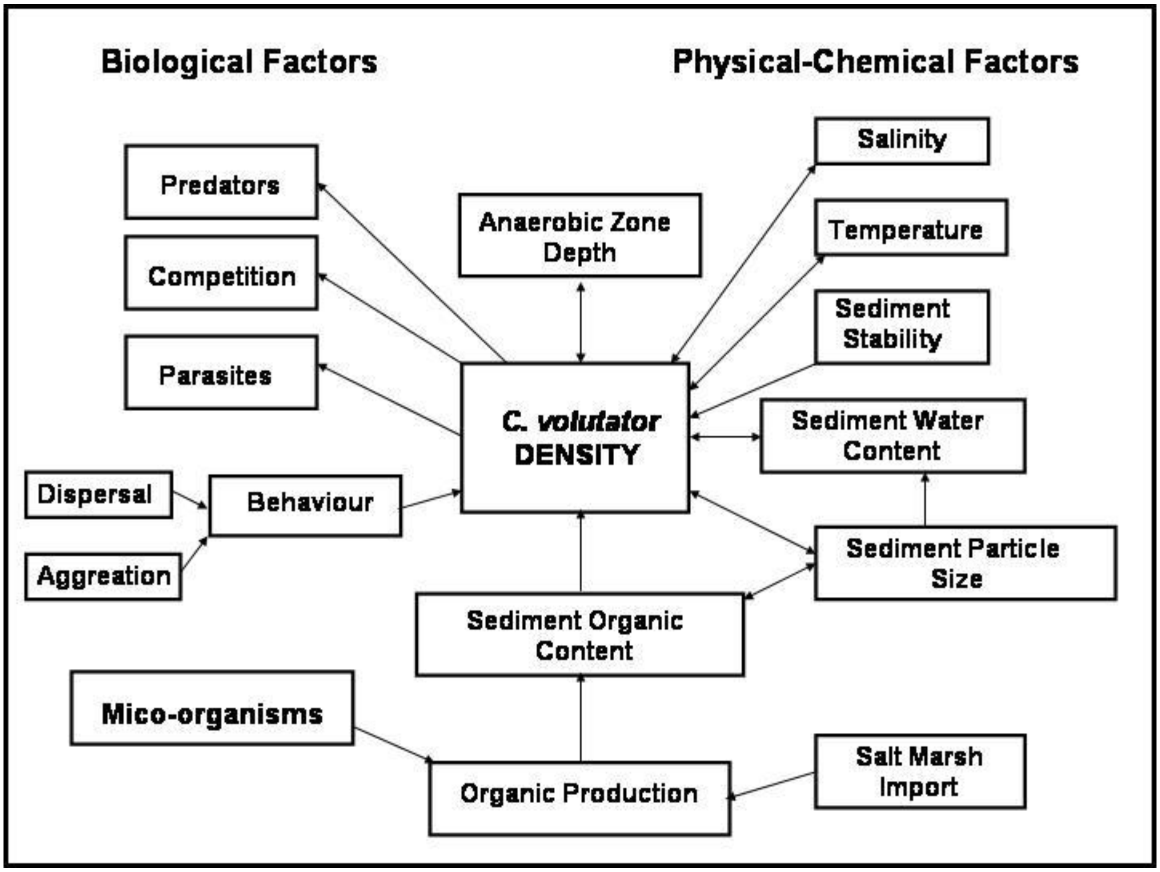

Figure 2.1. Summary of factors considered to be important in determining the distribution and abundance of *C. volutator* (arrows entering and leaving boxes indicate positive and negative effects, respectively; double headed arrows indicate a particular range of values is preferred).

3. Approach

Information on the abundance of *C. volutator* was obtained from numerous published and unpublished reports. The criteria for selection of data to include in the database was at least one measurement of *C. volutator* density during the period between late June and mid-July, and one measure of an associated sediment characteristic. *C. volutator* densities were limited to the early summer time period because of the often dramatic decrease in *C. volutator* densities that occur once migratory shorebirds arrive.

Although an extensive literature search was carried out, the amount of data meeting the above criteria is quite limited. Most studies that reported *C. volutator* densities did not contain measurements of sediment characteristics or, if they did, it was very general (non-quantitative) in nature or, if more specific and quantitative, difficult to determine if it was reflective of the exact locations at which the *C. volutator* densities were measured. In many cases, especially for studies carried out in Great Britain and Europe, *C. volutator* distribution and abundance was studied in relation to position within the intertidal rather than particular sediment characteristics. Only one European study, carried in Sweden, contained usable information. As a result, most of the data available for analysis is from studies carried out within Bay of Fundy.

Another major problem in the analysis was that there are numerous techniques available for measuring most of the relevant biological and sediment parameters, but there are no standardized protocols for these techniques. This was especially problematic in the case of *C. volutator* density measurements in which case sieves ranging from 250 to 850 microns were used. Because of the variation in size class frequencies of organisms, it is difficult to convert densities measured using different size sieves into comparable numbers.

Measurements of sediment particle size were often made as percentages of clay, silt and sand. It would have been useful to have had information on the median particle size as well.

Sediment organic content measurements were also a problem as some measurements were made with a carbon analyzer while others were made using a loss on combustion technique. The former technique appears to give values that are almost always an order of magnitude lower than the loss on combustion procedure. As a result, only the more common loss on combustion data was used in the analysis.

4. Results

4.1 Database

The biological and sediment characteristics that were included in the analysis, along with the total number of observations and range of measurements, are listed in Table 4.1.

Other variables contained in the database include: source of data, general location of sample site, station number if multiple stations were sampled, date of sample collection, and size of sieve used to process samples.

The database was constructed in Microsoft® Access and consists of three tables, one containing the biological data, another containing the physical data and another containing the data sources. All of the tables are linked by primary keys in a way that allows any combination of data to be generated using appropriate queries. The biological and physical data was also tabulated in Microsoft® Excel format and this is contained in Appendix I.

Table 4.1. Summary of number of observations, mean values and range of values of parameters contained in the database.

Parameter	Number of Observations	Mean	Range of Values
C. volutator:			
Density (#/sq m)	156	3015	0 – 47640
Biomass (gm/sq m)	48	0.91	0 – 2.61
Chlorophyll *a*: (µg/sq cm)	27	8.4	2.2 – 18.2
Water Content (%)	100	38.5	16.6 – 92.0
Organic Content (%)	25	6.16	3.0 – 16.6
Sediment Bulk Density (gm/cc)	23	0.83	0.48-2.00
Particle Size (%):			
Sand	65	29.5	6.6 – 89.1
Silt	65	53.1	3.4 – 80.0
Clay	65	16.8	1.0 – 37.0

4.2 Relationships Between Variables

To determine the degree to which each parameter is related to each other, simple Pearson correlations were calculated. The results are listed in Table 4.2, and a matrix of scatterplots graphically illustrating the relationships between all parameters is shown in Figure 4.1.

There are a number of statistically significant correlations between the various parameters. The strongest are between the percentages of the various particle size classes, and between percent particle size class and water content (Figure 4.2). The relationships between percent sediment particle size classes is to be expected since as the percentage of one size class decreases, another will increase. The relationships between percent sediment particle size class and water content simply reflects the well established fact that coarser soils drain much better than finer soils.

Sediment organic content showed little relationship to any of the sediment particle size classes (Figure 4.3). This is surprising since numerous studies have shown that sediment organic content tends to increase as particle size decreases (e.g., Anderson 1972).

Table 4.2. Pearson correlation coefficients (numbers in brackets are the number of samples correlation is based on; numbers in parenthesis represent significance level of the correlation; shaded areas indicate correlations significant at the 95 % level).

	Corophium Number	**Corophium Biomass**	**Sediment Chl *a***	**% Clay**	**% Silt**	**% Sand**	**% Organic**	**% Water**	**Bulk Density**
Corophium Density	1.000 [156] -								
Corophium Biomass	0.828 [48] (0.000)	1.000 [48] -							
Sediment Chl *a*	-0.289 [27] (0.143)	1.000 [2] -	1.000 [27] -						
% Clay	-0.327 [65] (0.008)	0.045 [38] (0.789)	0.577 [16] (0.019)	1.000 [65] -					
% Silt	-.0544 [65] (0.000)	-0.310 [38] (0.058)	-0.192 [16] (0.476)	0.341 [65] (0.005)	1.000 [65] -				
% Sand	-0.576 [65] (0.000)	-0.286 [38] (0.682)	-0.507 [16] (0.045)	0.622 [65] (0.000)	0.947 [65] (0.000)	1.000 [65] -			
% Organic	0.076 [25] (0.718)	-1.000 [2] (-)	-0.201 [21] (0.382)	0.047 [18] (0.854)	0.350 [18] (0.154)	-0.321 [18] (0.194)	1.000 [25] -		
% Water	-0.154 [100] (0.127)	-0.398 [20] (0.083)	0.090 [22] (0.691)	0.253 [44] (0.097)	0.359 [44] (0.017)	-0.364 [44] (0.015)	0.111 [23] (0.614)	1.000 [100] -	
Bulk Density	0.734 [23] (0.000)	-	-0.294 [22] (0.184)	-0.209 [17] (0.422)	0.381 [17] (0.131)	-0.046 [17] (0.858)	-0.026 [22] (0.907)	-0.720 [23] (0.000)	1.000 [23] -

C. volutator density does not show a strong relationship to any single sediment characteristic (Figure 4.4). The highest correlation is with bulk density, but this is based on a small set of data recently collected at the Windsor mudflat. In addition, the high correlation is largely due to one outlier.

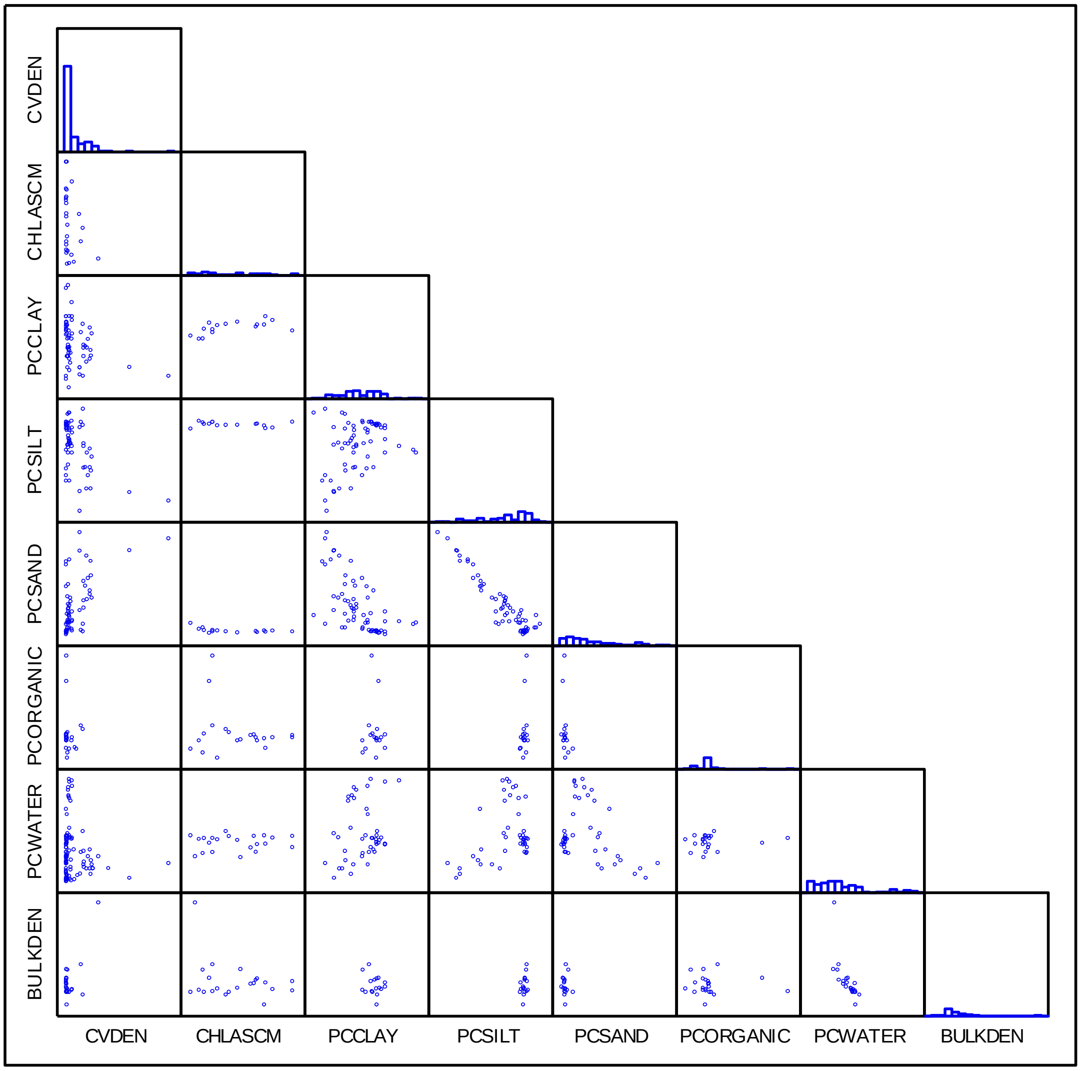

Figure 4.1. Matrix of scatterplots illustrating relationship between each variable contained in the database.

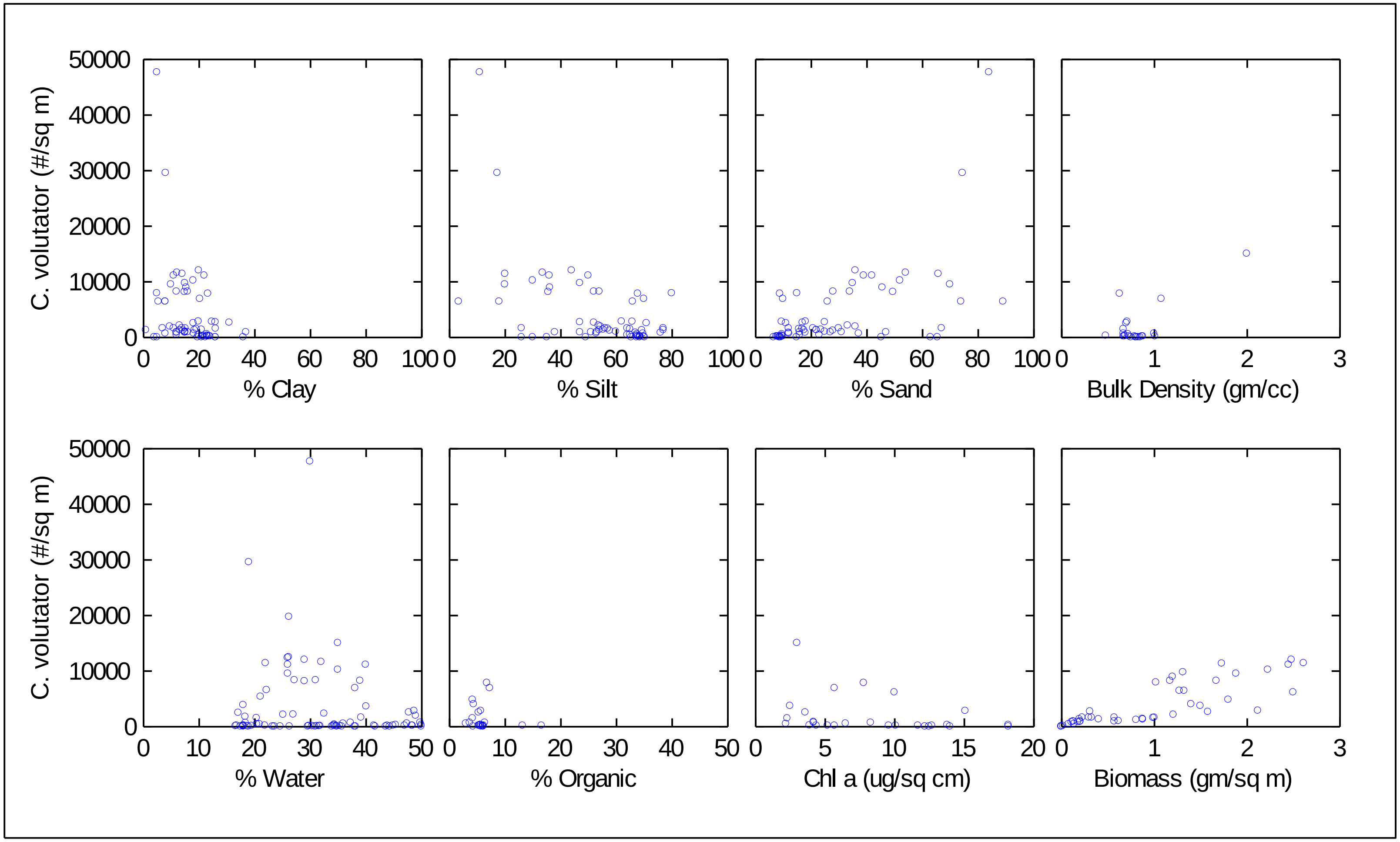

Figure 4.2 Relationship of *C .volutator* density to individual sediment parameters.

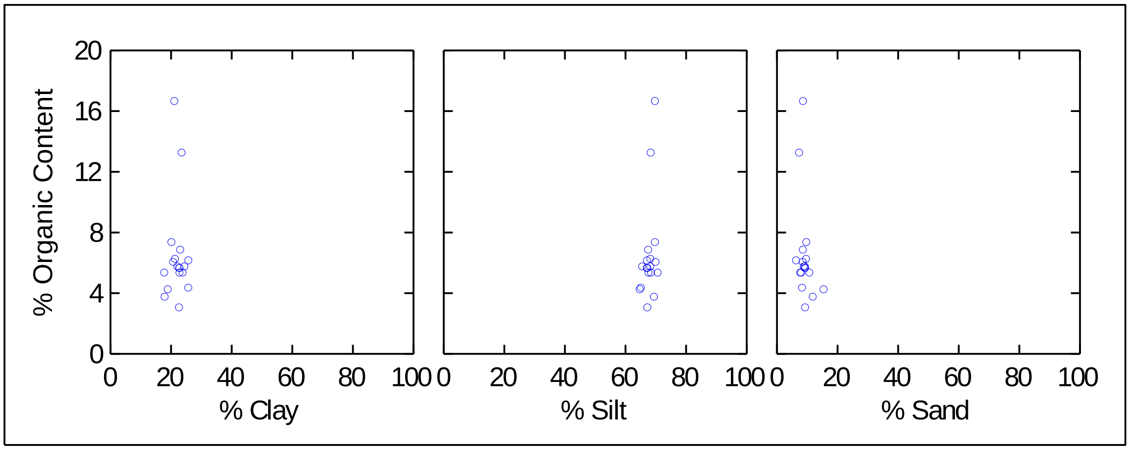

Figure 4.3. Relationship of sediment organic content to sediment particle size

It is possible that the poor relationship between *C. volutator* density and sediment physical-chemical characteristics is due to densities having been measured using a diversity of sieve sizes. If this were true it would be expected that densities measured with smaller sized sieves would generally be greater than those measured with larger sieves. To test this idea, mean *C. volutator* densities measured using the three most commonly employed sieve sizes were compared to each other. The results, shown in Figure 4.4, indicate that this is unlikely to be the reason for the poor relationships as the greatest densities were measured using the intermediate sieve size.

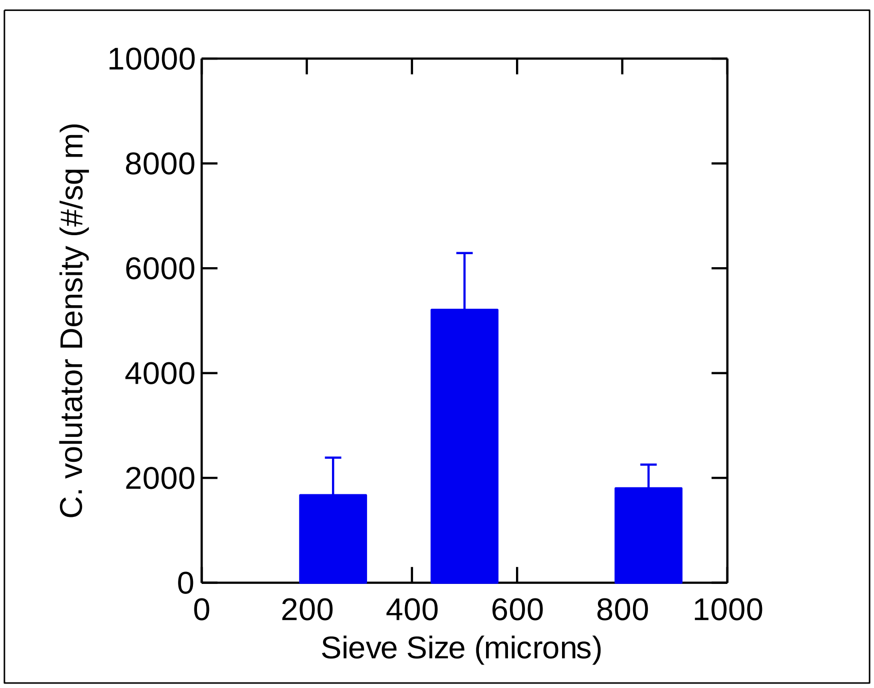

Figure 4.4. Mean *C. volutator* densities measured using the three most commonly employed sieve sizes.

Attempts to make predictions of *C. volutator* density from the sediment parameters using multivariate regression techniques were unsuccessful.

5. Discussion

Although numerous studies have shown that the abundance and distribution of *C. volutator* is controlled, at least in part, by the physical and chemical characteristics of the sediments available for its colonization, the analysis carried out in this study has not been successful in finding a combination of sediment parameters that would allow its density to be predicted with any degree of dependability. The reasons for this are not entirely clear, and may be a result of the nature of the data available for analysis, the specific factors included, or not included, in the analysis, and/or the invalidity of the conceptual framework on which the analysis was based.

Problems associated with the data available for analysis, in terms of comparability, have been discussed in Section 3. Of particular note is the diversity of sieve sizes used to obtain density estimates. It may also be true that the efficiency of sample processing, in terms of the care taken to enumerate individual organisms, has varied considerably between investigators.

It may also be true that other factors are at least, or even more, important in determining the density and distribution of *C. volutator*. The analysis did not address most of the biological factors that have been shown to influence *C. volutator* densities. These include predation by shorebirds, fish and other invertebrates, competitors (e.g., Flach 1993; Flach and de Bruin 1993), parasites (e.g., Jensen and Moutitsen 1992), and dispersal and aggregation behaviour (Meadows 1964a; Campbell. and Meadows. 1974; Hughes 1988; Lawrie et al. 2000). In addition, because of the limited data available, the analysis did not attempt to determine the importance of the affect of sediment stability or intertidal ice cover and scour.

The fact that some sediment characteristics, such as porosity, and therefore water content, are altered by the activities of *C. volutator* may make the approach adopted in this analysis somewhat circular. Hughs and Gerdol (1997) point out that many sediment parameters are affected by amphipods and that "... any effect they [sediment parameters] may have in determining their natural occurrence would be difficult to elucidate from distributional data".

6. Acknowledgements

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APPENDIX I

Excel Database