

THE ECOLOGICAL SIGNIFICANCE OF LARGE MARINE
PELECYPODS IN SHALLOW-WATER BENTHIC COMMUNITIES
IN BRITISH COLUMBIA

by

JAMES MARTIN GODDARD

B.Sc., University of Salford, 1967

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in the Department

of

Biology

ACCEPTED
FACULTY OF GRADUATE STUDIES

DEAN

DATE 24 Oct. 73

We accept this thesis as conforming
to the required standard

©

James Martin Goddard
UNIVERSITY OF VICTORIA
May 1973

ABSTRACT
Supervisor: Dr. D. V. Ellis

Quantitative benthic sampling of the marine infauna at shallow water stations showed species associations dominated by small lamellibranchs. Two large lamellibranchs, *Tresus capax* and *Modiolus rectus*, occurred at the sampling sites but were not taken in grab samples. Census by divers showed the population densities of these animals to be 0.5 to 0.7 specimens/m² at the sampling sites. The contribution of *T. capax* and *M. rectus* to the total respiration rate of the infauna was determined by in situ measurements using a diver-operated bell jar technique. *Tresus capax* accounted for 17.2% of the macrofaunal respiration, whilst *Modiolus rectus* accounted for 26.9% and 61.8% at two sites. The respiration rates indicated that the large lamellibranchs rank high in importance amongst the macrofaunal species. A rank order of species by an index known to correlate with respiration rates ^{ranking} placed *T. capax* and *M. rectus* ^{relatively} much lower in importance in the consumption of energy available to the communities. Respiration rates of the sediments (excluding *T. capax* and *M. rectus*) were correlated with silt + clay content at the sample sites. The highest respiration rate occurred in a sediment type known to support high population levels of interstitial ciliates. It is suggested that the correlation between respiration rate and silt + clay content may be due in part to ciliate population levels.

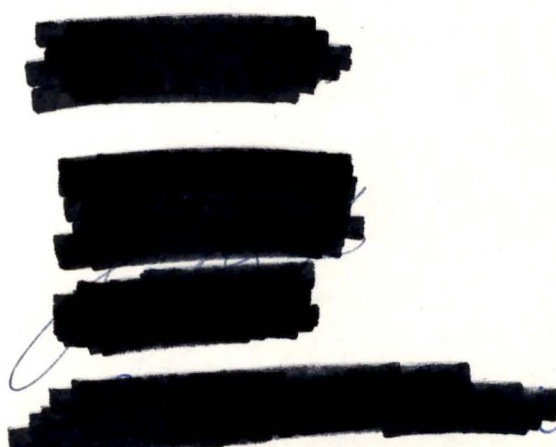


TABLE OF CONTENTS

	<u>Page No.</u>
Abstract.	ii
Table of Contents	iii
List of Tables.	iv
List of Appendices.	v
List of Figures	vi
Acknowledgements.	vii
Introduction.	1
Materials and Methods	6
Description of sampling sites	6
Fulford Harbour	6
Saanichton Bay.	8
Population density - <i>Tresus capax</i>	10
Population density - <i>Modiolus rectus</i>	10
In situ identification of deeply-burrowing pelecypods.	12
Oxygen consumption measurements (1971).	12
Oxygen consumption measurements (1972).	13
Measurement of dissolved oxygen content	17
Components of the infauna	18
Sediment analysis	18
Results.	21
Population density of <i>T. capax</i> and <i>M. rectus</i>	21
Oxygen consumption measurements	23
Components of the infauna	27
Summary of infaunal species lists	31
Mechanical analysis of sediment particle size distribution	33
Discussion.	35
Ecological significance of <i>T. capax</i> and <i>M. rectus</i>	35
Significance of <i>T. capax</i> and <i>M. rectus</i> as indicated by respiration data	38
Infaunal community respiration rates.	46
Hypothesis to explain the high sediment oxygen consumption in Fulford Harbour	49
Summary	53
Literature Cited.	56
Appendix.	59

LIST OF TABLES

<u>Table</u>		<u>Page No.</u>
1	Summary of population density sampling.	22
2	Summary of results of oxygen consumption measurements.	24
3	Comparison of characterising species at three sampling sites.	32
4	Sediment composition at sampling sites in Fulford Harbour and Saanichton Bay.	34
5	Comparison of estimated biomass of large pelecypods with biomass of other infauna.	37
6	Partitioning of oxygen consumption in Fulford Harbour and Saanichton Bay.	42
7	Revised partitioning of oxygen consumption.	43
8	Respiration rates of various benthic communities. . .	47
9	Oxygen consumption of the seabed in Puget Sound	48
10	Correlation between sediment oxygen consumption and silt + clay fraction of sediments	52

LIST OF APPENDICES

<u>Appendix</u>		<u>Page No.</u>
1	Procedure for mechanical analysis of sediment particle size distribution.	59
2	Population densities of <i>Tresus capax</i> and <i>Modiolus rectus</i> - census data.	62
3	Oxygen consumption measurements - Fulford Harbour (1971)	68
4	Oxygen consumption measurements - Fulford Harbour (1972) and Saanichton Bay (1972)	72
5	Components of the infauna - Fulford Harbour 1971: Species rank orders	79
6	Components of the infauna - Fulford Harbour 1972: Species rank orders	84
7	Components of the infauna - Saanichton Bay 1972: Species rank orders	88
8	Sediment mechanical analysis data: Fulford Harbour 1971	92
9	Sediment mechanical analysis data: Fulford Harbour 1972	101
10	Sediment mechanical analysis data: Saanichton Bay 1972	107
11	Biomass of <i>T. capax</i> and <i>M. rectus</i>	112
12	Rank order of species by Pamatmat's Index.	115

LIST OF FIGURES .

<u>Figure</u>		<u>Page No.</u>
1	Map of Southern Vancouver Island, showing Fulford Harbour and Saanichton Bay.	2
2	Map of Fulford Harbour, showing location of sampling sites.	7
3	Map of Saanichton Bay, showing location of sampling site	9
4	Arrangement of line transects in the census of <i>Modiolus rectus</i> in Fulford Harbour (1972) and Saanichton Bay.	11
5	Diagram of oxygen measurement jar	14
<u>Plate 1</u>	The modified 0.1 m ² van Veen grab	20

ACKNOWLEDGEMENTS

I wish to thank my wife Briony for her encouragement throughout this project, and for her help in all aspects of the preparation of the thesis. I am grateful to my supervisor, Dr. Ellis, for his encouragement, thoughtful criticism and instruction, and financial support through some critical periods. I am also indebted to Dr. Littlepage and Dr. Bergerud for their reviews of the manuscript and suggestions, many of which have been incorporated in this thesis; to Mr. Doug Hartley and Mr. Brian Lea for assistance in the field; to Mr. Hugh Barclay and Mr. Pat Konkin for statistical guidance. Finally I thank Mr. Bill Wilkey for his diving assistance, without which the study could not have been executed. I also thank my employer, Dobrocky Seatech Ltd, for leave of absence and the use of facilities.

INTRODUCTION

Casual diving in Fulford Harbour, British Columbia, (Figure 1) revealed large numbers of siphons of the horse clam, *Tresus capax*, at one of the stations sampled by Ellis (1967a, b). Ellis' data, based on 0.1 m^2 van Veen grab samples, gave no indication of the presence of *T. capax*, nor of any other large pelecypods. Repeat sampling with the van Veen grab during this investigation occasionally yielded siphon tips of *T. capax* and of *Modiolus rectus*, a large infaunal mussel. Thus the absence of the animals from Ellis' grab samples may have been due to the depth in the sediment at which the species live and not a real absence from the infaunal population.

Lie and Pamatmat (1965), and Gallardo (1965), demonstrated the flat biting profile and sampling efficiency of the 0.1 m^2 van Veen grab. These data indicate that full grab samples, averaging twelve liters volume, are representative of the top 12 cms. of sediment. Large pelecypods may live deeper than this; for instance, McCallum and Ellis (M.S.) showed that intertidal specimens of *T. capax* usually lie 20 to 70 cms. deep in the sediment. Thus benthic descriptions based only upon sampling with the 0.1 m^2 van Veen grab may overlook a large biomass of deeply-burrowing pelecypods.

There are no published data for the subtidal distribution of large deeply-burrowing pelecypods. According to Pearce (1965) *T. capax* is widely distributed on sheltered intertidal flats along the west coast of North America. Observations by scuba diver during the present study revealed *T. capax* siphons at a density of approximately one per meter² down to a depth of 18 meters off Galiano Island, B.C. (Figure 1), and at a depth of 25 meters in Fulford Harbour. It seems probable that the

FIGURE 1

Map of southern Vancouver Island, showing Fulford Harbour and
Saanichton Bay.

123° 0' W

Galiano Is.

Vancouver Island

(1)

(2)

San Juan Is.

48° 30' N

(3)

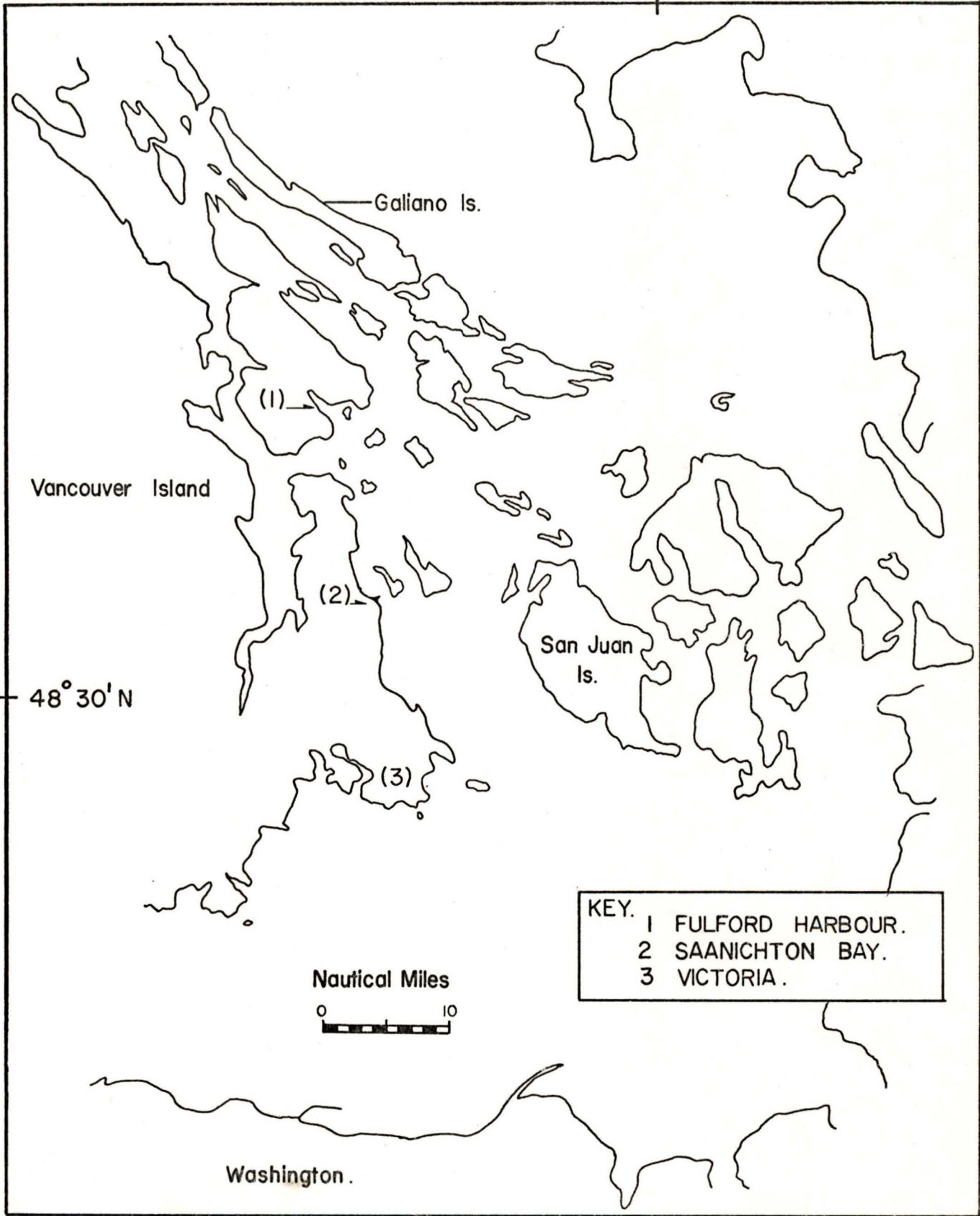
KEY.

- 1 FULFORD HARBOUR.
- 2 SAANICHTON BAY.
- 3 VICTORIA.

Nautical Miles



Washington.



animal could exhibit, throughout its geographical range, a bathymetric distribution similar to that observed at the above-mentioned locations and hence be distributed widely in shallow water benthic communities. The documented intertidal distribution of *T. capax* could then be used as an index of possible subtidal distribution. Subtidal communities may include other large pelecypods (eg: *Tresus nuttalli*, *Panope generosa*, *Modiolus rectus*) which are known to inhabit the intertidal areas in certain locations in southern British Columbia (Quayle, 1970).

The objective of this investigation is to explore the significance of these large, deeply-burrowing species within shallow water benthic communities.

In marine benthic communities, abundance and biomass have been used as indicators of species significance until recent years (eg: Shelford, 1935). Community description on this basis can be misleading as abundance (nos./unit area) or biomass (weight/unit area) may not be proportional to the more significant ecological properties of metabolic rates or energy utilization of the species involved. For instance, the description of a community by numbers alone may overestimate the energy utilization of some small and numerous animals, whilst their importance may be underestimated by biomass data. The converse may be true for large animals.

It has been demonstrated in recent years that significant community information is given by a description of the flow of energy through the component species (eg: Teal, 1957, 1962). Experimental measurement of the respiration rates of individual species can be used to indicate their relative rates of energy utilization within the community. Oxygen consumption is directly correlated with the oxidation of a unit mass of

organic matter and can be used as a measure of metabolism (Macfadyen, 1963). In this way the metabolic importance of species within the energy budget of the community can be compared directly. The value of these methods has been demonstrated by Richman (1958), Teal, (1957, 1962), Carey (1962, 1967), Pamatmat (1966, 1968) and others. Teal (1962) showed that the various species in a community may be investigated separately and the results compiled to describe the energy flow through the community. Similarly, Pamatmat (1966, 1968) calculated the energy budget of an intertidal sandflat and measured the contribution of one species (*Transenella tantilla*) to the total budget.

These studies have demonstrated the effectiveness of respiration measurement in the determination of significance of individual species within the benthic community. Oxygen consumption measurements were thus adopted as the means of testing the significance of the large pelecypods in the subtidal community of some bays near Victoria.

Tresus capax is very abundant in the intertidal and shallow subtidal flats of Fulford Harbour, and was readily available as an experimental subject. The species was adopted as a representative of the large, deeply-burrowing pelecypods, and was used in a preliminary series of measurements conducted in the spring of 1971. Further measurements were performed in late summer of 1972, but at that time the original shallow-water site was overgrown by green algae (*Ulva* sp. or *Monostroma* sp.). These conditions interfered with the sampling methods and probably increased experimental error. The oxygen consumption measurements were therefore carried out in slightly deeper water where the bottom was free from algal cover. At that depth *T. capax* was much less numerous than the mussel, *Modiolus rectus*; the latter was therefore adopted as the

representative species for the second series of measurements.

Fulford Harbour was selected as the site of the investigation since some benthic community data were already available for the deeper, level-bottom part of the inlet (Ellis, 1967a, b). The shallow-water investigation reported here will complement the existing benthic population data for the Harbour.

Measurement of the oxygen consumption by *M. rectus* was also carried out in Saanichton Bay (Figure 1), in order to obtain a duplicate set of data. Since Saanichton Bay and the sampling area in Fulford have similar sediment characteristics, a similar infauna was expected. This is in accordance with Thorson's (1957) concept of parallel, level-bottom communities. Comparison of oxygen uptake rates of the large pelecypods in similar locations may be used as confirmation of results, and as an indication of the normal range of values.

MATERIALS AND METHODS

Description of sampling sites.Fulford Harbour.

Fulford Harbour, in Saltspring Island, B.C., is a harbour approximately 2.5 miles in length and 2 miles wide at the entrance, narrowing to 0.5 miles width near the head (Figure 2). The water is approximately 40 meters deep at the entrance, and the depth decreases at a uniform rate towards the mud flats at the head. The north-eastern side of the harbour is rocky in the intertidal region and slopes steeply into deeper water. The south-western side is bordered by a sandy beach, which slopes more gently down to the deep water in the middle. The long axis of the harbour runs from northwest to southeast, and is exposed to the southeast gales characteristic of the winter months. Even during such storms there is little wave action within the harbour because of the limited fetch available (Figure 1).

There is freshwater inflow from three small streams at the head of the harbour, but these are probably too small to have any detectable effect upon the water circulation. The local tidal pattern is of the irregular semidiurnal type characteristic of southern Vancouver Island (Herlinveaux, 1962).

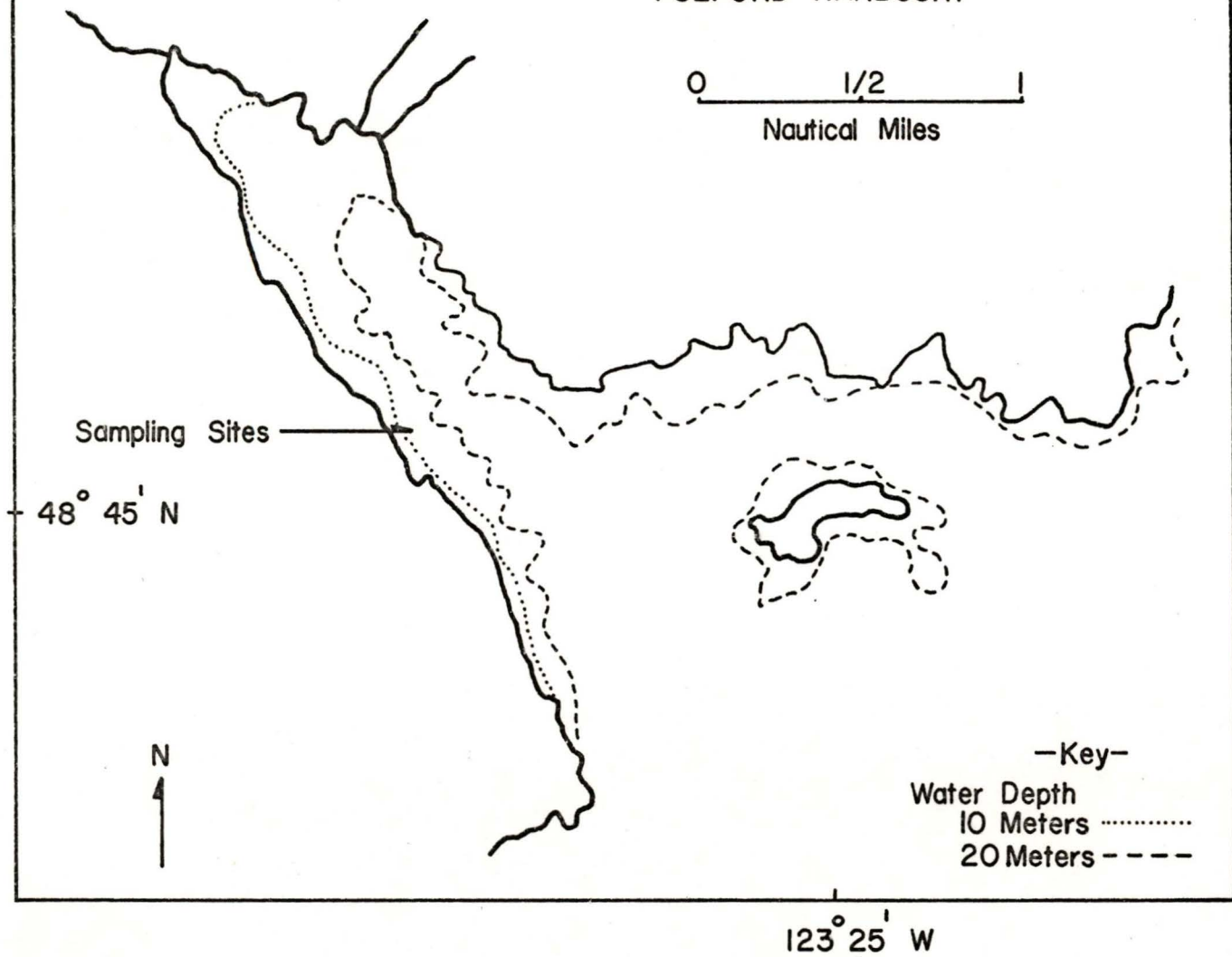
The sampling site was located on the southwest side of the harbour (Figure 2). The sandy beach sloped very gently in the intertidal region and supported an eel-grass bed. Below the low tidal level the slope of the bottom increased to 15 to 20° (visual estimate) and the eel-grass disappeared rapidly as the water depth approached 6 meters. From 6 to 15 meters depth the bottom continued to slope at 15 to 20° (visual

Figure 2.

Map of Fulford Harbour, showing location of sampling site.

FULFORD HARBOUR.

0 $\frac{1}{2}$ 1
Nautical Miles



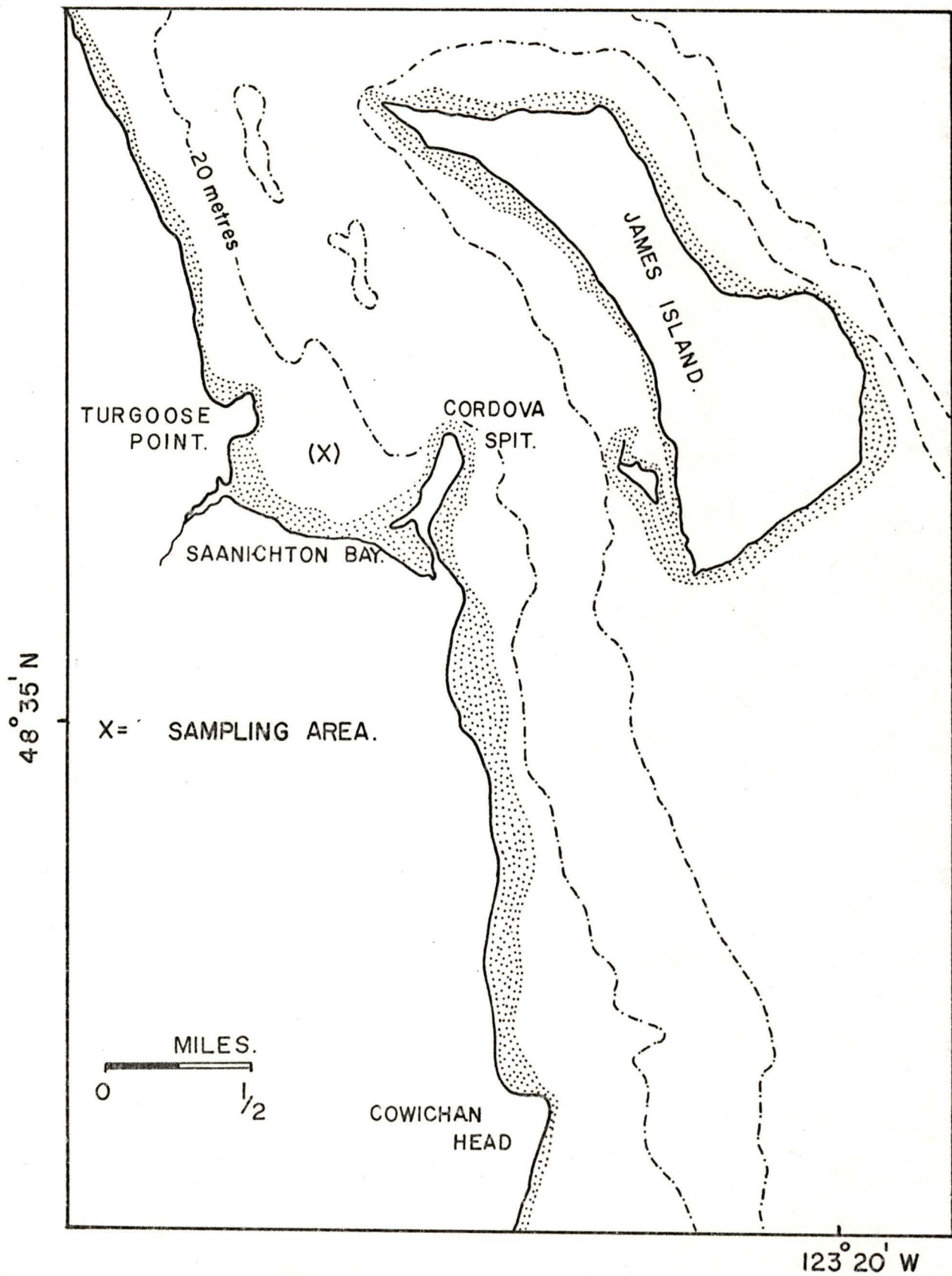
estimate) and was extensively littered with empty clam shells, both intact and fragmented. The horse clam, *Tresus capax*, was common in this area. Accordingly, the 1971 measurements were carried out at approximately 10 meters depth. Below 15 meters the slope of the bottom decreased to about 5° (visual estimate). Between the depths of 10 and 25 meters the mussel *Modiolus rectus* was common, as indicated by visible siphon tips. The 1972 sampling was carried out in this area, at a mean depth of 10 to 12 meters.

Saanichton Bay.

Saanichton Bay is located approximately 10 miles south of Fulford Harbour, on the eastern side of the Saanich peninsula (Figure 1). The bay is bounded by Turgoose Point on the west and Cordova Spit on the east (Figure 3). The shoreline of the bay is formed of gently sloping sand flats: the gentle slope continues in the subtidal region to a maximum depth of 20-22 meters. During the summer there is an eel-grass bed from the intertidal down to approximately 6 meters depth. Below that depth the bottom supports no attached vegetation, except where isolated small rock outcrops occur. The sampling site was located approximately at the centre of the bay (Figure 3), at a depth of approximately 10 meters. The bottom here was smooth sand, with few empty shells, and little evidence of tidal ripples. During certain tidal periods a current of approximately 0.5 knot may be experienced within the bay.

Figure 3.

Map of Saanichton Bay, showing sampling site.



Population density - *Tresus capax*.

A census was carried out on May 27, 1971 to determine the population density of *T. capax* within the Fulford Harbour sampling site. Siphons of *T. capax* lying within one meter radius of a weight lowered from the surface were counted by a diver. A total of twenty counts were made in this way at irregular intervals along a course parallel to the shore. All measurements were made within the sampling area. The population of *T. capax* extended well beyond the limits of the sampling area. The census data therefore may not represent the periphery of the population.

Population density - *Modiolus rectus*.

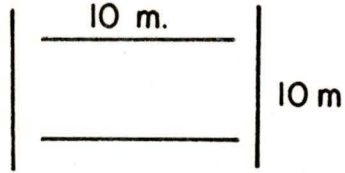
The population density of *M. rectus* in the Fulford Harbour sampling site was determined by census on August 4, 1972, using a line transect method. Four transects were established by laying weighted ropes on the bottom; each rope was 10 meters in length and was marked off in one meter intervals. A diver swam along the rope with a 1-meter rule and counted *Modiolus* siphons in each square of 1 meter side delimited along one side of the rope. This technique was developed by Forster (1958) and Larsson (1968) for use by divers in sampling subtidal organisms. A total of 40 quadrats were counted in this fashion. The transects were laid out so that two sides were parallel to the shore and 10 meters apart, whilst the other two were laid perpendicular to the shore (Figure 4).

The population density of the mussel (*Modiolus rectus*) in the Fulford Harbour site was also estimated by means of a random quadrat method on October 28, 1972. A lead weight was lowered from the surface to the bottom at random points. Siphons of *M. rectus* lying within one meter

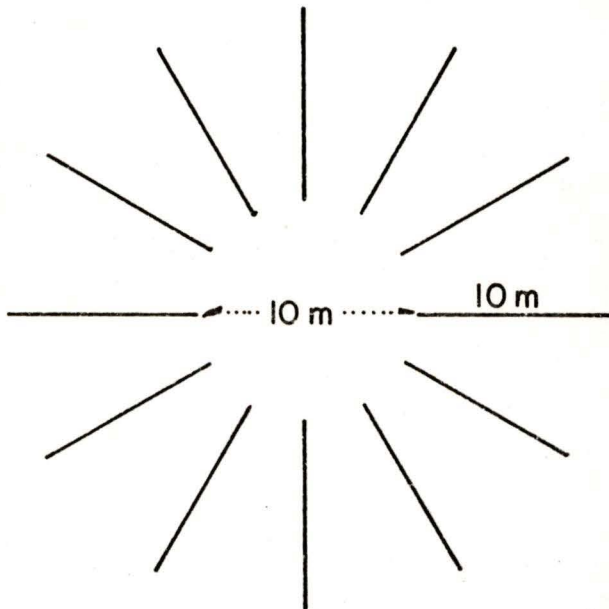
FIGURE 4

Arrangement of line transects in the census of *Modiolus rectus* in Fulford Harbour (1972) and in Saanichton Bay.

FULFORD HARBOUR



SAANICHTON BAY



radius of the weight were counted by a diver.

The population density of *M. rectus* in the Saanichton Bay sampling area was estimated by the same procedures. The line transect method was implemented on August 26, 1972, using ten transects of 10 meters length. The decision to use ten transects, rather than four as in Fulford Harbour, was based upon a preliminary survey which indicated that variability of the quadrat data was much greater in Saanichton Bay than at the former site. The ten quadrats were arranged as shown (Figure 4) in order to avoid overlapping whilst remaining within the sampling area. Enumeration of the *Modiolus* population was repeated on October 29, 1972, by the random quadrat method, as described above for the census of *M. rectus* in the Fulford Harbour site.

"In situ" identification of deeply-burrowing pelecypods.

Specimens of the deeply-burrowing pelecypods studied were dug from the sediment for positive identification using keys. The species were *Tresus capax* and *Modiolus rectus*. Subsequent identification of the species "in situ" by divers was by recognition of the characteristic siphon tips.

Specimens of *T. capax* were obtained by digging at low tide on a beach in Fulford Harbour, B.C., adjacent to one of the sampling sites. *Modiolus rectus* was not found intertidally in the areas investigated. The specimen taken for identification was obtained by digging underwater.

Oxygen consumption measurements (1971).

"In situ" oxygen consumption measurements were carried out by means of a modified bell jar technique using glass battery jars. The clear

glass permitted observation of the contents after the jar had been carefully positioned on the sediment.

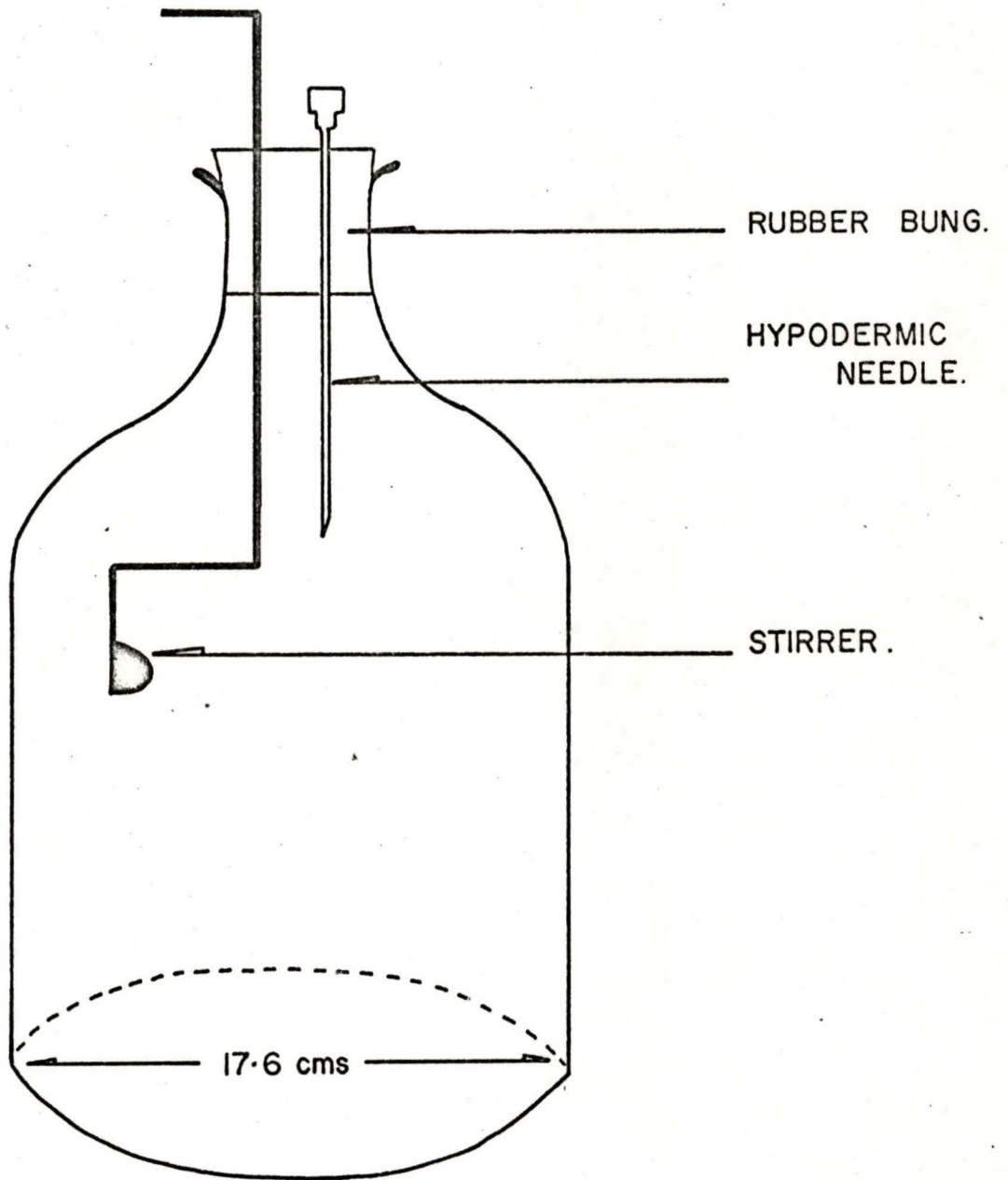
Respiration of *Tresus capax* was measured at the Fulford Harbour sampling site on four days (May 14, 17, 18 and 20, 1971). The oxygen consumption by the sediment at the sampling site was measured on June 2 and 3, 1971. Both series of measurements were carried out using the techniques and procedures described in the following section.

Oxygen consumption measurements (1972).

"In situ" oxygen consumption measurements were carried out by means of a modified bell jar technique using glass jars. The jars (Figure 5) were manufactured by removal of the bases from commercially available wine bottles. The carrying handle of the bottle was of great assistance to the divers when handling the bottles with wet, gloved hands. The modified jars had a volumes of 3.9 liters and an internal diameter of 17.6 cms. at the base. For each measurement a jar was positioned carefully on the sediment to avoid disturbance of the sediment-water interface, and the accompanying chemical uptake of oxygen. The jar was pushed down so that the edges penetrated 1.0 cms. (marked on the jars) into the sediment. This ensured that there were no direct openings under the edges of the jar permitting water exchange. The clear glass of the jar allowed observation of the contents. This was especially significant in tests with *Modiolus*, when the siphon was visible. If the siphon closed or withdrew into the sediment, the animal was abandoned and the jar was moved to another siphon. The preliminary tests of 1971 indicated that whilst the siphon remained open a respiratory current of water was maintained.

FIGURE 5

Diagram of oxygen measurement jar.



After the jar was successfully positioned a sample of water (56 ml.) was withdrawn by a plastic syringe through a hypodermic needle positioned in the top of the jar (Figure 5). The sample was immediately taken to the surface, and treated as described in the following section (measurement of dissolved oxygen). This sample measured the oxygen content of the water at the start of the test. When the jar had been in position for 20 minutes the water inside was stirred manually for two minutes by means of a stirrer mounted in the top of the jar (Figure 5). The water was stirred with the maximum vigour compatible with not disturbing the sediment interface. A water sample of 56 ml. was withdrawn and taken immediately to the surface to measure the dissolved oxygen content at the end of the test. The jar was removed from the sediment, flushed out with seawater, and positioned elsewhere for repetition of measurements.

In the measurements with *Modiolus* combined with the rest of the infauna the jar was positioned over a single siphon and surrounding sediment so that the siphon was in the centre of the enclosed area. When the jar was positioned and the siphon showed no visible reaction, it was assumed that the respiratory current of water was maintained, and the test proceeded. The siphon was observed intermittently by the diver during the sampling to ensure that it had not closed or retracted.

A series of control measurements was also performed to determine the oxygen uptake by the sediment alone. In these measurements, the jars were positioned to avoid inclusion of any large siphons and also to avoid large holes, which were probably the siphon holes of *Modiolus rectus* or *Tresus capax*.

During each measurement the jars were arranged in pairs. One jar (#1) was used in measurement of the oxygen uptake by *Modiolus* + sediment,¹

whilst the second jar (#2), placed immediately adjacent to the first, was used to measure sediment¹ oxygen uptake. The calculation of oxygen uptake by the large clam alone was as follows:

$$MS - (S \times A) = \text{oxygen change due to } \textit{Modiolus}$$

where

MS = change in dissolved O₂ due to *Modiolus* + sediment uptake (jar #1); ml./test

S = sediment oxygen uptake/unit area of surface (Calculated from jar #2); ml./cm²/test

A = area of sediment surface in Jar #1 available for sediment oxygen uptake (base area of jar - mean area occupied by *Modiolus* siphon)

The most desirable experimental design for this type of measurement would utilize only one jar. After measurements of oxygen uptake by *Tresus* or *Modiolus* + sediment were completed, the siphon of the clam would be induced to close and withdraw into the sediment. A second measurement (sediment oxygen uptake alone) could then be made in exactly the same place. In experiments with *Modiolus* this procedure is not feasible, because of the difficulty of ensuring that the siphon remained closed during the latter part of the experiment. Therefore the two-jar procedure was adopted. The positioning of the two jars as close to each other as possible is regarded as the best approximation of the ideal procedure described above.

¹ The sediment will contain an infauna which is assumed to be constant between test and control jars. Sediment oxygen uptake includes oxygen uptake by all organisms other than the large pelecypods.

Measurement of dissolved oxygen content of water samples.

The dissolved oxygen content of the water samples was measured by the modified Winkler technique (U.S. Navy, 1968). Each water sample was taken from the jar using a hypodermic syringe which was flushed with seawater and emptied underwater. This ensured that no air bubbles were trapped in the syringe. As each water sample was obtained underwater, it was immediately taken to the surface in the syringe and transferred to a 53 ml. reagent bottle with a ground glass stopper. The transfer to the bottle was accomplished with the aid of a hypodermic needle which was pushed down to the bottom of the receiving bottle. The water was transferred slowly to avoid aeration of the sample by bubbling or agitation, and examined for suspended organic detritus which could alter the dissolved oxygen content by oxidation during storage. The sample was treated with 1.0 ml. of each of the manganous sulphate and alkaline reagent solutions, shaken and stored in a dark place. To avoid any deterioration of the sample in storage, titrations were usually carried out within 24 hours of obtaining the samples. Before titration each sample was treated with 1.0 ml. of concentrated sulphuric acid. This represents a modification of the U.S. Navy (1968) procedure, and is standard procedure in the University of Victoria Oceanographic Laboratory. Two aliquots of 25.0 ml. each were taken from each sample for titration, which was carried out using a 10.0 ml. burette graduated to 0.02 ml.

Components of the infauna.

The benthic macrofaunal community at the sampling site in Fulford Harbour was sampled on May 1, 1971. Further samples were taken at that site, and at the Saanichton Bay site on August 8, 1972. The 0.1 m^2 van Veen grab used was modified by addition of 80 pounds of lead weights to the jaws (Plate 1). This modification increased penetration to approximately 12 cm. into the packed sand in the sampling areas. The samples were screened through a 2.0 mm. mesh and the animals sorted by species. Preliminary tests in Fulford Harbour indicated that the mesh retained large numbers of the small pelecypods (eg: *Axinopsis* sp.) and of small polychaetes. Organisms passing the 2.0 mm. mesh present special problems in identification. In practice, a lower size limit for identification and quantification must be set. The procedure adopted here follows that used in the Marine Ecology laboratory of the University of Victoria. The animals retained on the 2.0 mm. mesh are clearly macrofauna as defined by Thorson, 1957. All organisms which occurred in two or more samples were identified to species, if possible, using keys and the University of Victoria reference collection. The specimens were counted and weighed by species: these data were summarised using computer program benth 2/6 (Ellis, 1968d) to obtain species ranking lists by wet weight/ m^2 , number of organisms/meter², and frequency of occurrence in the samples.

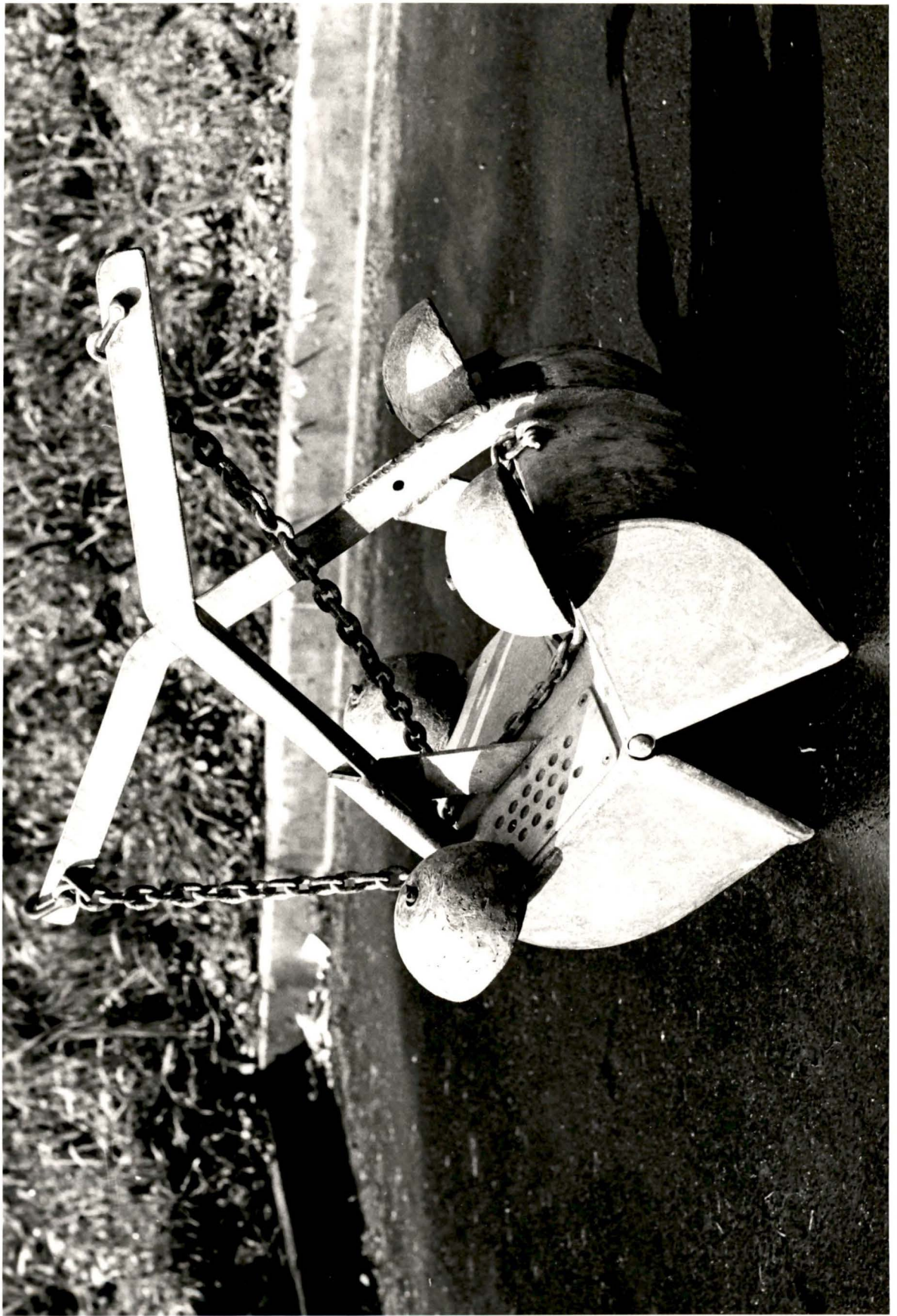
Sediment analysis.

Description of the sediments at the sampling sites was based upon mechanical analysis of particle size distribution of samples obtained from the van Veen grab. The analysis was carried out by the technique currently in use in the Marine Ecology laboratory of the University

of Victoria (Appendix 1).

Plate 1

The 0.1 m² van Veen grab modified
by addition of 4 x 20 lb. lead weights
for greater penetration in hard sediments.



RESULTS

Population density of *Tresus capax* and *Modiolus rectus*.

The mean density of *T. capax* in Fulford Harbour in the 1971 samples was 2.1 ± 0.51 (n=20) individuals per quadrat of 3.14 m^2 (Appendix Table 2.1). This gave an estimated population density of 0.7 ± 0.17 specimens per meter² (Table 1).

The mean density of *M. rectus* in Fulford Harbour was calculated from the line transect data (Appendix Table 2.2). The sample mean was 0.7 ± 0.11 (n=40) individuals per meter² (Table 1). The results of the random quadrat measurements (Appendix Table 2.3) gave a slightly lower sample mean, of 0.5 ± 0.06 (n=20) individuals/m² (Table 1). The 95% confidence limits (0.0 to 1.0) of the mean of the random quadrat data encompassed the mean of the line transect data. The means derived from the two different techniques are similar. The value of 0.5 individuals/meter² from the random quadrat method was selected as the best estimate of the mean population density at the Fulford Harbour site. This decision was based on the smaller variance of these data.

The mean density of *M. rectus* in Saanichton Bay was calculated from the line transect data (Appendix Table 2.4). The sample mean was 0.6 ± 0.08 (n=100) individuals per meter² (Table 1). By comparison, the sample mean of the random quadrat data (Appendix Table 2.5) was 0.6 ± 0.07 (n=20). The sample means from the two different methods are identical. The sample mean of 0.6 individuals per meter² was therefore accepted as a good estimate of the mean population density at the Saanichton Bay site.

Table 1. Summary of Population Density Sampling.

Species & Area	Sampling method	No. of quadrats	Mean density/m ² ± S.E.	Min. & Max. No. of animals
1) <i>Tresus capax</i> , Fulford Harbour, 1971	Systematic quadrats of 3.14 m ²	20	0.7 ± 0.17	0 - 2.6
2) <i>Modiolus rectus</i> , Fulford, 1972	1 m ² quadrats along transect	40	0.7 ± 0.11	0 - 2
Fulford, 1972	Random quadrats of 3.14 m ²	20	0.5 ± 0.06	0 - 0.9
Saanichton Bay, 1972	1 m ² quadrats along transect	100	0.6 ± 0.08	0 - 1
Saanichton, 1972	Random quadrats of 3.14 m ²	20	0.6 ± 0.07	0 - 0.9

Oxygen consumption measurements.

Oxygen consumption of the sediment in Fulford Harbour was measured by sampling carried out on June 2 and 3, 1971 (Appendix Table 3.1). The "in situ" measurements were carried out at approximately 10 meters below low tide level. The results (Table 2) showed mean sediment oxygen uptake rates of 2.1 and 1.3 ml. per test on June 2 and 3, respectively. There was a significant difference ($P < 0.05$) between the data obtained on the two sampling days (Appendix Table 3.2). The mean values (Table 2) indicate that the rate of sediment uptake of oxygen in Fulford Harbour may range from 174 to 281.5 ml. oxygen/m²/hour.

Experiments to measure the oxygen consumption by *T. capax* were carried out during four days (May 14, 17, 18 and 20, 1971). The data (Appendix Table 3.1) show considerable variation, which constituted a significant ($P < 0.05$) difference between sampling days (Appendix Table 3.3). The tests measured oxygen uptake from jars by single specimens of *T. capax* together with the sediment enclosed by the jars. Respiration rates of *T. capax* were calculated from the data by the expression:

$$R_t = R_{t+s} - R_s$$

where R_t = respiration rate of *T. capax* (ml. oxygen/hour)

R_{t+s} = oxygen consumption by *T. capax* + sediment (Appendix Table 3.1)

R_s = oxygen consumption by sediment (Appendix Table 3.1)

The results show such variation between sampling days that they may be used only as a sample of the variability to be expected. The extremes of the daily means of R_{t+s} were 18.6 and 6.3 ml. oxygen/hour, whilst those of R_s were 3.9 and 6.3 ml. oxygen/hour (Appendix Table 3.1). The maximum

Table 2.

Summary of results of oxygen consumption measurements.

Site	Mean sediment uptake (ml/test)		Mean uptake by sediment + clam ¹ (ml/test)			
	June 2	June 3	May 14	May 17	May 18	May 20
Fulford Harbour 1971	2.1	1.3	3.8	2.1	4.1	6.2
			¹ species = <i>Tresus capax</i>			
	Mean sediment uptake (ml/test) ± S.E.		Mean uptake by sediment + clam ² (ml/test) ± S.E.			
Fulford Harbour 1972	1.1 ± 0.07		3.7 ± 0.10			
Saanichton Bay 1972	0.5 ± 0.05		4.6 ± 0.17			
			² species = <i>Modiolus rectus</i>			

and minimum rates of respiration by *T. capax* are indicated by the following:

$$R_t (\text{max}) = R_{t+s} (\text{max}) - R_s (\text{min})$$

$$R_t (\text{min}) = R_{t+s} (\text{min}) - R_s (\text{max})$$

The maximum and minimum respiration rates are indicated as 14.7 and 0.0 ml./hour.

The estimated population density of *T. capax* in the sampling area permits expression of the species respiration rate in the context of bottom area, and comparison with sediment oxygen uptake. Thus the respiration rate of the population of *T. capax* lies within the range from 0.0 to 10.3 ml. oxygen/meter²/hour, compared with 174 to 281.5 ml. oxygen/meter²/hour by the sediment. The 1971 data thus indicate that large pelecypods may possibly consume as much as 6% of the respired oxygen of the benthic shallow-water community in Fulford Harbour.

Further measurements of community oxygen consumption were carried out in Fulford Harbour and Saanichton Bay in August, 1972, utilising a different species (*Modiolus rectus*) as representative of the large burrowing pelecypods (see page 4). The results (Appendix Table 4.1) were tested by analysis of variance, using a three-way, nested design (Sokal & Rohlf, 1969). The completed anova (Appendix Table 4.2) indicates a significant difference ($P < 0.05$) among tests*. The results of experiments with sediment only are thus shown to differ significantly from those of experiments which included single specimens of *M. rectus*. The

* The tests were (1) oxygen consumption by the sediment under a bell jar.
(2) oxygen consumption by the sediment under a bell jar plus a single specimen of *Modiolus*.

variability among locations within each test was also significant ($P < 0.05$), indicating that comparable sampling executed in Fulford Harbour and Saanichton Bay yielded different results. In each of the sampling sites however, variability among results obtained on different days was not significant. More precise scrutiny of the data was carried out using Student's t-test and single classification analysis of variance. Respiration rates of single specimens of *M. rectus*, derived by subtraction of control from test values (page 16) showed no significant variation by analysis of variance amongst sampling days at each site (Appendix Table 4.3). The pooled data for each site demonstrated significant differences by t-test between the results obtained at the two sites (Appendix Table 4.4). The mean values of oxygen uptake by specimens of *Modiolus* were $3.7 \pm 0.10^*$ ml./test and $4.6 \pm 0.17^*$ ml./test in Fulford Harbour and Saanichton Bay respectively. These rates may be expressed as 11.1 and 13.8 ml./hour per single specimen respectively.

In Fulford Harbour in 1972 the sediment oxygen consumption rate showed no significant difference between sampling days: this was also true for Saanichton Bay (Appendix Table 4.5). The pooled data for each site demonstrated significant differences by t-test between the results obtained at the two sites (Appendix Table 4.6). The mean values of sediment oxygen uptake at Fulford Harbour and Saanichton Bay were $1.1 \pm 0.07^*$ and $0.5 \pm 0.05^*$ ml./test respectively. These values indicate sediment respiration rates of 130 and 60 ml. oxygen/meter²/hour.

Based on the estimated densities of the two populations the respiration rates of the populations may be compared with the oxygen consumption

* n = 30.

of the sediments, on the basis of respiration per meter² per hour. The mean respiration rate of specimens of *Modiolus* in Fulford Harbour was 11.1 ml./hour, whilst the population density in the experiment site was 0.5 specimens/meter². Thus the respiration rate of the population of *Modiolus rectus* in the Fulford Harbour (1972) site may be expressed as 5.6 ml./meter²/hour. The sediment respiration rate in the same area was measured at 130 ml. oxygen/meter²/hour. The energy demand of the *Modiolus* population therefore represented 4.3% of the total energy requirements of the benthic community at the Fulford Harbour site.

Similar arguments show that in Saanichton Bay, the *Modiolus* population imposed an energetic demand equivalent to 11.9% of the total community oxygen uptake at the experiment site.

Components of the infauna.

Fulford Harbour, 1971.

The samples obtained in the van Veen grab showed the lamellibranch *Lucinoma tenuisculpta* to be most abundant, with 460 individuals/meter² (Appendix Table 5.1). The second most abundant species was *Axinopsis sericatus*, also a lamellibranch, with 362 individuals/meter². These were followed, in descending order of abundance, by *Acila castrensis* (lamellibranchia) and *Tellina carpenteri* (lamellibranchia) with 149 and 126 individuals per meter² respectively. The third rated taxon, unidentified polychaetes, included eight apparent species.

The highest biomass was shown by *Acila castrensis* with 40.5 gms. wet weight/meter² (Appendix Table 5.2). This was followed in descending order by *Lucinoma tenuisculpta* and *Nephtys* sp. with 22.5 and 7.5 gms./meter² respectively. This rank order was unchanged when the biomass

data were converted from wet weight to dry weight. The conversion factors employed are given in Appendix Table 5.4. The dry weight data showed *Acila castrensis* to have the greatest weight, at 2.02 gm./meter², followed in descending rank order by *Lucinoma tenuisculpta* (1.13 gm./meter²) and *Nephtys* sp. with 0.37 gms./meter².

The grab samples demonstrated that *Lucinoma tenuisculpta* was the most widely dispersed animal, as it appeared in all the samples taken. *Tellina carpenteri* occurred in 91% of the samples, whilst *Axinopsis sericatus* and *Acila castrensis* were found in 82% and 73% respectively of the grab samples. *Ninoe gemmea* (91%), with *Transenella tantilla* *Venericardia ventricosa* (82% each) were widely dispersed species with low density and biomass (Appendix Table 5.3). Thus although *Lucinoma tenuisculpta* occurred in the greatest abundance and was most widely dispersed, the greatest biomass was due to *Acila castrensis*, which had a much lower abundance and occurred in fewer of the samples. It is also noteworthy that few species of macrofaunal polychaetes are placed high in the rank orders discussed here (Appendix Table 5.3) in contrast to the results of Ellis (1967a, b; 1971) for deeper water in the same general area.

Fulford Harbour, 1972.

The most abundant species at the Fulford Harbour, 1972, site was the lamellibranch *Lucinoma tenuisculpta* with 862 individuals/meter² (Appendix Table 6.1). The second most abundant species, *Axinopsis sericatus* (602 individuals/meter²) was also a lamellibranch. Juvenile crabs (*Cancer* sp.) were ranked third (246 specimens/meter²), followed by another lamellibranch, *Transenella tantilla*, with 230 specimens per

meter². The fifth rank was accorded to the group Polychaeta Sedentaria.

The highest biomass was recorded by "*Tresus capax* siphon tips", with 63.8 gms./meter² wet weight. This is an indication of the great biomass due to *T. capax*, as the siphon tip represents only a small fraction of the weight of each specimen. A wet weight of 45.0 gms./meter² was due to *Lucinoma tenuisculpta*, followed by *Solen sicarius* (another lamellibranch) with 29.8 gms./meter². Ophiuroid parts totalled 26.0 gms./meter², followed in descending order by polychaetes of the family Nephthyidae, the lamellibranchs *Acila castrensis* and *Macoma nasuta*, and more polychaetes (Appendix Table 6.2).

Several species were widely dispersed, appearing in 100% of the samples. These included Amphipod B, juvenile crabs (*Cancer* sp.), and the lamellibranchs *Axinopsis sericatus*, *Lucinoma tenuisculpta*, *Tellina carpenteri*, and juvenile *Macoma* spp. (Appendix Table 6.3). The ophiuroid *Amphiodia urtica* also occurred in all samples, together with representatives of the Polychaeta Sedentaria and Polychaeta Errantia.

In summary, the lamellibranch *Lucinoma tenuisculpta* was present in all samples, occurred with the greatest population density, and yielded the greatest biomass (apart from *Tresus capax* siphon tips). Smaller species of lamellibranchs, especially *Axinopsis sericatus* and *Transenella tantilla*, were found in most of the samples, and at high densities, but were ranked low in terms of biomass. In spite of identifying the polychaetes only to family, and thus grouping several species as a single taxon, the greatest biomasses and densities were recorded by species of small lamellibranchs.

Saanichton Bay, 1972.

The grouped Polychaeta Sedentaria were ranked first in terms of density (Appendix Table 7.1); there were 420 specimens/meter², representing approximately 10 apparent species. The lamellibranch *Lucinoma tenuisculpta* was second in the rank order with 387 individuals/meter², followed by Amphipod A (203 organisms/meter²). These were followed, in decreasing order of abundance, by *Transenella tantilla* and *Axinopsis sericatus* (both lamellibranchs) with 123 and 112 specimens/meter² respectively. The errant polychaetes of the family Lumbrinereidae accounted for 92 organisms/meter², whilst the combined Goniadidae and Glyceridae (Polychaeta Errantia) yielded 52 specimens/meter².

The rank order on the basis of wet biomass placed *Solen sicarius* (lamellibranchia) in first position with 71.0 gms./meter², followed by the grouped sedentary polychaetes (22.0 gms./meter²) and *Lucinoma tenuisculpta* with 13.7 gms./meter², just ahead of a series of polychaete groups.

The most widely dispersed organisms (those found in 100% of the samples) were the lamellibranchs *Lucinoma tenuisculpta*, *Axinopsis sericatus* and *Clinocardium nuttalli*, the siphunculids, and the grouped Polychaeta Sedentaria. The errant polychaetes of the family Lumbrinereidae also occurred in all samples, closely followed by other errant polychaetes (family Nephthyidae, and the combined Goniadidae and Glyceridae) in 83% of the samples (Appendix Table 7.3).

In summary, sedentary polychaetes were present in all samples taken in Saanichton Bay, and occurred at the highest population density. The lamellibranch *Solen sicarius* yielded the greatest biomass, whilst occurring in only 50% of the samples, and at a density of 7 specimens/meter².

The importance of the smaller lamellibranchs (especially *Lucinoma tenuisculpta*) cannot be underestimated. In spite of small individual size, the high density and frequency of occurrence placed *Lucinoma tenuisculpta* high in the three rank orders (Appendix 7). To a lesser extent this is also true for *Axinopsis sericatus* and *Transenella tantilla*.

Summary of infaunal species lists.

Thorson (1957) argued in his concept of parallel level-bottom communities that on the same type of sediment in different geographical areas, species of the same genera should be found replacing each other as characterising species. This concept has been applied by Lie (1968) and Ellis (1971) in their interpretations of the level-bottom communities of the Puget Sound and Strait of Georgia region. The shallow-water communities of Fulford Harbour and Saanichton Bay were characterised by *Lucinoma tenuisculpta*, *Axinopsis sericatus*, *Acila castrensis*, and *Transenella tantilla* (Table 3). *Nephtys* sp. and other polychaete genera were also present in small numbers. This group of characterising species does not correspond with any of the local communities discussed by Lie, or by Ellis. A similar species group was described from the North-west coast of Washington, USA, by Lie and Kelly (1970). This group was identified by statistical analysis of the species distributions, and was not interpreted in the context of level-bottom communities.

Table 3. Comparison of the characterising species at the three sampling sites. Taxa selected for comparison are those indicated as significant by Ellis' (1969) criteria in any one of the sampling sites. Large groups (eg: Polychaeta Sedentaria) omitted.

<u>Taxon</u>	<u>Fulford Harbour 1971</u>			<u>Fulford Harbour 1972</u>			<u>Saanichton Bay 1972</u>		
	<u>Freq.</u>	<u>Dens.</u>	<u>Biom.</u>	<u>Freq.</u>	<u>Dens.</u>	<u>Biom.</u>	<u>Freq.</u>	<u>Dens.</u>	<u>Biom.</u>
* <i>L. tenuisculpta</i>	100.0	460	22.5	100.0	862	45.0	100.0	387	13.7
* <i>T. tantilla</i>	82.0	45	0.9	80.0	230	3.0	83.3	123	2.2
* <i>A. sericatus</i>	82.0	362	3.3	100.0	602	5.0	100.0	112	1.2
<i>Cancer</i> sp. juv.	-	-	-	100.0	246	3.0	50.0	40	1.2
* <i>Macoma</i> spp. juv.	-	-	-	100.0	32	1.2	33.3	10	0.8
<i>A. urtica</i>	55.0	35	1.0	100.0	38	8.8	-	-	-
Siphunculoidea	-	-	-	100.0	66	10.8	100.0	48	7.7
* <i>C. nuttallii</i>	-	-	-	60.0	12	0.6	100.0	30	0.8
* <i>A. castrensis</i>	73.0	149	40.5	60.0	54	18.0	-	-	-
* <i>S. sicarius</i>	18.0	2	4.0	60.0	8	29.8	50.0	7	71.0
Totals for complete species lists		1825	134.3		2910	322.4		1660	142.0

* Pelecypoda.

Mechanical analysis of sediment particle size distribution.

The composition of the sediments at the sampling sites in Fulford Harbour and Saanichton Bay are summarised (Table 4). The sediment samples from Fulford Harbour indicated a well sorted, fine sand with a median particle diameter of 0.16 to 0.177 mm. (Appendix 8 and 9). Silt and clay content of the samples ranged from 1% to 8%, and 4.5 % to 10% respectively. The sand content ranged from 84% to 94% of the samples. No gravel was present.

The samples from Saanichton Bay indicated a fine sand, with a median particle diameter of 0.2 mm. The sorting coefficients were 3.5 and 4.5 (Appendix 10) indicating an average mixing of particle sizes. The sand content of the samples was 83.8 and 87.8%, with silt content at 3.0 to 6.0%, and 9.0% clay in both samples.

Table 4.

Sediment composition at the sampling sites in Fulford Harbour and Saanichton Bay.

<u>Site</u>	<u>Sample</u>	<u>Depth (m)</u>	<u>% Composition</u>			<u>Median diameter (mm.)</u>	<u>Sorting coefficient</u>
			<u>Sand</u>	<u>Silt</u>	<u>Clay</u>		
Fulford Harbour 1971	8	16	84.0	8.0	8.0	0.16	2.0
	9	6	92.0	4.0	5.0	0.177	1.33
	10	14	90.0	6.0	4.0	0.177	1.33
	11	11	94.0	1.5	4.5	0.177	1.33
Fulford Harbour 1972	1	12	89.0	1.0	10.0	0.177	1.3
	2	12	90.0	1.0	9.0	0.177	1.3
Saanichton Bay 1972	1	13	87.8	3.0	9.0	0.2	3.5
	2	13	83.8	6.0	9.0	0.2	4.5

DISCUSSION

Ecological significance of *Tresus capax* and *Modiolus rectus* within the macro-faunal communities.

Ellis (1969) proposed some criteria for indicating species which may play a major role in the metabolism or structure of the community. These criteria were as follows:

- 1) Frequency - species which are widely dispersed and occur in all samples.
- 2) Density - species which together constitute more than 50% of the total number of organisms per meter².
- 3) Biomass - species which together account for more than 50% of the total wet weight of specimens.
- 4) Dry weight/meter² x number/meter² (designated Pamatmat's Index by Ellis) - A species rank order based on this index has been shown to correspond with a rank order based on measured respiration rates (Pamatmat, 1966).

Ellis showed that at all stations sampled by him over a two-year period the majority of species were not abundant and represented little of the bound organic matter at the stations (Ellis, 1967b; 1968c). Amongst these forms there are, theoretically, species of high metabolic rate and short life-span which are never present in very great numbers or biomass. Such organisms may, by virtue of their rapid turnover rate, nevertheless represent important routes for energy transfer between trophic levels in the community. The importance of these species will not be detected by criteria of frequency, density or biomass, but could possibly be indicated by Pamatmat's Index. Pamatmat (1966) showed that this

index has the potential to indicate species of high metabolic rate which would be of importance in the transfer of energy between trophic levels. The application of the index to the detection of such species needs further exploration, and this thesis contributes to such exploration.

The population densities of *T. capax* and of *M. rectus* in the locations tested are insufficient to indicate the species as significant components of the communities. However, the biomass of such large animals is likely to be a significant factor in the distribution of bound organic matter. Unfortunately, sampling these large pelecypods for biomass determinations was not possible (Appendix 11). As an alternative, the mean individual weight of *Tresus capax* at the Fulford Harbour site was estimated using specimens collected intertidally near the sampling site (Appendix Table 11.1). *Modiolus rectus* was not found intertidally in the areas investigated. The weight of a single specimen (taken for identification) was used as an approximation of the mean weight of specimens in both Fulford Harbour and Saanichton Bay. These estimates are used only to indicate the order of magnitude of biomass of the large pelecypods in comparison with the other infauna.

The approximate biomasses of *T. capax* and *M. rectus* in the sampling areas (Appendix 11) were approximately 0.6 to 2.3 times the biomass of the remainder of the infauna (Table 5). However, biomass alone tends to overestimate the importance of large, slowly metabolising, long-lived species which, theoretically, are less important in the energy budget of communities than the smaller, quickly metabolising, short-lived animals (Zeuthen, 1947, 1953). Rank orders of species by values of Pamatmat's Index (Appendix 12) established the positions of *T. capax* and *M. rectus* in relation to the other infaunal species. Dry weight biomasses required

Table 5.

Comparison of estimated biomass (wt./m²) of large pelecypods
with biomass of the other infauna.

Taxon	Biomass - gms. wet wt./m ²		
	Fulford Harbour		Saanichton Bay
	1971	1972	1972
Total infauna	134.3	322.4	142.0
<i>Tresus capax</i>	312.6	--	--
<i>Modiolus rectus</i>	--	200.0	240.0

for the calculation were obtained by application of conversion factors (Appendix Table 5.4) to the wet weight biomasses. The rank orders confirmed the importance of small pelecypods, especially in Fulford Harbour (1971) samples, where polychaetes were not highly placed (Appendix 12). This is in contrast with the more general situation (in deeper water) for the southern British Columbia coast reported by Ellis (1971). The 1972 data for Fulford Harbour and Saanichton Bay gave high values of the index for the taxon Polychaeta Sedentaria. This group may include up to ten apparent species which by themselves may not achieve prominence in this index. The rank orders placed *T. capax* in 6th position (out of 41 total) in Fulford Harbour in 1971. *Modiolus rectus* was placed 17th out of 31 and 9th out of 24 in the rank orders for Fulford Harbour (1972) and Saanichton Bay (1972) respectively (Appendix Table 12.1, 12.2, 12.3). The population densities of *T. capax* and *M. rectus* are, therefore, sufficiently high that in spite of the expected low metabolic rates per unit of dry weight (metabolic rate \propto 1/dry wt. of organism: Zeuthen, 1947, 1953) the species are indicated as relatively high in the ranking lists for Pamatmat's Index in Fulford Harbour in 1971 (*T. capax*), but at or about the mid-point in the ranking scale in 1972 (*M. rectus*).

Significance of *T. capax* and *M. rectus* within the macro-faunal community, as indicated by respiration data.

The respiration rate of a community is the sum of the respiration rates of the component species. The total metabolism of the community can theoretically be partitioned to show the contribution of each species (or higher taxa) to the total. For example, Wieser and Kanwisher (1961) partitioned the energy utilization of the bottom as follows: nematodes

10-33%; macrofauna 10-15%; bacteria and protozoa, over 50%. Kanwisher (1962) estimated bacterial respiration in subtidal sediments to be 70-80% of the community respiration (thus, by implication, macrofauna and organisms other than bacteria contributed 20-30% of the total). Carey (1962) estimated that the total macrofaunal respiration in Long Island Sound was unlikely to exceed 10% of the community respiration. Pamatmat (1966) showed that the macrofauna accounted for 10% of the respiration of an intertidal sandflat community, whilst Banse et al (1971) found that the macrofauna at three stations investigated accounted for 14, 28 and 14% of the total community metabolism.

These data indicate that the metabolic importance of the organisms in the community increases with decreasing individual size. This is in keeping with the findings of Zeuthen (1947, 1953) and Bertalanffy (1957), who showed by laboratory measurement that respiration rate per unit of body tissue nitrogen is inversely proportional to the body weight of the organism. It therefore follows that a small biomass composed of a large number of bacteria will have a higher respiration rate than the same biomass of (for example) nematodes. This explains why the macrofauna, whilst representing the greater part of the bound organic matter, may account for only 10% to 15% of the community respiration, as determined by the previous citations.

If one assumes that the community respiration in Fulford Harbour and Saanichton Bay is similarly partitioned, the macrofauna (including large pelecypods) would be expected to account for 10% to 15% of the measured total respiration. The oxygen consumption measurements showed that the large pelecypods at the sampling sites accounted for 2.0%, 4.3%, and 11.9% of the community respiration rates. The large animals

therefore represent approximately 20%, 43% and 100% of the expected macrofaunal respiration rates (Table 6).

The significance of the large pelecypods, indicated by their apparent contribution to total macrofaunal respiration rates, may be compared with their respective positions in the rank orders based on Pamatmat's Index (Appendix 12). *Modiolus rectus* cannot rank 9th in respiration in Saanichton Bay (indicated by Pamatmat's Index rank) whilst simultaneously contributing 100% of the expected macrofaunal respiration. However, similar comparisons for *M. rectus* and *T. capax* in Fulford Harbour (1972 and 1971 respectively) do not indicate quite such gross disagreement. This disagreement will now be explored.

The accepted partitioning of community respiration rates (see previous citations) between macrofauna, meiofauna etc. and bacteria implies a constant ratio, independent of the population biomass or density. Thus, the macrofauna will presumably continue to represent 10% to 15% of the community respiration rate, although the absolute value of that rate may vary proportionately with population size.

It is suggested that the respiration rate of large *M. rectus* or *T. capax* is unlikely to be influenced by the population density of the other infauna. Occurrence of the species in numbers indicates favourable environmental conditions, and under such circumstances the respiration rate of the individuals will vary within a relatively narrow range, reflecting individual sizes, maturity and physiological state. Thus it is possible to have a similar population density of, for example, *M. rectus* in two different areas, each with different infaunal biomass and total community respiration rates. This is exemplified by the results of measurements with *M. rectus* in Fulford Harbour (1972) and in Saanichton

Bay. Although the absolute oxygen consumption by *M. rectus* was similar at the two sites, community respiration (and hence the value of the macrofaunal contribution) was markedly different (Table 6). The relationship between *M. rectus* respiration and macrofaunal respiration (calculated as shown in Table 6) was therefore distorted, resulting in disagreement with the ranking by Pamatmat's Index. Calculation of the relationship between *M. rectus* respiration and macrofaunal respiration (Table 6) should therefore be revised.

Earlier calculations (Table 6) included the respiration rate of the large pelecypods in calculation of community respiration. Total macrofaunal contribution was estimated at 10% of the latter. *M. rectus* respiration can be omitted from the calculation of community respiration (and hence of macrofaunal contribution). This is justified since it permits separation of the variable sediment oxygen uptake from the independent respiration of *M. rectus*. The proposed calculation is as follows:

(a) Macrofauna (except large pelecypods) respiration = 10% of
community respiration (exclude large pelecypods)

(b) Total macrofauna (T) = Macrofauna + Respiration of *M. rectus*
therefore % contribution of *M. rectus* to macrofaunal respiration =

(c)
$$\frac{\text{Respiration of } M. \text{ rectus}}{(T)} \times 100$$

In this way the calculated contribution of the large pelecypods to the macrofaunal respiration cannot exceed 100%.

Values obtained thus for *M. rectus* still show considerable disagreement with rank positions by Pamatmat's Index (Table 7). In Saanichton Bay, *M. rectus* was ranked 10th among 24 macrofaunal species by Pamatmat's

Table 6.

Partitioning of oxygen consumption in Fulford Harbour and Saanichton Bay.

Site	A	B		C	D	E	F	Rank by Pamatmat's Index
	Mean sediment respiration ml O ₂ /m ² /hr	Mean resp. of large pelecypods Species	ml O ₂ /m ² /hr	Mean community respiration (A + B) ml O ₂ /m ² /hr	% contrib. of large pelecypods (B/C x 100)	Theoretical macrofaunal resp. (10% of C) ml O ₂ /m ² /hr	% contrib. of large pelecypods to macrofauna resp. (B/E x 100)	
Fulford Harbour								
May 1971	244.0	<i>T. capax</i>	5.0	249.0	2%	25.0	20%	5th
Fulford Harbour								
August 1972	130.0	<i>M. rectus</i>	5.6	135.6	4.3%	13.5	41%	16th
Saanichton Bay								
August 1972	60.0	<i>M. rectus</i>	9.7	69.7	11.9%	7.0	>100%	9th

Table 7.

Revised partitioning of oxygen consumption in Fulford Harbour and Saanichton Bay.

Site	A Mean sediment resp. (= comm. resp.) ml O ₂ /m ² /hr	B Mean resp. of large pelecypods Species ml O ₂ /m ² /hr	C macrofauna (10% of A) ml O ₂ /m ² /hr	D Total macrofauna (C + B)	% contrib. of large pelecypods to macrofauna resp. (B/D x 100)	Rank by Pamatmat's Index
Fulford Harbour						
May 1971	244.0	<i>T. capax</i> 5.0	24.4	29.4	17.2%	6th (41 total)
Fulford Harbour						
August 1972	130.0	<i>M. rectus</i> 5.6	13	18.6	26.9%	16th (31 total)
Saanichton Bay						
August 1972	60.0	<i>M. rectus</i> 9.7	6	15.7	61.8%	10th (24 total)

Index, whilst contributing approximately 62% of the macrofaunal respiration. The ranking by Pamatmat's Index is evidently far too low, since any species which accounts for more than 50% of macrofaunal respiration must be ranked first in importance. Similarly, the rank order by Pamatmat's Index of species from Fulford Harbour (1972) places *M. rectus* in 16th place (31 species), whilst the species accounted for approximately 27% of the macrofaunal respiration. Again, the ranking by Pamatmat's Index is too low.

Calculation of Index values for *M. rectus* was based upon an estimated mean individual wet weight of 400 grams (see page 36). A low biomass estimate would yield a low calculated value of the Index, but not by a significant margin. For example, should 500 grams be a more accurate biomass estimate, positions of *M. rectus* in the Index ranks (Appendix 12) would be upgraded by one or two places only, if at all. Thus in the Fulford Harbour rank order, *M. rectus* would move upwards by two places (Appendix Table 12.2) whilst in the Saanichton Bay order, the positions would remain unchanged (Appendix Table 12.3). single?

A significant change (eg. from 10th place to near 1st) in the position of *M. rectus* could occur only with great change in biomass or density, as shown above. Thus, the disagreement between the respiration measurements and ranking by Pamatmat's Index (as presently calculated) appears insoluble. Values of Pamatmat's Index are more strongly influenced by changes in density than by changes in population biomass. The latter is converted to dry weight for the calculation, whilst the former acts directly. Thus a large change in wet biomass, producing a corresponding, but far less dramatic change in dry weight, has much less influence upon the Index value than changes in population density. When

dealing with species whose individual sizes are similar within an order of magnitude, no discrepancy is likely to occur. Thus Pamatmat (1966) was able to establish the correlation between Index rank position and contribution to community respiration. However, when very large individuals, whose density is (relatively) very low, are included in the Index ranking, the correlation with respiration breaks down. This is clearly demonstrated by the results of the tests carried out in Fulford Harbour and Saanichton Bay. Further exploration is required to determine if the discrepancy between ranking by measured respiration rate and by Pamatmat's Index can be reduced for populations of differing size animals. In the meantime, measured oxygen consumption remains the best way of determining the importance of large pelecypods in benthic communities.

In this way the importance of *M. rectus* and *T. capax* in the sampling areas may be evaluated. In Saanichton Bay, *M. rectus* contributed approximately 62% of the expected macrofaunal respiration. That rate of oxygen consumption places *M. rectus* first in importance among the macrofauna. In Fulford Harbour (1972), *M. rectus* accounted for approximately 27% of macrofaunal respiration: thus the species must rank high in macrofaunal importance. A slightly lower, but still high significance is indicated for *T. capax* (Fulford Harbour, 1971), which contributed 17% of macrofaunal respiration.

In summary, large pelecypods (exemplified by *M. rectus* and *T. capax*) are very important in the oxygen consumption by benthic communities. Measurements of respiration rates of two species, carried out in two widely separated locations, indicated that large pelecypods may contribute from 17% to 62% of macrofaunal respiration.

The infaunal community respiration rates in Fulford Harbour and Saanichton Bay.

Some data for benthic community respiration rates were reviewed by Pamatmat (1968). He noted that in shallow water, organically rich soft bottom communities without macrovegetation the rate of oxygen uptake is generally less than $100 \text{ ml./meter}^2/\text{hour}$ (Table 8). Communities which support macrovegetation have respiration rates within the range 200-450 $\text{ml./meter}^2/\text{hour}$ (Table 8). Pamatmat and Banse (1969) working in Puget Sound found benthic community respiration rates ranging from 10-100 $\text{ml. oxygen/meter}^2/\text{hour}$, in depths from 11-180 meters (Table 9). Wieser and Kanwisher (1961) found the oxygen uptake of intertidal sandy mud to be 26 and 36 $\text{ml./meter}^2/\text{hour}$ at two stations, whilst Pamatmat (1966) measured oxygen uptake at the rate of 15 $\text{ml./meter}^2/\text{hour}$ (mean value over several months) in an intertidal sandflat. In Long Island Sound, Riley (1956) used oceanographic data to calculate a mean oxygen uptake by the bottom of 13.7 $\text{ml./meter}^2/\text{hour}$ (range 4.6-36.6 ml.). In the same region Carey (1962) measured benthic oxygen uptake using core samples and found a mean value of 23.68 $\text{ml./meter}^2/\text{hour}$ (range 3.02-70.31 ml.) over a two year period.

In contrast with these data the measured community respiration rates in Fulford Harbour (Table 6, column C) were high. In the study conducted in May 1971 the mean community respiration was 249 $\text{ml. oxygen/meter}^2/\text{hour}$. This is more than twice the highest value found by other studies with the bell-jar method in communities devoid of macrovegetation (Table 8). Nevertheless the data are considered to be accurate, as possible technical error sources have been minimised. Further studies at the Fulford Harbour sampling site were carried out in August 1972, in slightly deeper

Table 8.

Respiration rates of various benthic communities.

Type of community	Respiration (ml O ₂ /m ² per hr.)	Method of Measurement
Eniwetok coral reef	746	Diurnal O ₂
Central Long Island Sound	4.6 to 36.7 mean: 13.8	Est. by diff. from plankton metabolism.
Silver Springs, Fla.	455	Diurnal O ₂
Silver Springs, Fla.	154	Bell jar
Texas bays (some with <i>Thalassia</i> beds)	29 to 490	Diurnal O ₂
Texas bays (some with <i>Thalassia</i> beds)	5.5 to 78.7	Bell jar
Eastern Canadian lakes	4.3 to 31.0	Core and bottles
Bare intertidal salt marsh (Georgia)	18 to 29	Bell jar
Bare sediment and turtle grass (Fla.)	15 to 52	Bell jar
Bare intertidal salt marsh (Georgia)	34 to 70	Core
Intertidal salt marsh with <i>Spartina</i> (Georgia)	200 to 328	Opaque box
Intertidal salt marsh (Woods Hole, Mass.)	26 to 36	Core
Long Island Sound	2.6 to 75 Mean: 24	Core
Ivel River mud, England (spring-summer)	87 to 117	Core
Ivel River, total community including macrovegetation	102 to 408	Diurnal O ₂
Ivel River mud	64	Core
Bare salt marsh mud:		
Georgia, winter (10°C)	18 to 45	Core
Georgia, summer (25°C)	45 to 190	Core
Nova Scotia, winter (2°C)	30 to 40	Core
Nova Scotia, summer (20°C)	65 to 190	Core
False Bay, year round	1 to 125	Bell jar

(After Pamatmat, 1968)

Table 9.

Oxygen consumption of the seabed in Puget Sound. (Pamatmat and Banse, 1969).

<u>Station</u>	<u>Depth (m)</u>	<u>Sediment Composition</u>			<u>Mean grain size (mm)</u>	<u>Ash-free dry wt. of macrofauna (gm/m²)</u>	<u>Avg. O₂ consumption (ml/m²/hr)</u>
		<u>% gravel</u>	<u>% sand</u>	<u>% silt & clay</u>			
6	30	0.0	85.4	14.6	.09	4.6	19
11	15-18	1.0-13.1	88.5-80.5	10.7-6.3	.18-.40	6.6	35
10	75-80	3.0-0.0	74.6-27.5	22.4-27.5	.12-.02	9.3	35
4	20-23	0.0	63.1	36.9	.063	10.6	33
7	180	0.0	30.0	70.0	--	19.6	17
5	70	0.4	56.8	42.8	.05	31.4	25

water. The results (Table 6, column C) were considerably lower than the 1971 data, and were comparable with the higher values published by other workers (eg. Pamatmat, 1968). The results from Saanichton Bay gave the lowest values of this series of tests; the mean community respiration rate (Table 6) lay within the range of values found by other studies.

The differences between the results obtained in the three sets of measurements were not correlated with macrofaunal biomass. The Fulford Harbour (1971) site, which yielded the highest community respiration rate, showed a macrofaunal biomass (on the basis of van Veen grab samples) of 134.3 gms./meter² (Appendix Table 5.2) with the exclusion of *Tresus capax*. The site of the 1972 series of tests in Fulford Harbour gave a lower community respiration rate, but showed a higher macrofaunal biomass (322.4 gms./meter²) from the grab samples (Appendix Table 6.2). Similarly, the Saanichton Bay site, which gave the lowest total respiration rate, yielded a macrofaunal biomass of 142.0 gms./meter² (Appendix Table 7.2) which corresponds with the biomass of the Fulford Harbour (1971) site.

Hypothesis to explain the high sediment oxygen consumption in Fulford Harbour 1971.

Fenchel (1969) reported that in sediments with a median particle diameter between 0.125 and 0.250 mm. there was a high population of interstitial protozoa, which accounted for 65% of the animal respiration. The sediment at the Fulford Harbour stations (1971 and 1972) showed a median particle diameter of 0.16 to 0.177 mm. (Table 4) and may therefore support a population of interstitial ciliates similar to that described by Fenchel. This is also true for Saanichton Bay, with a median particle

diameter of 0.2 mm.

Apart from the reports of Pamatmat (1966) and Carey (1962) the data on respiration rates of the sediment from other authors were not accompanied by sediment particle size data. It is impossible to speculate on the importance of ciliates in those respiration rates. Carey's (1962) measurements were carried out in an area of clay-silt; Fenchel (1969) showed that high silt and clay fractions lowered the population level of the ciliates almost to zero. Thus ciliates were probably not important in Carey's respiration measurements. Pamatmat's (1966) study on the intertidal sandflat community involved sediments whose median diameters were between 0.1-0.25 mm. According to Fenchel's data a rich ciliate fauna should occur there.

The bacterial component of the infauna has been ignored in the community descriptions of all the workers whose oxygen uptake data have been reviewed here. Thus there is no way of deciding to what extent differences in respiration of the sediments reflect differences in bacterial populations. If it is assumed that bacteria generally may account for 60-80% of the sediment respiration, failure to include an estimate of the population density of aerobic bacteria in community descriptions must be a significant omission.

Community respiration is apparently most strongly influenced by those infaunal components (bacteria, nematodes, and protozoa) which have not been enumerated in the respiration reports reviewed, with the exception of Fenchel (1969).

Sediment oxygen consumption at the three sites appears to be correlated with the silt + clay fraction of the sediments (Table 10). The highest oxygen consumption occurred in the shallower water site in

Fulford Harbour 1971. Sediment samples from that site yielded the lowest silt + clay fraction. Conversely, the Saanichton Bay site yielded the lowest sediment oxygen uptake and the highest silt + clay fraction.

Fenchel (1969) showed that the ciliate population level declined with increasing silt and clay fraction. The correlation (shown above) between sediment oxygen uptake and silt + clay content may be due to changes in the ciliate population levels. The very high oxygen uptake values recorded in Fulford Harbour (1971) may therefore be due, in part, to a high population level of interstitial ciliates.

Table 10.

Correlation between sediment oxygen consumption and silt + clay fraction of sediments.

<u>Site</u>	<u>Sediment oxygen consumption ml/m²/hr</u>	<u>Silt + clay fraction (%)</u>
Fulford Harbour 1971	244.0	6 to 10
Fulford Harbour 1972	130.0	10 to 11
Saanichton Bay 1972	60.0	12 to 15

SUMMARY

- 1) A quantitative survey of the marine benthic infauna in shallow water was carried out in Fulford Harbour and Saanichton Bay. A 0.1 m^2 van Veen grab was used for sampling the smaller infauna. The large, deeply-burrowing pelecypods *Tresus capax* and *Modiolus rectus* were sampled by divers.
- 2) The numerically dominant organisms in the grab samples were small lamellibranchs, eg: *Lucinoma tenuisculpta*, *Acila castrensis*, *Axinopsis sericatus*, *Tellina carpenteri* and *Transenella tantilla*. Polychaete species were poorly represented, in contrast with the infaunal associates previously reported in the vicinity of Fulford Harbour.
- 3) The population density of *Tresus capax* in the Fulford Harbour sample site (1971) was $0.7 \text{ individuals/meter}^2$, with an estimated biomass of $312.2 \text{ gms./meter}^2$. The density of *Modiolus rectus* in the Fulford Harbour site (1972) was $0.5 \text{ individuals/meter}^2$, and had an estimated biomass of 200 gms./meter^2 . In Saanichton Bay, the population density of *M. rectus* was $0.6 \text{ individuals/meter}^2$, with an estimated biomass of 240 gms./m^2 .
- 4) Mechanical analysis of samples showed that the sediments at all the sampling sites were fine sands (median diameters 0.16 to 0.2 mm.). The silt + clay contents increased with depth of water at the sample site, from 6% to 15%.
- 5) "In situ" oxygen consumption of *T. capax* and *M. rectus* was measured using a bell jar technique and the Winkler procedure. The oxygen consumption rates of the large pelecypods were obtained by differences between values for tests which included single specimens of *T. capax* or

M. rectus and values for control measurements using sediment (with infauna) only.

6) Mean oxygen consumption by individual large pelecypods ranged from 7.0 ml/hour for *T. capax* to 13.8 ml/hour for *M. rectus*. Oxygen uptake by the sediment and infauna other than the large pelecypods ranged from 244 ml/hour/meter² to 60 ml/hour/meter².

7) Oxygen consumption by the large pelecypods accounted for 1.7%, 2.7% and 6.2% of the total community requirements in the three series of measurements, or 17%, 27% and 62% of the theoretical macrofaunal contribution to the total community oxygen requirements. These values did not agree well with Pamatmat's Index (no./m² x dry wt./m²) ranking.

8) The value of Pamatmat's Index as an indicator of the metabolic importance of infaunal species appears to be reduced when the population includes species of widely differing size.

9) The accepted partitioning of community oxygen consumption (ie. macrofauna contributing approximately 10% of the total) appears to be invalid in the Fulford Harbour and Saanichton Bay sites. These are communities occupying a sandy or sandy-silt bottom, in which much of the infaunal biomass is due to large organisms.

10) The oxygen consumption measurements indicate that large marine pelecypods may make a significant contribution to total oxygen consumption, and hence energy flow within the shallow-water community.

11) Oxygen consumption by the sediment was correlated with silt + clay content of the sediment. Highest consumption occurred in the shallowest site (Fulford Harbour, 1971), where sediment characteristics of median grain size (0.16 to 0.177 mm.) and low silt + clay content (6 to 10%) correspond with conditions known to support high populations of

interstitial ciliates. The unusually high oxygen consumption by the sediment in Fulford Harbour (1971) may result from an unusually high population of interstitial ciliates.

LITERATURE CITED

- Banse, K., F. H. Nichols and D. R. May. 1971. "Oxygen consumption of the seabed. III. On the role of the macrofauna at 3 stations." *Extract de Vie et Milieu. Troisième Symposium Européen de Biologie Marine Supplément 22*, pp. 31-52.
- Bertalanffy, L. von. 1957. "Quantitative laws in metabolism and growth." *Quart. Rev. Biology*, 32:217-231.
- British Columbia Dept. of Highways. 1967. "Procedure for sediment mechanical analysis."
- Carey, A. G. 1962. "An ecological study of two animal populations in Long Island Sound." Ph.D. dissertation, Yale University, 61 pp.
- _____. 1967. "Energetics of the benthos of Long Island Sound: I. Oxygen utilization of sediment." *Bull. Bing. Oceanog. Coll.* 19:136-144.
- Ellis, D. V. 1967a. "Quantitative benthic investigations: I. Satellite Channel biomass summaries and major taxon rank orders, February 1965-May 1967." *Fish. Res. Bd. Canada, Tech. Report 25*, 6 pp., 43 tables.
- _____. 1967b. "Quantitative benthic investigations: II. Satellite Channel species data, February 1965-May 1967." *Fish. Res. Bd. Canada, Tech. Report 35*, 8 pp., 169 tables.
- _____. 1968a. "Quantitative benthic investigations: III. Locality and environmental data for selected stations (mainly from Satellite Channel, Strait of Georgia and adjacent inlets)." *Fish. Res. Bd. Canada, Tech. Report 59*, 10 pp., 61 tables.
- _____. 1968b. "Quantitative benthic investigations: IV. Biomass summaries and major taxon rank orders for selected stations (mainly strait of Georgia and adjacent inlets)." *Fish. Res. Bd. Canada, Tech. Report 60*, 8 pp., 81 tables.
- _____. 1968c. "Quantitative benthic investigations: V. Species data for selected stations (Strait of Georgia and adjacent inlets)." *Fish. Res. Bd. Canada, Tech. Report 73*, 6 pp., 306 tables.
- _____. 1968d. "A series of computer programs for summarising data from quantitative benthic investigations." *J. Fish. Res. Bd. Canada*, 25(8):1737-1738.
- _____. 1969. "Ecologically significant species from coastal marine sediments of British Columbia." *Syesis* 2:171-181.

- Ellis, D. V. 1971. "A review of marine infaunal community studies in the Strait of Georgia and adjacent inlets." *Syesis*. 4:3-9.
- Fenchel, T. 1969. "The ecology of the marine microbenthos; IV. Structure and function of the benthic ecosystem, its chemical and physical factors, and the microfauna communities with special reference to the ciliated Protozoa." *Ophelia* 6:1-182.
- Forster, G. R. 1955. "Underwater observations on shallow rocky areas in the neighbourhood of Plymouth." *Mar. Biol. Assoc. U.K. Journal* 37:473-482.
- Gallardo, V. A. 1965. "Observations on the biting profiles of three 0.1 meter² bottom samplers." *Ophelia* 2(2):319-322.
- Herlinveaux, R. H. 1962. "Oceanography of Saanich Inlet in Vancouver Island." *J. Fish. Res. Bd. Canada*, 19(1):1-36.
- Kanwisher, J. W. 1962. "Gas exchange in shallow marine sediments." In "Proceedings of symposium on the environmental chemistry of marine sediments." *Occas. Publ. #1* (Grad. Sch. Oceanog., Univ. of Rhode Is.):12-19.
- Larsson, B. A. S. 1968. "Scuba studies on vertical distribution of Swedish rocky-bottom echinoderms." *Ophelia* 5(1):137-156.
- Lie, U. 1968. "A quantitative study of benthic infauna in Puget Sound, Washington, USA in 1963-1964." *Fiske, Skrift. Ser. Havunder* 14(5):229-556.
- _____, and J. C. Kelley. 1970. "Benthic infauna communities off the coast of Washington and in Puget Sound: identification and distribution of the communities." *J. Fish. Res. Bd. Canada*, 27(4):621-651.
- _____, and M. M. Pamatmat. 1965. "Digging characteristics and sampling efficiency of the 0.1 m² van Veen grab." *Limnol. & Oceanog.* 10(3):379-384.
- Macfadyen, A. 1963. "Animal ecology, aims and methods." 2nd. ed. Sir Isaac Pitman & Sons, Ltd., London. 344 pp.
- McCallum, J. and D. V. Ellis. "Volumes of infaunal benthos and their potential effects on the physical properties of shallow-water sediments." Manuscript.
- Pamatmat, M. M. 1966. "The ecology and metabolism of a benthic community on an intertidal sandflat." Ph.D. dissertation, Univ. of Washington, 243 pp.

- Pamatmat, M. M. 1968. "The ecology and metabolism of a benthic community on an intertidal sandflat." *Int. Revue ges. Hydrobiol.* 53(2):211-298.
- _____, and K. Banse. 1969. "Oxygen consumption by the Seabed II. In situ measurements to a depth of 180 m." *Limnol. & Oceanog.* 14(2):250-259.
- Pearse, J. 1965. "On the distribution of *Tresus nuttalli* and *Tresus capax* in the waters of Puget Sound and the San Juan archipelago." *The Veliger*, 7(3):166-170.
- Quayle, D. B. 1970. "The Intertidal Bivalves of British Columbia." *British Columbia Provincial Museum Handbook* #17.
- Richman, S. 1958. "The transformation of energy by *Daphnia pulex*." *Ecol. Monog.* 28:273-291.
- Riley, G. A. 1956. "Oceanography of Long Island Sound. IX. Production and utilization of organic matter." *Bull. Bing. Oceanog. Coll.* 15:324-344.
- Shelford, V. E. 1935. "The major communities." In: "Some marine biotic communities of the Pacific coast of North America, Part 1." *Ecol. Monographs*, 5:251-292.
- Sokal, R. R., and F. J. Rohlf. 1969. "Biometry." W. H. Freeman, San Francisco.
- Teal, J. L. 1957. "Community metabolism in a temperate cold spring." *Ecol. Monog.* 27:283-302.
- _____. 1962. "Energy flow in the salt marsh ecosystem of Georgia." *Ecology* 43:614-624.
- Thorson, G. 1957. "Bottom communities." In: *Treatise on marine ecology and paleoecology*, Vol. I Geol. Soc. Amer., Memoir #67.
- U. S. Navy Hydrographic Office. 1968. "Intruaction Manual for oceanographic Observations." Publ. 607, U. S. Navy Hydrographic Office.
- Wieser, W. and J. Kanwisher. 1961. "Ecological and physiological studies on marine nematodes from a small salt marsh near Woods Hole, Mass." *Limnol. & Oceanog.* 6(3):262-270.
- Zeuthen, E. 1947. "Body size and metabolic rate in the animal kingdom, with special regard to the marine microfauna." *Compt.-rend. Lab. Carlsberg, ser. Chim.* 26(3):20-161.
- _____. 1953. "Oxygen uptake as related to body size in organisms." *Quart. Rev. Biol.* 28:1-12.

APPENDIX 1

PROCEDURE FOR MECHANICAL ANALYSIS
OF SEDIMENT PARTICLE SIZE DISTRIBUTION

Sediment Analysis

Each sediment sample was dried under a 150 watt flood lamp. As the sample dried, the sediment aggregates were broken up by hand. When completely dry, the remaining aggregates were further broken down in a mortar, using a rubber covered pestle with an "up and down" motion rather than one of grinding. A 55 gram sub-sample was taken from the sample and mixed in a beaker with 125 ml. of 4% solution of Calgon (sodium hexametaphosphate) which served as a deflocculating agent. This mixture was allowed to stand for 18 hours and was then washed into the cup of a milkshake stirrer for one minute. Immediately after dispersion, the mixture was transferred to a 1000 ml. graduated hydrometry cylinder and made up to one liter by addition of distilled water at room temperature. The cylinder was stoppered and the mixture was dispersed by repeatedly upending the flask for one minute. The cessation of shaking was recorded as time zero. A clean hydrometer, calibrated in grams of suspended material per liter, was inserted and hydrometer readings were recorded at 1/2, 1, 2, and 4 minutes from time zero. The hydrometer was then placed in distilled water at room temperature until the next reading, at 8 minutes. Subsequent readings were taken at 15, 30, 60, 120, 240, 360 and 2240 minutes from time zero. A correction factor of 5 grams/liter was applied to the hydrometer readings to account for the dissolved Calgon (B. C. Dept. of Highways, 1967).

After the final hydrometer reading the sediment was washed on a #230 Endecott test sieve (Mesh size 0.0625 mm.), then the sieve and retained sediment were dried under a flood lamp. The dried sediment was weighed (recorded as "dry weight after washing") and transferred to the top of a bank of Endecott test sieves, including numbers 10, 35, 60, 80,

120, and 230 (U.S. Standard sieves) and the pan at the bottom. The screen bank was shaken for 2 minutes on a mechanical shaker, and the weight of sediment retained on each screen was recorded.

The hydrometer and sieve data (expressed in grams) were converted to "percent finer by weight" and plotted as cumulative curves.

APPENDIX 2

POPULATION DENSITIES OF *TRESUS CAPAX*
AND *MODIOLUS RECTUS* - CENSUS DATA

Appendix Table 2.1Population density of *Tresus capax*: census data. 1971Quadrat area = 3.14 meter²

<u>Sample number</u>	<u>Siphons/quadrat</u>	<u>Siphons/meter²</u>
1	0	0.0
2	0	0.0
3	2	0.6
4	4	1.3
5	1	0.3
6	3	1.0
7	2	0.6
8	0	0.0
9	0	0.0
10	2	0.6
11	3	1.0
12	8	2.6
13	2	0.6
14	0	0.0
15	0	0.0
16	2	0.6
17	0	0.0
18	4	1.3
19	2	0.6
20	7	1.6

$$\bar{Y} = 0.7 \text{ siphons/m}^2$$

Appendix Table 2.2Population density of *Modiolus rectus*.

Fulford Harbour, Line transect data.

August 4, 1972

Quadrat area = 1 meter²

	Transect #			
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
	0	0	0	2
	0	0	1	0
	1	0	0	2
No: siphons	1	2	2	0
per quadrat	1	0	0	0
	1	1	1	1
(= siphons/meter ²)	1	0	1	0
	0	1	0	0
	2	1	1	0
	0	2	1	0

$$\bar{Y} = 0.7 \pm 0.11 \text{ siphons/meter}^2$$

Appendix Table 2.3Random quadrat data (October 28, 1972). *M. rectus* in Fulford HarbourQuadrat area = 3.14 meter²

<u>Quadrat #</u>	<u>Siphons/quadrat</u>	<u>Siphons/meter²</u>
1	2	0.6
2	3	0.9
3	3	0.9
4	0	0.0
5	1	0.3
6	2	0.6
7	1	0.3
8	2	0.6
9	2	0.6
10	2	0.6
11	1	0.3
12	3	0.9
13	2	0.6
14	3	0.9
15	1	0.3
16	0	0.0
17	2	0.6
18	2	0.6
19	1	0.3
20	3	0.9

$$\bar{Y} = 0.5 \pm 0.06 \text{ siphons/m}^2$$

Appendix Table 2.4Population density of *Modiolus rectus*.

Saanichton Bay, Line transect data. August 26, 1972.

Quadrat area = 1 meter²

	Transect #									
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>
Siphons per	0	0	1	1	2	3	0	1	2	1
quadrat	1	2	0	0	0	0	0	0	0	1
(= siphons/m ²)	0	1	1	0	1	0	0	1	0	2
	2	0	0	1	0	0	0	0	0	0
	2	0	0	0	0	1	1	2	2	2
	1	1	0	1	0	2	0	0	1	0
	0	1	0	1	2	2	1	2	2	1
	1	0	2	0	0	1	1	0	0	0
	0	0	1	0	1	0	0	0	1	0
	0	1	1	1	0	0	1	0	0	0

$$\bar{Y} = 0.6 \pm 0.08 \text{ siphons/meter}^2$$

Appendix Table 2.5

Random quadrat data. (October 29, 1972.). *M. rectus* in Saanichton Bay.

Quadrat area = 3.14 meter²

<u>Quadrat #</u>	<u>Siphons/quadrat</u>	<u>Siphons/meter²</u>
1	3	0.9
2	2	0.6
3	2	0.6
4	1	0.3
5	3	0.9
6	1	0.3
7	2	0.6
8	1	0.3
9	3	0.9
10	0	0.0
11	2	0.6
12	2	0.6
13	3	0.9
14	1	0.3
15	1	0.3
16	1	0.3
17	0	0.0
18	3	0.9
19	2	0.6
20	2	0.6

$$\bar{Y} = 0.6 \pm 0.07 \text{ siphons/meter}^2$$

APPENDIX 3

OXYGEN CONSUMPTION MEASUREMENTS

Fulford Harbour, 1971

Appendix Table 3.1

Oxygen uptake by *Tresus capax* and by the sediment - 1971.

Changes in dissolved oxygen (ml.) during sampling of 20 minutes duration.

<u><i>T. capax</i> + sediment</u>				<u>Sediment</u>	
<u>May 14</u>	<u>May 17</u>	<u>May 18</u>	<u>May 20</u>	<u>June 2</u>	<u>June 3</u>
3.8	1.4	3.9	3.1	2.5	0.7
4.9	3.2	4.1	7.0	1.8	1.1
2.6	1.7	3.4	6.7	2.5	1.9
3.9		4.9	5.9	2.8	1.4
			8.3	1.8	1.2
				1.7	2.2
				1.4	0.7
					1.4
<u>—</u>	<u>—</u>	<u>—</u>	<u>—</u>	<u>—</u>	<u>—</u>
\bar{Y} (ml)				\bar{Y} (ml)	
3.8	2.1	4.1	6.2	2.1	1.3
\bar{Y} (ml. hour ⁻¹ /test.)				\bar{Y} (ml. hour ⁻¹ /test.)	
11.4	6.3	12.3	18.6	6.3	3.9

Appendix Table 3.2

Oxygen uptake by sediment alone.

Analysis of variance - single classification, unequal 'n'.

<u>Source</u>	<u>df</u>	<u>Sum of squares</u>	<u>Mean squares</u>	<u>F_s</u>
Among days	1	2.1	2.1	7.8
Within days	13	3.6	0.27	
Total	14	5.7		

$$F_{.05}[1,13] = 4.67$$

$$F_{.01}[1,13] = 9.07$$

Conclusion: there is a significant ($P < .05$) added variance component among sampling days for oxygen uptake.

Appendix Table 3.3

Oxygen uptake by *T. capax* + sediment.

Analysis of variance - single classification, unequal 'n'.

<u>Source</u>	<u>df</u>	<u>Sum of squares</u>	<u>Mean squares</u>	<u>Fs</u>
Among days	3	33.8	11.3	6.6
Within days	12	20.7	1.7	
Total	15	54.5		

$$F_{.05} [3, 12] = 3.49$$

$$F_{.01} [3, 12] = 5.95$$

Conclusion: There is a significant ($P < .01$) added variance component among sampling days.

APPENDIX 4

OXYGEN CONSUMPTION MEASUREMENTS

Fulford Harbour, 1972

and

Saanichton Bay, 1972

Appendix Table 4.1 Oxygen uptake by *Modiolus* and by the sediment, 1972. (August 2-11)

Changes in dissolved oxygen (ml.) during tests of 20 minutes duration.

I. <i>Modiolus</i> + sediment						II Sediment						Single specimens of <i>Modiolus</i> (I-II)											
Fulford Harbour			Saanichton Bay			Fulford Harbour			Saanichton Bay			Fulford Harbour			Saanichton Bay								
2	3	4	9	10	11	2	3	4	9	10	11	2	3	4	9	10	11						
4.7	4.1	3.8	8.0	5.7	5.8	1.0	1.2	0.2	1.4	0.2	0.6	3.7	2.9	3.6	6.6	5.5	5.2						
4.5	5.2	4.7	6.6	5.0	5.1	1.2	0.8	1.8	0.5	0.3	0.5	3.3	4.4	2.9	6.1	4.7	4.6						
5.0	4.9	5.5	5.6	5.6	5.3	0.8	0.5	1.4	0.2	0.5	0.9	4.2	4.4	4.1	5.4	5.1	4.4						
4.6	5.5	5.3	5.8	4.2	5.6	1.1	2.2	0.5	0.9	0.7	0.8	3.5	3.3	4.8	4.9	3.5	4.8						
4.0	3.9	4.9	4.8	4.8	2.5	0.7	0.9	1.8	0.2	0.6	0.3	3.3	3.0	3.1	4.6	4.2	2.2						
5.0	5.2	4.8	4.1	4.7	3.9	1.6	1.2	1.7	0.6	0.6	0.2	3.4	4.0	3.1	3.5	4.1	3.7						
4.4	5.3	4.0	4.1	6.6	7.2	0.9	0.8	0.5	0.2	0.7	0.8	3.5	4.5	3.5	3.9	5.9	6.4						
5.2	5.8	5.5	5.7	5.1	4.3	1.6	1.6	1.4	0.5	0.4	0.5	3.6	4.2	4.1	5.2	4.7	3.8						
4.4	4.5	4.8	4.9	5.1	4.7	0.5	0.9	0.2	1.1	0.5	0.5	3.9	3.6	4.6	3.8	4.6	4.2						
4.8	4.9	5.3	5.1	4.9	5.7	1.2	0.8	2.6	0.8	0.8	0.2	3.6	4.1	2.7	4.3	4.1	5.5						
$\bar{Y} = 1.1 \pm 0.07$						$\bar{Y} = 0.5 \pm 0.05$						$\bar{Y} = 3.7 \pm 0.10$						$\bar{Y} = 4.6 \pm 0.17$					
$= 130 \text{ ml.m}^{-2}\text{hr}^{-1}$						$= 60 \text{ ml.m}^{-2}\text{hr}^{-1}$						$= 11.1 \text{ ml.hr}^{-1}$						$= 13.8 \text{ ml.hr}^{-1}$					

Calculation as follows:

\bar{Y} = mean uptake during 20 minutes from jar of base 17.6 cms. diameter

\bar{Y} = 1.1 ml./experiment

= 1.1 ml./20 minutes/base area of jar

= 130 ml./hour/meter²

Appendix Table 4.2.

Oxygen uptake by the sediment and by *Modiolus* + sediment.

Analysis of variance - 3 way nested anova.

<u>Source of variation</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F_s</u>	
Among tests	1	522.5	522.5	149.3	*
Among sites within tests	2	7.0	3.5	17.5	*
Among days within sites	8	1.6	0.2	0.05	ns
Error	<u>108</u>	<u>50.3</u>	0.4		
Total	119	581.4			

$$F_{.05(1,2)} = 18.5$$

* P < .05

$$F_{.05(2,8)} = 4.46$$

ns not significant

$$F_{.05(8,108)} = 3.9$$

Appendix Table 4.3

Oxygen uptake by specimens of *Modiolus rectus* in Fulford Harbour and Saanichton Bay.

Analysis of variance - single classification, equal 'n'.

(a) Fulford Harbour	<u>Source</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F_s</u>
	Between days	2	0.3	0.15	0.47
	Within days	27	8.7	0.32	
	Total	29	9.0		
	$F_{.05}[2,15]^* = 3.68$ Since $F_s \ll F_{.05}[2,15]$ the null hypothesis is accepted.				
(b) Saanichton Bay	<u>Source</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F_s</u>
	Between days	2	0.6	0.3	0.33
	Within days	27	25.5	0.9	
	Total	29	26.1		
	$F_{.05}[2,15]^* = 3.68$ Since $F_s \ll F_{.05}[2,15]$ the null hypothesis is accepted.				

* Extrapolation of Sokal & Rohlf's table of Critical Values of the F-distribution to $F_{.05}[2,27]$ was considered unnecessary since F_s will obviously be much less than $F_{.05}[2,27]$.

Appendix Table 4.4

Respiration rates of specimens of *M. rectus* in Fulford Harbour
and Saanichton Bay.

Student's 't' test for significance of variation between locations.

Difference between variances found to be insignificant - proceed with
Student's t-test.

$$t_s = \frac{\bar{Y}_1 - \bar{Y}_2}{\sqrt{\frac{1}{n} (S_1^2 + S_2^2)}} = 4.50$$

$$t_{.05}[60] = 2.000$$

$$t_{.02}[60] = 2.390$$

Since $t_s > t_{.02}$ the null hypothesis is rejected.

The mean respiration rate of the *Modiolus* population in Fulford Harbour
is therefore significantly different from the mean rate of the Saanich-
ton Bay population.

Appendix Table 4.5

Oxygen uptake by the sediment in Fulford Harbour and Saanichton Bay.

Analysis of variance - single classification, equal 'n'.

(a) Fulford Harbour	<u>Source</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F_s</u>
	Between days	2	0.1	0.05	0.15
	Within days	27	9.4	0.34	
	Total	29	9.5		
	$F_{.05}[2,15]^* = 3.68$ Since $F_s \ll F_{.05}$ the null hypothesis is accepted.				
(b) Saanichton Bay	<u>Source</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F_s</u>
	Between days	2	0.1	0.05	0.55
	Within days	27	2.4	0.09	
	Total	29	2.5		
	$F_{.05}[2,15]^* = 3.68$ Since $F_s \ll F_{.05}$ the null hypothesis is accepted.				

* Extrapolation of Sokal & Rohlf's table of Critical Values of the F-distribution of $F_{.05}(2,27)$ was considered unnecessary since F_s will obviously be much less than $F_{.05}(2,27)$.

Appendix Table 4.6

Respiration rates of sediments in Fulford Harbour and Saanichton Bay.

Student's 't' test for significance of variation between locations.

Difference between variances insignificant - employ Student's t-test.

$$t_s = \frac{\bar{Y}_1 - \bar{Y}_2}{\sqrt{\frac{1}{n} (s_1^2 + s_2^2)}} = 5.00$$

$$t_{.05}[60] = 2.000$$

$$t_{.02}[60] = 2.390$$

Since $t_s > t_{.02}$ the null hypothesis is rejected.

This indicates a significant difference between the rates of sediment oxygen uptake in Fulford Harbour and Saanichton Bay.

APPENDIX 5

COMPONENTS OF THE INFAUNA, FULFORD HARBOUR, 1971

SPECIES RANK ORDERS

Appendix Table 5.1Species rank order by density (number/meter²): Fulford Harbour. 1971.

<i>Lucinoma tenuisculpta</i>	460
<i>Axinopsis sericatus</i>	362
Polychaetes unidentified	185
<i>Acila castrensis</i>	149
<i>Tellina carpenteri</i>	126
<i>Pinnixa</i> sp.	90
<i>Ninoe gemma</i>	55
<i>Transenella tantilla</i>	45
<i>Amphiodia urtica</i>	35
<i>Glycinde</i> sp.	29
Amphipod A	27
<i>Praxillella gracilis</i>	26
<i>Nephtys</i> sp.	25
<i>Amage anops</i>	21
<i>Venericardia ventricosa</i>	18
<i>Molpadia intermedia</i>	16
Amphipod C	15
Polychaete A	15
<i>Onuphis elegans</i>	13
Pelecypods unidentified	10
<i>Pentamera</i> sp.	10
<i>Macoma nasuta</i>	9
<i>Onuphis</i> sp.	9
<i>Ampharete arctica</i>	8
<i>Artacama conifera</i>	7
Amphipod B	7
Cumacea and copepoda	7
<i>Nucula tenuis</i>	6
<i>Macoma calcarea</i>	5
<i>Sternaspis fossor</i>	5
Amphipods unidentified	5
<i>Macoma alaskana</i>	4
<i>Protothaca</i> sp.	4
<i>Macoma carlottensis</i>	4
<i>Compsomyax subdiaphana</i>	3
Decapod A (Maidae)	3
<i>Thyasira gouldii</i>	2
<i>Solen sicarius</i>	2
<i>Polinices</i> sp.	2
<i>Macoma elimata</i>	1
Ophiuroid parts	-
Total:	1825

Appendix Table 5.2

Species rank order by biomass (gms./meter²): Fulford Harbour 1971.

	<u>Wet</u>	<u>Dry</u>
<i>Acila castrensis</i>	40.5	2.02
<i>Lucinoma tenuisculpta</i>	22.5	1.13
Pelecypods unidentified	13.4	0.67
Polychaetes unidentified	11.5	1.62
<i>Nephtys</i> sp.	7.5	0.37
<i>Tellina carpenteri</i>	5.6	
Ophiuroid parts	4.1	
<i>Solen sicarius</i>	4.0	
<i>Axinopsis sericatus</i>	3.3	
<i>Macoma nasuta</i>	2.8	
<i>Pentamera</i> sp.	2.2	
<i>Compsomya subdiaphana</i>	1.9	
<i>Praxillella gracilis</i>	1.5	
<i>Macoma elimata</i>	1.3	
<i>Ninoe gemma</i>	1.3	
<i>Venericardia ventricosa</i>	1.2	
<i>Onuphis</i> sp.	1.1	
<i>Artacama conifera</i>	1.1	
<i>Amphiodia urtica</i>	1.0	
<i>Transenella tantilla</i>	0.9	
<i>Macoma calcarea</i>	0.8	
<i>Polinices</i> sp.	0.8	
<i>Protothaca</i> sp.	0.6	
<i>Pinnixa</i> sp.	0.5	
<i>Molpadia intermedia</i>	0.5	
<i>Glycinde</i> sp.	0.4	
<i>Ampharete arctica</i>	0.4	
<i>Thyasira gouldii</i>	0.3	
<i>Macoma carlottensis</i>	0.3	
<i>Amage anops</i>	0.3	
<i>Macoma alaskana</i>	0.2	
<i>Onuphis elegans</i>	0.2	
Amphipod A	0.2	
<i>Nucula tenuis</i>	0.1	
<i>Sternaspis fossor</i>	0.1	
Amphipod C	0.1	
Polychaete A	0.1	
Amphipod B	0.0	
Amphipods unidentified	0.0	
Cumacea and copepoda	0.0	
Decapoda A (Maidae)	0.0	

Total: 134.3

Appendix Table 5.3

Species rank order by frequency of occurrence in samples (percent of hauls): Fulford Harbour, 1971.

<i>Lucinoma tenuisculpta</i>	100
Polychaetes unidentified	100
<i>Tellina carpenteri</i>	91
<i>Ninoe gemmea</i>	91
<i>Transenella tantilla</i>	82
<i>Venericardia ventricosa</i>	82
<i>Axinopsis sericatus</i>	82
<i>Nephtys</i> sp.	82
<i>Glycinde</i> sp.	82
<i>Pinnixa</i> sp.	82
<i>Acila castrensis</i>	73
<i>Macoma nasuta</i>	73
Pelecypods unidentified	64
<i>Amage anops</i>	64
<i>Onuphis elegans</i>	55
<i>Praxillella gracilis</i>	55
Amphipod B	55
<i>Amphiodia urtica</i>	55
<i>Onuphis</i> sp.	46
<i>Artacama conifera</i>	46
Amphipod A	46
Amphipod C	46
<i>Pentamera</i> sp.	46
<i>Molpadia intermedia</i>	46
<i>Sternaspis fossor</i>	36
<i>Ampharete arctica</i>	36
Cumacea and copepoda	36
Polychaete A	36
<i>Compsomyax subdiaphana</i>	27
<i>Macoma carlottensis</i>	27
<i>Nucula tenuis</i>	27
Decapod A (Maidae)	27
<i>Macoma alaskana</i>	18
<i>Solen sicarius</i>	18
<i>Protothaca</i> sp.	18
<i>Macoma calcarea</i>	18
Amphipods unidentified	18
<i>Polinices</i> sp.	18
<i>Thyasira gouldii</i>	9
<i>Macoma elimata</i>	9
Ophiuroid parts	-

Appendix Table 5.4

% dry organic matter of living (or wet) weight of some marine bottom invertebrates (after Thorson, 1957).

<u>Species</u>	<u>% of dry org.mat.</u>	<u>Species</u>	<u>% of dry org.mat.</u>
<u>Free living polychaetes</u>	about	<u>Lamellibranchs</u>	
<i>Perinereis cultrifera</i>	21.5-22.5	<i>Nucula nitida</i>	5.5
<i>Nereis diversicolor</i>	22.0-27.5	" nucleus	7.0
<i>Nereis pelagica</i>	20.5	<i>Venus ovata</i>	7.0
<i>Nereis virens</i>	5.5	<i>Cardium fasciata</i>	7.5
<i>Nephtys hombergi</i>	20.0	<i>Mytilus edulis</i>	4.25-6.5
<i>Nephtys scolopendroides</i>	18.25	<i>Modiola modiolus</i>	3.0
<i>Aphrodite aculeata</i>	16.0	<i>Cultellus pellucidus</i>	8.25
<i>Hermione hystrix</i>	13.5	<i>Macoma baltica</i>	5.0
<i>Sigalion squamatum</i>	16.5	<i>Syndosmya alba</i>	8.5
<i>Lumbrinereis impatiens</i>	24.5	<i>Mya arenaria</i>	6.0-10.5
<i>Eunice gigantea</i>	24.0	Average % of dry org.	
<i>Eunice siciliensis</i>	28.25	mat.	6.6%
<i>Halla parthenopeia</i>	26.0		
<i>Diopatra neapolitana</i>	17.25		
<i>Marphysa sanguinea</i>	23.75		
<i>Staurocephalus rudolphi</i>	19.0		
<i>Glycera siphonostoma</i>	18.75		
Average % of dry org.			
mat.	19.7%		
<u>Sedentary polychaetes</u>	about		
<i>Aricia foetida</i>	13.75		
<i>Scolecoplepis fuliginosa</i>	13.75-14.5		
<i>Nerine cirratulus</i>	23.75		
<i>Chaetopterus norvegicus</i>	19.0		
<i>Chaetopterus variopedatus</i>	10.75-12.0		
<i>Audouinia tentaculata</i>	12.5-22.0		
<i>Dasybranchus caducus</i>	11.0		
<i>Arenicola marina</i>	21.0		
<i>Owenia fusiformis</i>	21.5		
<i>Pectinaria koreni</i>	16.0-18.5		
<i>Amphitrite rubra</i>	17.0		
<i>Terebella lapidaria</i>	22.5		
<i>Terebella nebulosa</i>	14.75		
<i>Lanica conchilega</i>	29.0		
<i>Thelepus cincinnatus</i>	18.5		
<i>Sabella penicillus</i>	14.0		
<i>Spirographis spallanzani</i>	29.0		
<i>Branchiommma vesiculosum</i>	20.5		
<i>Myxicola infundibulum</i>	23.5		
<i>Protula protula</i>	15.5		
Average % of dry org.			
mat.	18.4%		
Average % for all polych	19.0%		

APPENDIX 6

COMPONENTS OF THE INFAUNA, FULFORD HARBOUR, 1972

SPECIES RANK ORDERS

Appendix Table 6.1Species rank order by density (number/meter²): Fulford Harbour, 1972.

<i>Lucinoma tenuisculpta</i>	862
<i>Axinopsis sericatus</i>	602
<i>Cancer</i> sp. juveniles	246
<i>Transenella tantilla</i>	230
Polychaeta sedentaria	198
Nephtyidae	124
Goniadidae & Glyceridae	112
Other polychaeta errantia	112
Siphunculoidea	66
<i>Tellina carpenteri</i>	64
<i>Acila castrensis</i>	54
<i>Amphiodia urtica</i>	38
Amphipod B	32
<i>Macoma</i> spp. juveniles	32
<i>Nucula tenuis</i>	22
Nereidae	18
Lumbrinereidae	14
<i>Venericardia ventricosa</i>	14
<i>Clinocardium nuttalli</i>	12
Amphipod A	8
<i>Macoma nasuta</i>	8
<i>Solen sicarius</i>	8
Pelecypod A	6
<i>Pentamera</i> sp.	6
Decapoda juveniles	4
Other Arthropoda	4
<i>Macoma carlottensis</i>	4
<i>Macoma elimata</i>	4
Gastropoda	4
<i>Tresus capax</i> siphon tip	2
Ophiuroid parts	0

Total: 2910

Appendix Table 6.2Species rank order by biomass (gms./meter²): Fulford Harbour, 1972.

<i>Tresus capax</i> siphon tip	63.8
<i>Lucinoma tenuisculpta</i>	45.0
<i>Solen sicarius</i>	29.8
Ophiuroid parts	26.0
Nephtyidae	24.2
<i>Acila castrensis</i>	18.0
<i>Macoma nasuta</i>	16.2
Nereidae	15.4
Polychaeta sedentaria	15.2
Other Polychaeta errantia	12.2
Siphunculoidea	10.8
<i>Amphiodia urtica</i>	8.8
Goniadidae & Glyceridae	7.2
<i>Asinopsis sericatus</i>	5.0
<i>Tellina carpenteri</i>	4.8
<i>Pentamera</i> sp.	3.8
<i>Cancer</i> sp. juveniles	3.0
<i>Venericardia ventricosa</i>	3.0
<i>Transenella tantilla</i>	3.0
<i>Macoma</i> spp. juveniles	1.2
<i>Macoma carlottensis</i>	1.2
Pelecypod A	0.8
Gastropoda	0.6
Lumbrinereidae	0.6
<i>Clinocardium nuttallii</i>	0.6
<i>Nucula tenuis</i>	0.6
Other arthropoda	0.4
Amphipod B	0.4
Decapoda juveniles	0.4
Amphipod A	0.2
<i>Macoma elimata</i>	0.2

Total:	322.4
--------	-------

Appendix Table 6.3

Species rank order by frequency of occurrence in samples (percent of hauls): Fulford Harbour 1972.

Polychaeta sedentaria	100.0
Nephtyidae	100.0
Goniadidae & Glyceridae	100.0
Other Polychaeta errantia	100.0
Amphipod B	100.0
<i>Cancer</i> sp. juveniles	100.0
<i>Axinopsis sericatus</i>	100.0
<i>Lucinoma tenuisculpta</i>	100.0
<i>Macoma</i> spp. juveniles	100.0
<i>Tellina carpenteri</i>	100.0
<i>Amphiodia urtica</i>	100.0
Siphunculoidea	100.0
<i>Nucula tenuis</i>	80.0
<i>Transenella tantilla</i>	80.0
Nereidae	60.0
Lumbrinereidae	60.0
Pelecypod A	60.0
<i>Acila castrensis</i>	60.0
<i>Clinocardium nuttallii</i>	60.0
<i>Solen sicarius</i>	60.0
Amphipod A	40.0
Decapoda juveniles	40.0
Other arthropoda	40.0
<i>Venericardia ventricosa</i>	40.0
<i>Macoma nasuta</i>	40.0
<i>Pentamera</i> sp.	40.0
<i>Macoma carlottensis</i>	20.0
<i>Macoma elimata</i>	20.0
<i>Tresus capax</i> siphon tip	20.0
Gastropoda	20.0
Ophiuroid parts	0.0

APPENDIX 7

COMPONENTS OF THE INFAUNA, SAANICHTON BAY, 1972

SPECIES RANK ORDERS

Appendix Table 7.1Species rank order by density (number/meter²): Saanichton Bay, 1972.

Polychaeta sedentaria	420
<i>Lucinoma tenuisculpta</i>	387
Amphipod A	203
<i>Transenella tantilla</i>	123
<i>Axinopsis sericatus</i>	112
Lumbrinereidae	92
Goniadidae & Glyceridae	52
Siphunculoidea	48
Nephtyidae	40
<i>Cancer</i> sp. juveniles	40
Other Polychaeta errantia	35
<i>Clinocardium nuttallii</i>	30
Amphipod B	28
<i>Macoma</i> spp. juveniles	10
Other Arthropoda	8
<i>Solen sicarius</i>	7
Nereidae	5
<i>Tellina carpenteri</i>	5
<i>Venericardia ventricosa</i>	3
<i>Nucula tenuis</i>	3
<i>Thyasira barbarensis</i>	3
Decapoda juveniles	2
<i>Macoma nasuta</i>	2
Holothuroidea	2
Ophiuroid parts	0

Total: 1660

Appendix Table 7.2

Species rank order by biomass (gms./meter²): Saanichton Bay, 1972.

<i>Solen sicarius</i>	71.0
Polychaeta sedentaria	22.0
<i>Lucinoma tenuisculpta</i>	13.7
Siphunculoidea	7.7
Nephtyidae	4.8
<i>Macoma nasuta</i>	3.7
Nereidae	3.2
Amphipod A	2.3
Lumbrinereidae	2.3
Goniadidae & Glyceridae	2.2
<i>Transenella tantilla</i>	2.2
Other Polychaeta errantia	1.3
<i>Cancer</i> sp. juveniles	1.2
<i>Axinopsis sericatus</i>	1.2
<i>Clinocardium nuttallii</i>	0.8
<i>Macoma</i> spp. juveniles	0.8
Ophiuroid parts	0.3
Holothuroidea	0.3
Amphipod B	0.3
Decapoda juveniles	0.2
<i>Nucula tenuis</i>	0.2
<i>Tellina carpenteri</i>	0.2
<i>Thyasira barbarensis</i>	0.2
Other Arthropoda	0.0
<i>Venericardia ventricosa</i>	0.0
Total:	142.0

Appendix Table 7.3

Species rank order by frequency of occurrence in samples (percent of hauls): Saanichton Bay, 1972.

Polychaeta sedentaria	100.0
Lumbrinereidae	100.0
<i>Acinopsis sericatus</i>	100.0
<i>Clinocardium nuttallii</i>	100.0
<i>Lucinoma tenuisculpta</i>	100.0
Siphunculoidea	100.0
Nephthyidae	83.3
Goniadidae & Glyceridae	83.3
<i>Transenella tantilla</i>	83.3
Other Polychaeta errantia	66.7
Amphipod A	66.7
Amphipod B	50.0
<i>Cancer</i> sp. juveniles	50.0
<i>Solen sicarius</i>	50.0
Nereidae	33.3
Other Arthropoda	33.3
<i>Venericardia ventricosa</i>	33.3
<i>Macoma</i> spp. juveniles	33.3
Decapoda juveniles	16.7
<i>Macoma nasuta</i>	16.7
<i>Nucula tenuis</i>	16.7
<i>Tellina carpenteri</i>	16.7
<i>Thyasira barbarensis</i>	16.7
Holothuroidea	16.7
Ophiuroid parts	0.0

APPENDIX 8

SEDIMENT MECHANICAL ANALYSIS DATA

Fulford Harbour (1971)

Appendix Table 8.1.

Sediment mechanical analysis data.

Haul number 11. Depth: 11 meters.

Hydrometer test.

Dry weight of sample: 55.0 gms.

<u>Time interval</u>	<u>Hydrometer reading</u>	<u>Corrected hydrom:</u>	<u>Grain size (mm)</u>	<u>% finer by weight</u>
0.5 min.	9.5	4.5	0.076	8.2
1.0 "	8.0	3.0	0.056	5.4
2.0 "	8.0	3.0	0.038	5.4
4.0 "	8.0	3.0	0.027	5.4
8.0 "	8.0	3.0	0.020	5.4
15.0 "	8.0	3.0	0.015	5.4
30.0 "	8.0	3.0	0.0102	5.4
60.0 "	8.0	3.0	0.0072	5.4
120.0 "	---	---		
240.0 "	7.5	2.5	0.0038	4.5
360.0 "	---	---		
2240.0 "	7.5	2.5	0.0016	4.5

Wash test.

Dry weight of sample	=	55.0 gms.
Dry weight after washing	=	51.1 "
Loss in weight (Δt)	=	3.9 "

Sieve analysis.

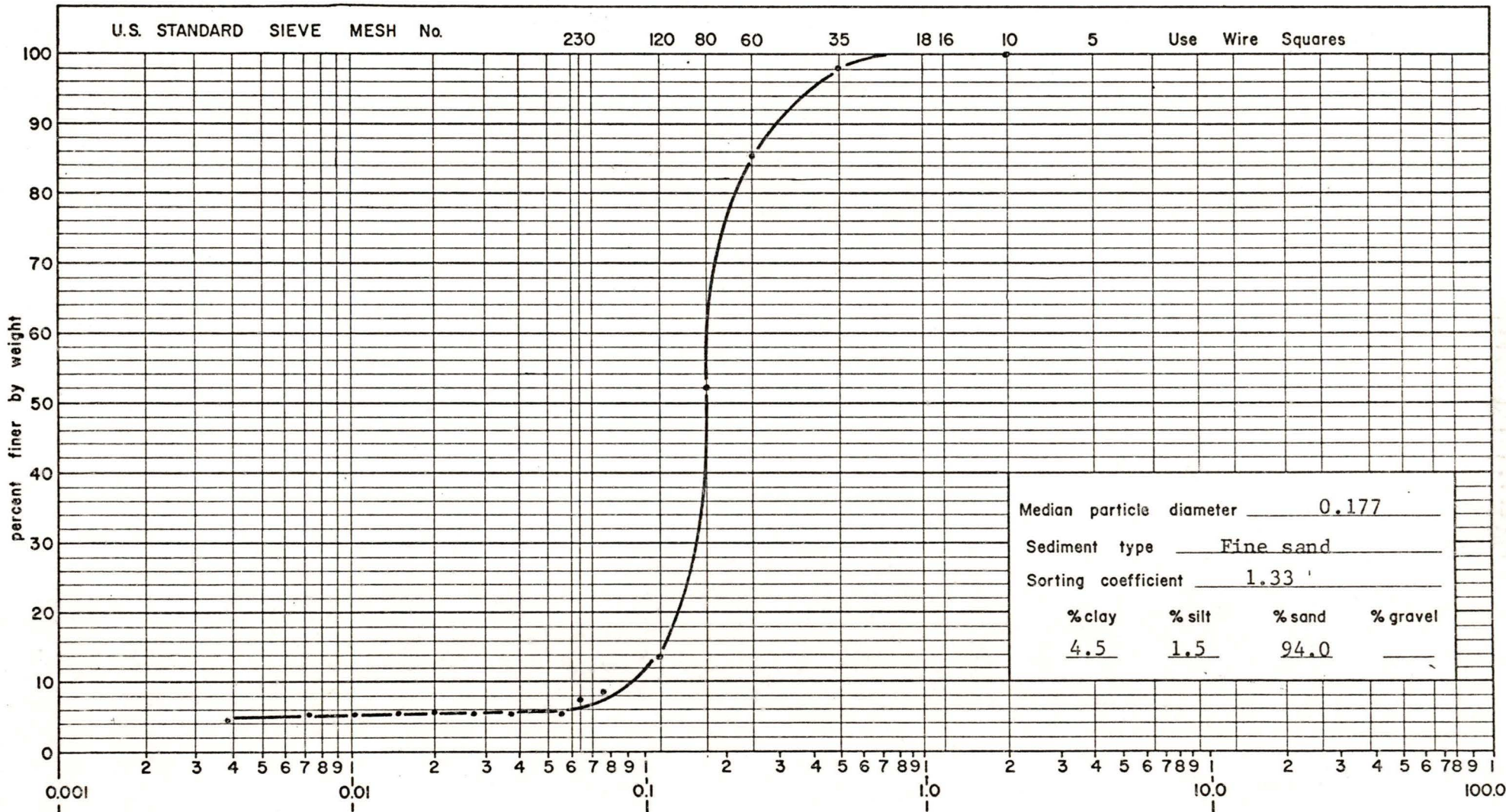
<u>U.S. Std: sieve size</u>	<u>Weight retained</u>	<u>% retained</u>	<u>% finer by weight</u>
10	0.0 gms.	0.0	100.0
35	0.9 "	1.6	98.4
60	6.9 "	12.5	85.8
80	18.7 "	34.0	51.8
120	21.2 "	38.5	13.5
230	3.2 "	5.8	7.7
Pan + Δt	3.9 "	7.1	

CUMULATIVE CURVE

BASED ON WENTWORTH GRADE SCALE

TESTED BY	
LOCATION	Fulford Harbour
STATION No.	Haul 11
DEPTH	11 meters

DATE	1971
DATE TESTED	



WENTWORTH Size Class	CLAY				SILT				SAND					GRAVEL		
	very fine	fine	medium	coarse	very fine	fine	medium	coarse	very coarse	granule	pebble	coble				
PHI (φ)	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	-1.0	-2.0	-6.0				
GRAIN SIZE (mm.)	.0039	.0079	.0156	.031	.0625	.125	.25	.50	1.0	2.0	4.0					

Appendix Table 8.2.

Sediment mechanical analysis data.

Haul number 10. Depth: 14 meters.

Hydrometer test.

Dry weight of sample: 55.0 gms.

<u>Time interval</u>	<u>Hydrometer reading</u>	<u>Corrected hydrom:</u>	<u>Grain size (mm)</u>	<u>% finer by weight</u>
0.5 min.	10.5	5.5	0.076	10.0
1.0 "	10.0	5.0	0.055	9.1
2.0 "	9.5	4.5	0.038	8.2
4.0 "	9.0	4.0	0.027	7.3
8.0 "	9.0	4.0	0.020	7.3
15.0 "	8.5	3.5	0.015	6.4
30.0 "	8.0	3.0	0.012	5.4
60.0 "	7.5	2.5	0.0074	4.5
120.0 "	---	---		
240.0 "	7.0	2.0	0.0038	3.6
360.0 "	---	---		
2240.0 "	7.0	2.0	0.0016	3.6

Wash test.

Dry weight of sample	=	55.0 gms.
Dry weight after washing	=	50.0 "
Loss in weight (Δt)	=	5.0 "

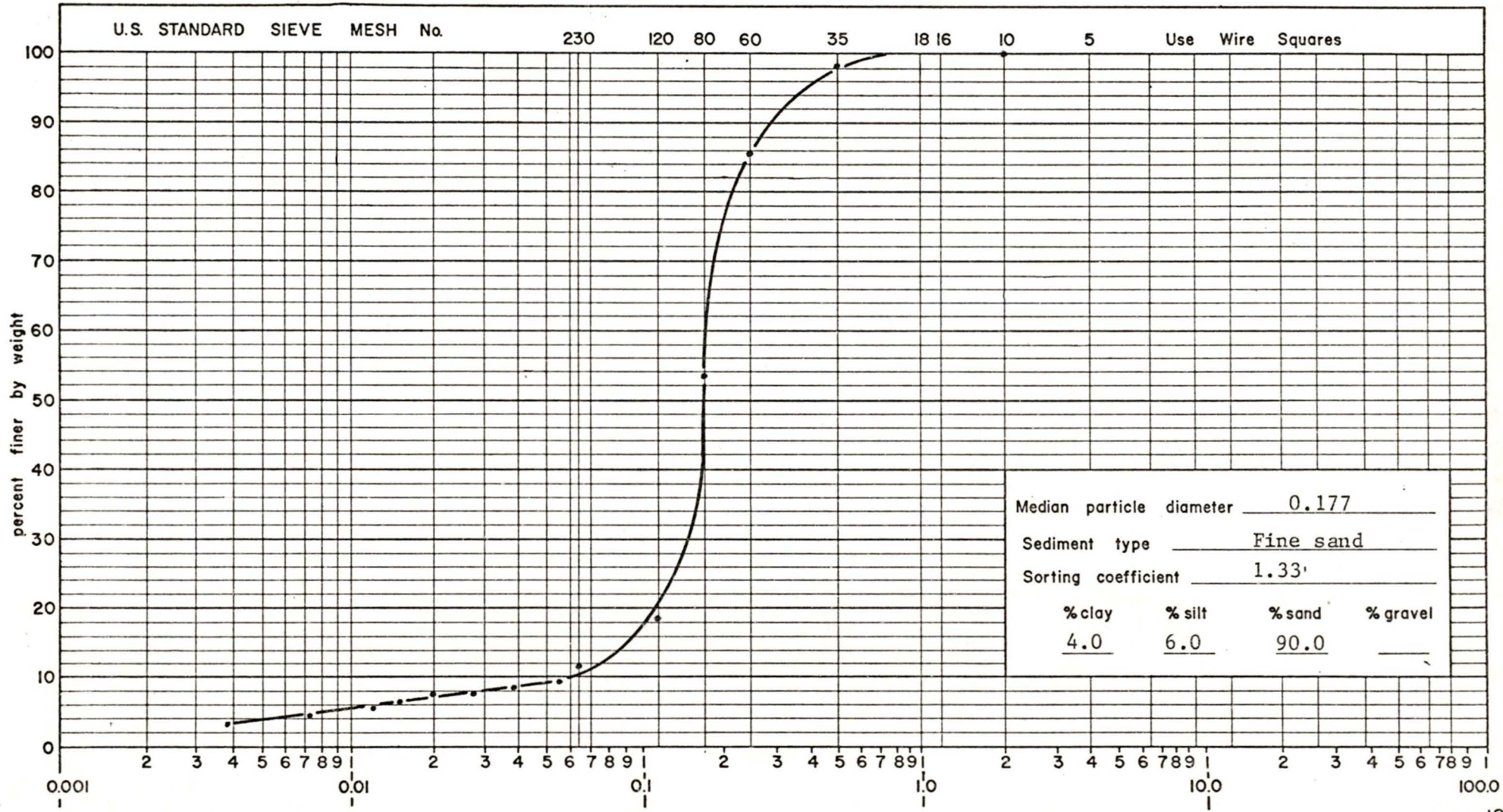
Sieve analysis.

<u>U.S. Std: sieve size</u>	<u>Weight retained</u>	<u>% retained</u>	<u>% finer by weight</u>
10	0.0 gms.	0.0	100.0
35	0.9 "	1.64	98.36
60	7.1 "	12.9	85.46
80	17.7 "	32.2	53.26
120	19.2 "	34.9	18.36
230	3.6 "	6.6	11.76
Pan + Δt	6.4 "	11.6	

CUMULATIVE CURVE

BASED ON WENTWORTH GRADE SCALE

TESTED BY		DATE	1971
LOCATION	Fulford Harbour	DATE TESTED	
STATION No.	Haul 10		
DEPTH	14 meters		



CLAY	SILT				SAND					GRAVEL		
	very fine	fine	medium	coarse	very fine	fine	medium	coarse	very coarse	granule	pebble	coble
WENTWORTH Size Class	80	70	6.0	5.0	4.0	3.0	2.0	1.0	0.0	-1.0	-2.0	-6.0
PHI (φ)												
GRAIN SIZE (mm.)	.0039	.0079	.0156	.031	.0625	.125	.25	.50	1.0	2.0	4.0	

Appendix Table 8.3.

Sediment mechanical analysis data.

Haul number 9. Depth: 6 meters.

Hydrometer test.

Dry weight of sample: 55.0 gms.

<u>Time interval</u>	<u>Hydrometer reading</u>	<u>Corrected hydrom:</u>	<u>Grain size (mm)</u>	<u>% finer by weight</u>
0.5 min.	10.0	5.0	0.076	9.1
1.0 "	9.5	4.5	0.055	8.2
2.0 "	9.0	4.0	0.038	7.3
4.0 "	9.0	4.0	0.027	7.3
8.0 "	8.5	3.5	0.020	6.4
15.0 "	8.0	3.0	0.015	5.4
30.0 "	8.0	3.0	0.012	5.4
60.0 "	8.0	3.0	0.0071	5.4
120.0 "	8.0	3.0	0.0052	5.4
240.0 "	8.0	3.0	0.0036	5.4
360.0 "	7.5	2.5	0.0030	4.5
2240.0 "	7.5	2.5	0.0015	4.5

Wash test.

Dry weight of sample	=	55.0 gms.
Dry weight after washing	=	50.0 "
Loss in weight (Δt)	=	5.0 "

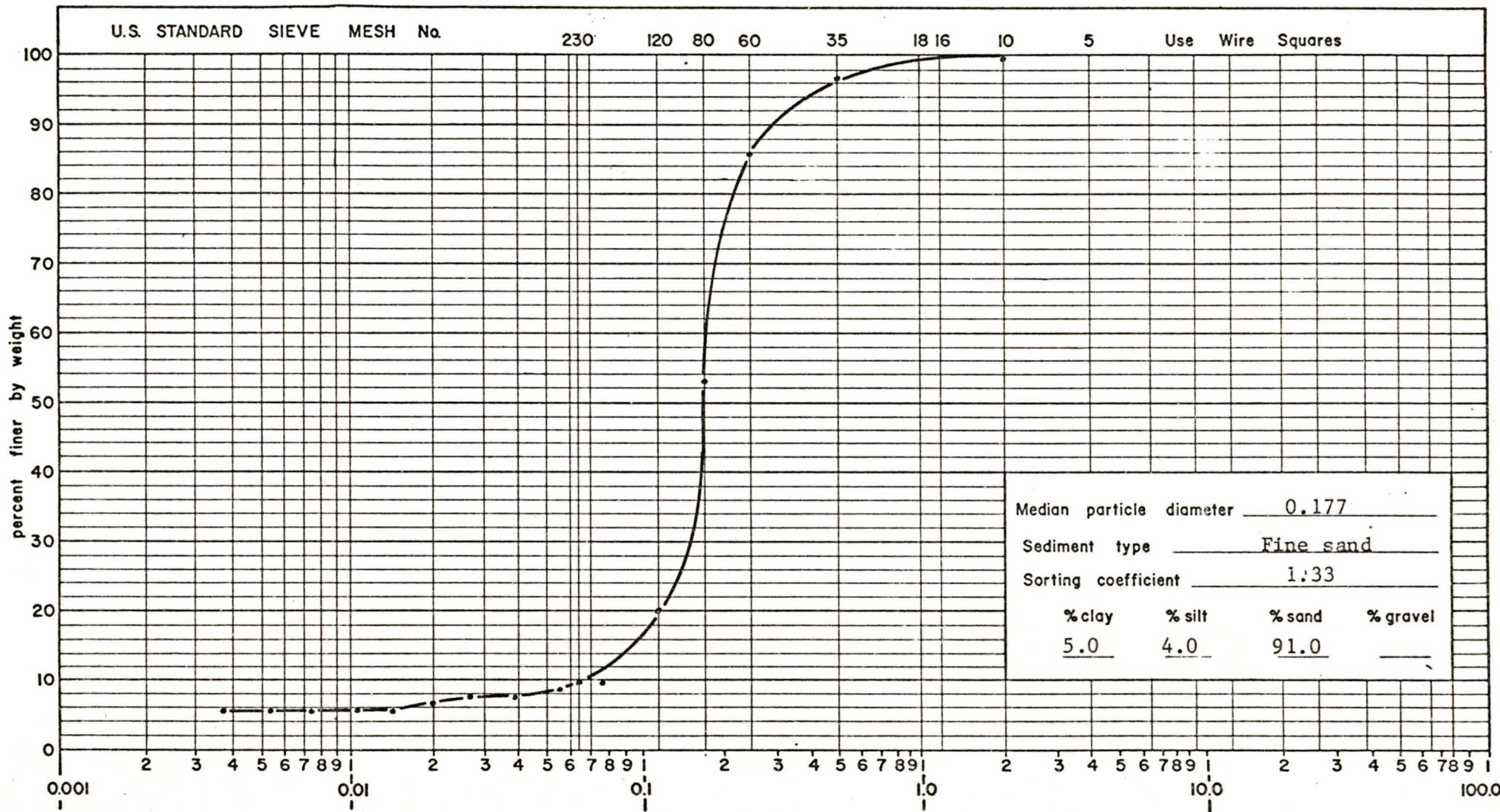
Sieve analysis.

<u>U.S. Std: sieve size</u>	<u>Weight retained</u>	<u>% retained</u>	<u>% finer by weight</u>
10	0.6 gms.	1.1	98.9
35	1.3 "	2.3	96.6
60	6.0 "	10.9	85.7
80	18.4 "	33.4	52.3
120	17.7 "	32.2	20.1
230	5.2 "	10.3	9.8
Pan + Δt	5.2 "	9.5	

CUMULATIVE CURVE

BASED ON WENTWORTH GRADE SCALE

TESTED BY		DATE	1971
LOCATION	Fulford Harbour	DATE TESTED	
STATION No.	Haul 9		
DEPTH	6 meters		



CLAY	SILT				SAND					GRAVEL		
	WENTWORTH Size Class	very fine	fine	medium	coarse	very fine	fine	medium	coarse	very coarse	granule	pebble
PHI (ϕ)	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	-1.0	-2.0	-6.0
GRAIN SIZE (mm.)	.0039	.0079	.0156	.031	.0625	.125	.25	.50	1.0	2.0	4.0	

Appendix Table 8.4.

Sediment mechanical analysis data.

Haul number 8. Depth: 16 meters.

Hydrometer test.

Dry weight of sample: 55.0 gms.

<u>Time interval</u>	<u>Hydrometer reading</u>	<u>Corrected hydrom:</u>	<u>Grain size (mm)</u>	<u>% finer by weight</u>
0.5 min.	15.0	10.0	0.074	18.2
1.0 "	13.0	8.0	0.054	14.5
2.0 "	12.5	7.5	0.038	13.6
4.0 "	11.5	6.5	0.027	11.8
8.0 "	11.0	6.0	0.020	10.9
15.0 "	10.5	5.5	0.015	10.0
30.0 "	10.0	5.0	0.010	9.1
60.0 "	9.5	4.5	0.0072	8.2
120.0 "	9.0	4.0	0.0051	7.3
240.0 "	9.0	4.0	0.0037	7.3
360.0 "	8.5	3.5	0.0029	6.4
2240.0 "	8.0	3.0	0.0015	5.4

Wash test.

Dry weight of sample	=	55.0 gms.
Dry weight after washing	=	45.8 "
Loss in weight (Δt)	=	9.2 "

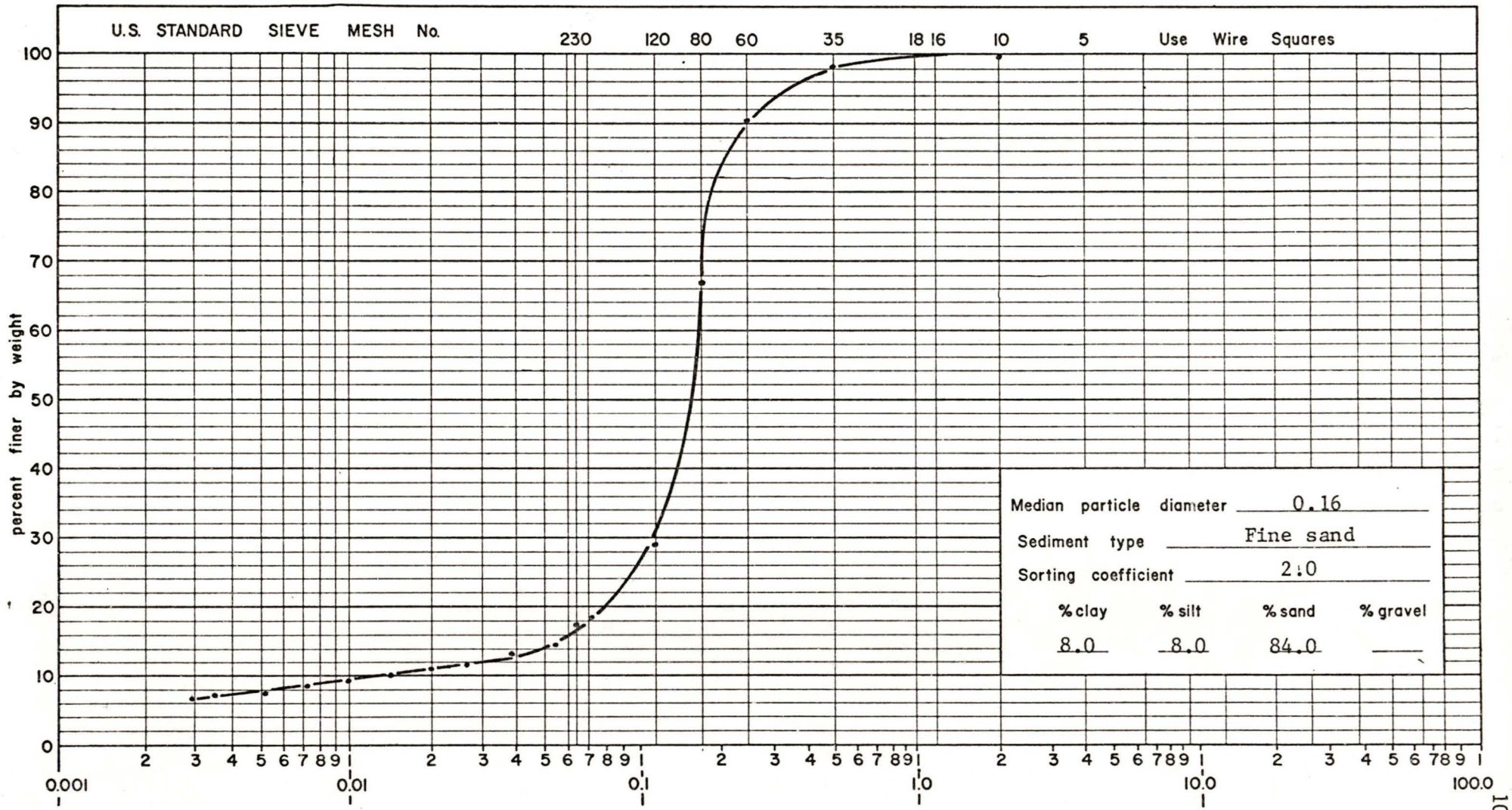
Sieve analysis.

<u>U.S. Std: sieve size</u>	<u>Weight retained</u>	<u>% retained</u>	<u>% finer by weight</u>
10	0.1 gm.	0.18	99.82
35	0.9 "	1.6	98.22
60	4.3 "	7.8	90.40
80	12.9 "	23.5	66.90
120	20.8 "	37.8	29.10
230	6.2 "	11.3	17.80
Pan + Δt	9.4 "	17.1	

CUMULATIVE CURVE

BASED ON WENTWORTH GRADE SCALE

TESTED BY		DATE	1971
LOCATION	Fulford Harbour	DATE TESTED	
STATION No.	Haul 8		
DEPTH	16 meters		



CLAY		SILT				SAND					GRAVEL		
WENTWORTH Size Class		very fine	fine	medium	coarse	very fine	fine	medium	coarse	very coarse	granule	pebble	cobble
PHI (φ)		8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	-1.0	-2.0	-6.0
GRAIN SIZE (mm.)		.0039	.0079	.0156	.031	.0625	.125	.25	.50	1.0	2.0	4.0	

APPENDIX 9

SEDIMENT MECHANICAL ANALYSIS DATA

Fulford Harbour (1972)

Appendix Table 9.1.

Sediment mechanical analysis data.

Haul number 1. Depth: 12 meters.

Hydrometer test.

Dry weight of sample: 55.0 gms.

<u>Time interval</u>	<u>Hydrometer reading</u>	<u>Corrected hydrom:</u>	<u>Grain size (mm)</u>	<u>% finer by weight</u>
0.5 min.	11.0	6.0	0.076	10.9
1.0 "	11.0	6.0	0.055	10.9
2.0 "	11.0	6.0	0.038	10.9
4.0 "	11.0	6.0	0.017	10.9
8.0 "	11.0	6.0	0.020	10.9
15.0 "	11.0	6.0	0.015	10.9
30.0 "	11.0	6.0	0.010	10.9
60.0 "	10.5	5.5	0.007	10.0
120.0 "	10.0	5.0	*	
240.0 "				
360.0 "				
2240.0 "				

Wash test.

Dry weight of sample	=	55.0 gms.
Dry weight after washing	=	51.1 "
Loss in weight (Δt)	=	3.9 "

Sieve analysis.

<u>U.S. Std: sieve size</u>	<u>Weight retained</u>	<u>% retained</u>	<u>% finer by weight</u>
10	0.0 gms.	0.0	100.0
35	0.7 "	1.3	98.7
60	5.8 "	10.5	88.2
80	20.3	36.9	51.3
120	20.1	36.5	14.8
230	3.9	7.1	7.7
Pan + Δt	4.2	7.6	

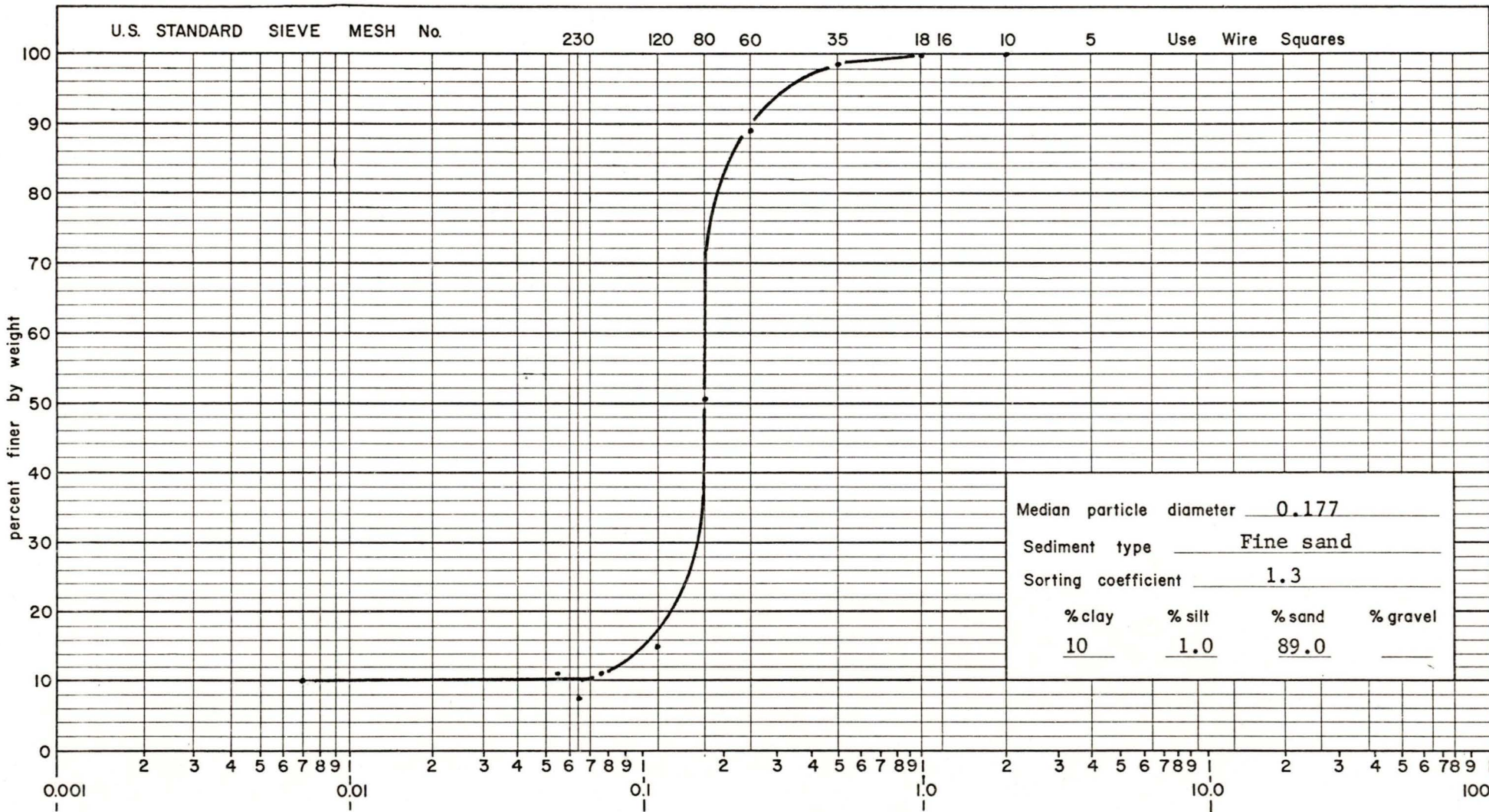
* Table of values (Appendix Table 9.3) cannot be extrapolated to such low hydrometer values.

CUMULATIVE CURVE

BASED ON WENTWORTH GRADE SCALE

TESTED BY	
LOCATION	Fulford Harbour
STATION No.	Sample 1
DEPTH	12 meters

DATE	1972
DATE TESTED	



CLAY		SILT				SAND					GRAVEL		
WENTWORTH Size Class	very fine	fine	medium	coarse	very fine	fine	medium	coarse	very coarse	granule	pebble		cobble
PHI (φ)	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	-1.0	-2.0		-6.0
GRAIN SIZE (mm.)	.0039	.0079	.0156	.031	.0625	.125	.25	.50	1.0	2.0	4.0		

Appendix Table 9.2.

Sediment mechanical analysis data.

Haul number 2. Depth: 12 meters.

Hydrometer test.

Dry weight of sample: 55.0 gms.

<u>Time interval</u>	<u>Hydrometer reading</u>	<u>Corrected hydrom:</u>	<u>Grain size (mm)</u>	<u>% finer by weight</u>
0.5 min.	10.5	5.5	0.076	10.0
1.0 "	10.5	5.5	0.055	10.0
2.0 "	10.5	5.5	0.038	10.0
4.0 "	10.5	5.5	0.027	10.0
8.0 "	10.0	5.0	0.020	9.1
15.0 "	10.0	5.0	0.015	9.1
30.0 "	9.5	4.5	*	
60.0 "				
120.0 "				
240.0 "				
360.0 "				
2240.0 "				

Wash test.

Dry weight of sample	=	55.0 gms.
Dry weight after washing	=	51.5 "
Loss in weight (Δt)	=	3.5 "

Sieve analysis.

<u>U.S. Std: sieve size</u>	<u>Weight retained</u>	<u>% retained</u>	<u>% finer by weight</u>
10	0.0 gms.	0.0	100.0
35	0.9 "	1.7	98.3
60	6.2 "	11.3	87.0
80	21.0 "	38.2	48.8
120	19.6 "	35.6	13.2
230	3.7 "	6.7	6.5
Pan + Δt	3.7 "	6.7	

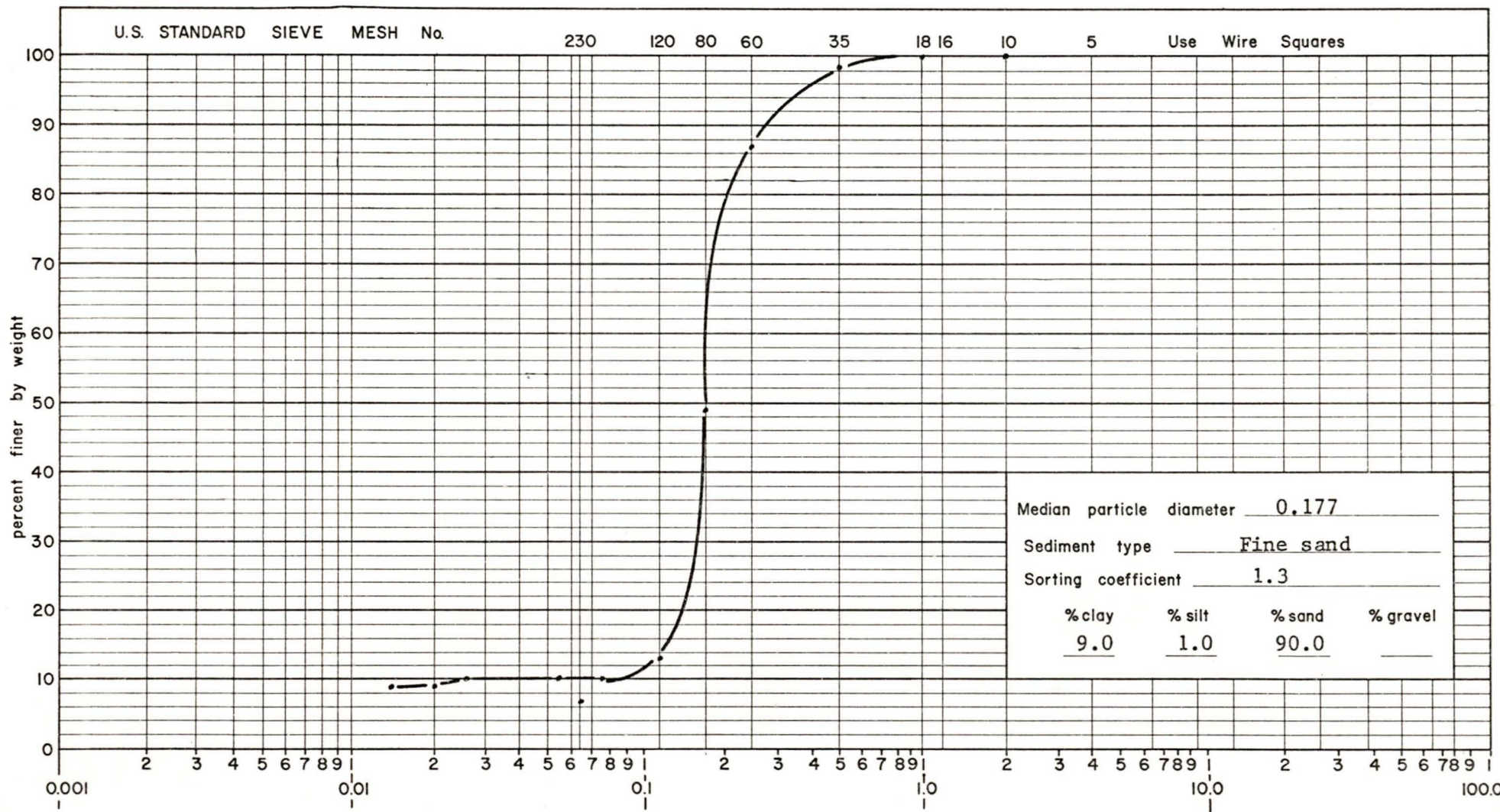
* Table of values (Appendix Table 9.3) cannot be extrapolated to such low hydrometer values.

CUMULATIVE CURVE

BASED ON WENTWORTH GRADE SCALE

TESTED BY	
LOCATION	Fulford Harbour
STATION No.	Sample 2
DEPTH	12 meters

DATE	1972
DATE TESTED	



CLAY	SILT				SAND					GRAVEL			
	WENTWORTH Size Class	very fine	fine	medium	coarse	very fine	fine	medium	coarse	very coarse	granule	pebble	coble
PHI (φ)	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	-1.0	-2.0		-6.0
GRAIN SIZE (mm.)	.0039	.0079	.0156	.031	.0625	.125	.25	.50	1.0	2.0	4.0		

Appendix Table 9.3

Particle sizes in suspension. (mm. diameter).

Hydrometer Reading	60	55	50	45	40	35	30	25	20	15	10
Time											
½ min.	.051	.054	.055	.059	.061	.064	.067	.068	.069	.072	.074
1 "	.036	.037	.039	.041	.043	.045	.047	.048	.049	.051	.053
2 "	.025	.027	.028	.029	.031	.032	.034	.035	.035	.036	.037
4 "	.018	.019	.020	.021	.021	.022	.023	.024	.024	.025	.026
8 "	.013	.013	.014	.015	.015	.016	.017	.017	.017	.018	.019
15 "	.0098	.0098	.010	.011	.011	.011	.012	.012	.013	.013	.014
30 "	.0066	.0069	.0071	.0076	.0080	.0083	.0086	.0089	.0090	.0093	.0097
60 "			.0051	.0054	.0056	.0059	.0062	.0064	.0064	.0066	.0069
120 "				.0039	.0040	.0042	.0043	.0044	.0045	.0047	.0049
240 "				.0027	.0028	.0029	.0031	.0032	.0032	.0033	.0035
360 "					.0021	.0022	.0025	.0025	.0026	.0027	.0028
2240 "							.0014	.0014	.0014	.0015	.0015

APPENDIX 10

SEDIMENT MECHANICAL ANALYSIS DATA

Saanichton Bay (1972)

Appendix Table 10.1

Sediment mechanical analysis data.

Haul number 1.

Depth: 13 meters.

Hydrometer test.

Dry weight of sample: 55.0 gms.

<u>Time interval</u>	<u>Hydrometer reading</u>	<u>Corrected hydrom:</u>	<u>Grain size (mm)</u>	<u>% finer by weight</u>
0.5 min.	12.5	7.5	0.075	13.6
1.0 "	11.0	6.0	0.055	10.9
2.0 "	10.5	5.5	0.038	10.0
4.0 "	10.0	5.0	0.027	9.1
8.0 "	10.0	5.0	0.020	9.1
15.0 "	10.0	5.0	0.015	9.1
30.0 "			*	
60.0 "				
120.0 "				
240.0 "				
360.0 "				
2240.0 "				

Wash test.

Dry weight of sample	=	55.0 gms.
Dry weight after washing	=	46.6 "
Loss in weight (Δt)	=	8.4 "

Sieve analysis.

<u>U.S. Std: sieve size</u>	<u>Weight retained</u>	<u>% retained</u>	<u>% finer by weight</u>
10	0.1 gms.	0.2	99.8
35	8.3 "	15.0	84.8
60	14.4 "	26.2	58.6
80	8.1 "	14.7	43.9
120	8.1 "	14.7	29.2
230	6.5 "	11.8	17.4
Pan + Δt	9.3 "	16.9	

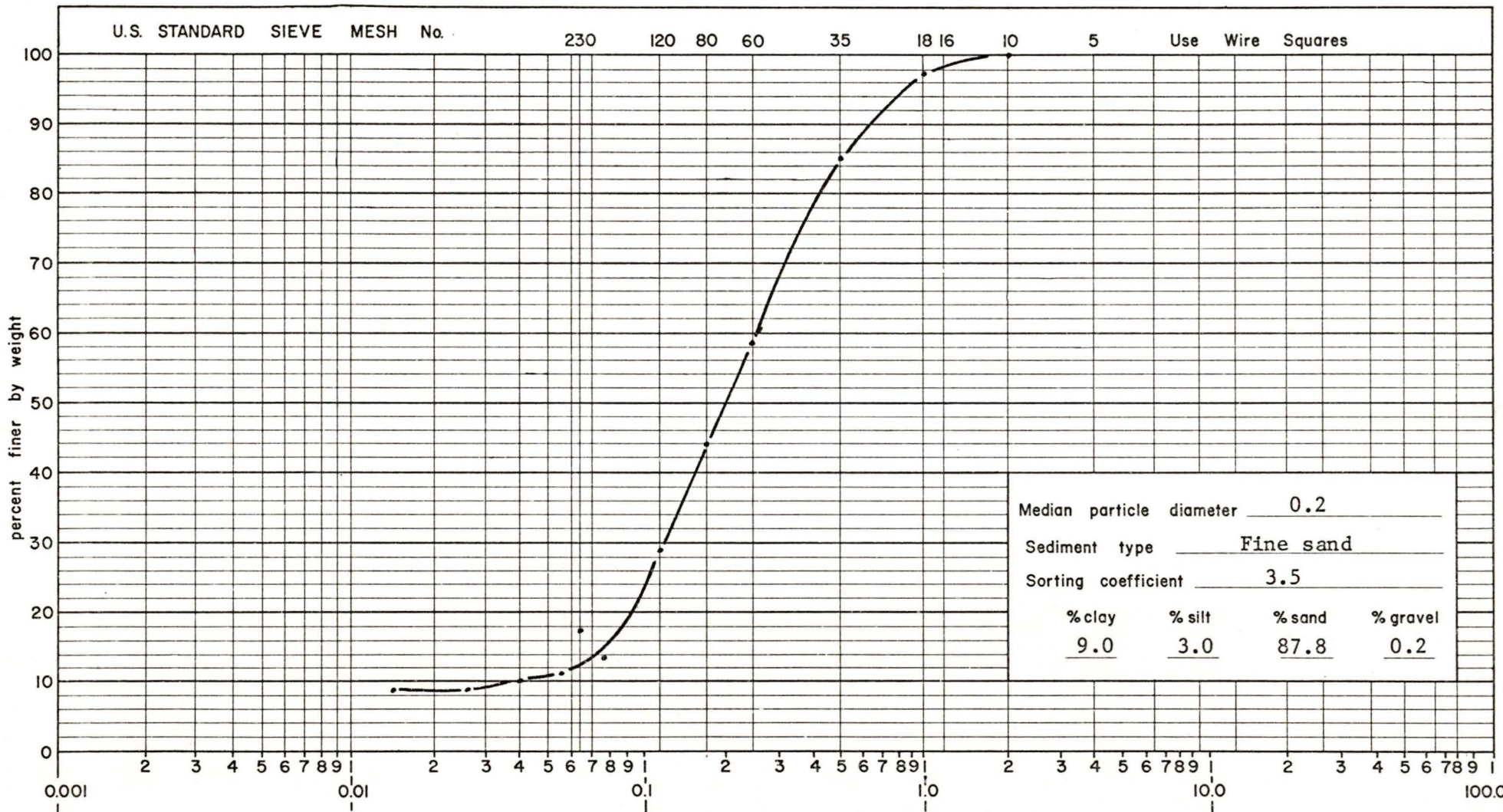
* Table of values (Appendix Table 9.3) cannot be extrapolated to such low hydrometer values.

CUMULATIVE CURVE

BASED ON WENTWORTH GRADE SCALE

TESTED BY	
LOCATION	Saanichton Bay
STATION No.	Sample 1
DEPTH	13 meters

DATE	1972
DATE TESTED	



CLAY	SILT				SAND					GRAVEL		
	WENTWORTH Size Class	very fine	fine	medium	coarse	very fine	fine	medium	coarse	very coarse	granule	pebble
PHI (ϕ)	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	-1.0	-2.0	-6.0
GRAIN SIZE (mm.)	.0039	.0079	.0156	.031	.0625	.125	.25	.50	1.0	2.0	4.0	

Appendix Table 10.2

Sediment mechanical analysis data.

Haul number 2. Depth: 13 meters.

Hydrometer test.

Dry weight of sample: 55.0 gms.

<u>Time interval</u>	<u>Hydrometer reading</u>	<u>Corrected hydrom:</u>	<u>Grain size (mm)</u>	<u>% finer by weight</u>
0.5 min.	15.0	10.0	0.074	18.2
1.0 "	11.0	6.0	0.055	10.9
2.0 "	10.5	5.5	0.038	10.0
4.0 "	10.5	5.5	0.027	10.0
8.0 "	10.5	5.5	0.020	10.0
15.0 "	10.0	5.0	0.015	9.1
30.0 "		4.5	*	
60.0 "				
120.0 "				
240.0 "				
360.0 "				
2240.0 "				

Wash test.

Dry weight of sample	=	55.0 gms.
Dry weight after washing	=	47.3 "
Loss in weight (Δt)	=	7.7 "

Sieve analysis.

<u>U.S. Std: sieve size</u>	<u>Weight retained</u>	<u>% retained</u>	<u>% finer by weight</u>
10	0.1 gms.	0.2	99.8
35	10.1 "	18.3	81.5
60	15.0 "	27.3	54.2
80	7.9 "	14.4	39.8
120	8.0 "	14.5	25.3
230	5.5 "	10.0	15.3
Pan + Δt	8.2 "	14.9	

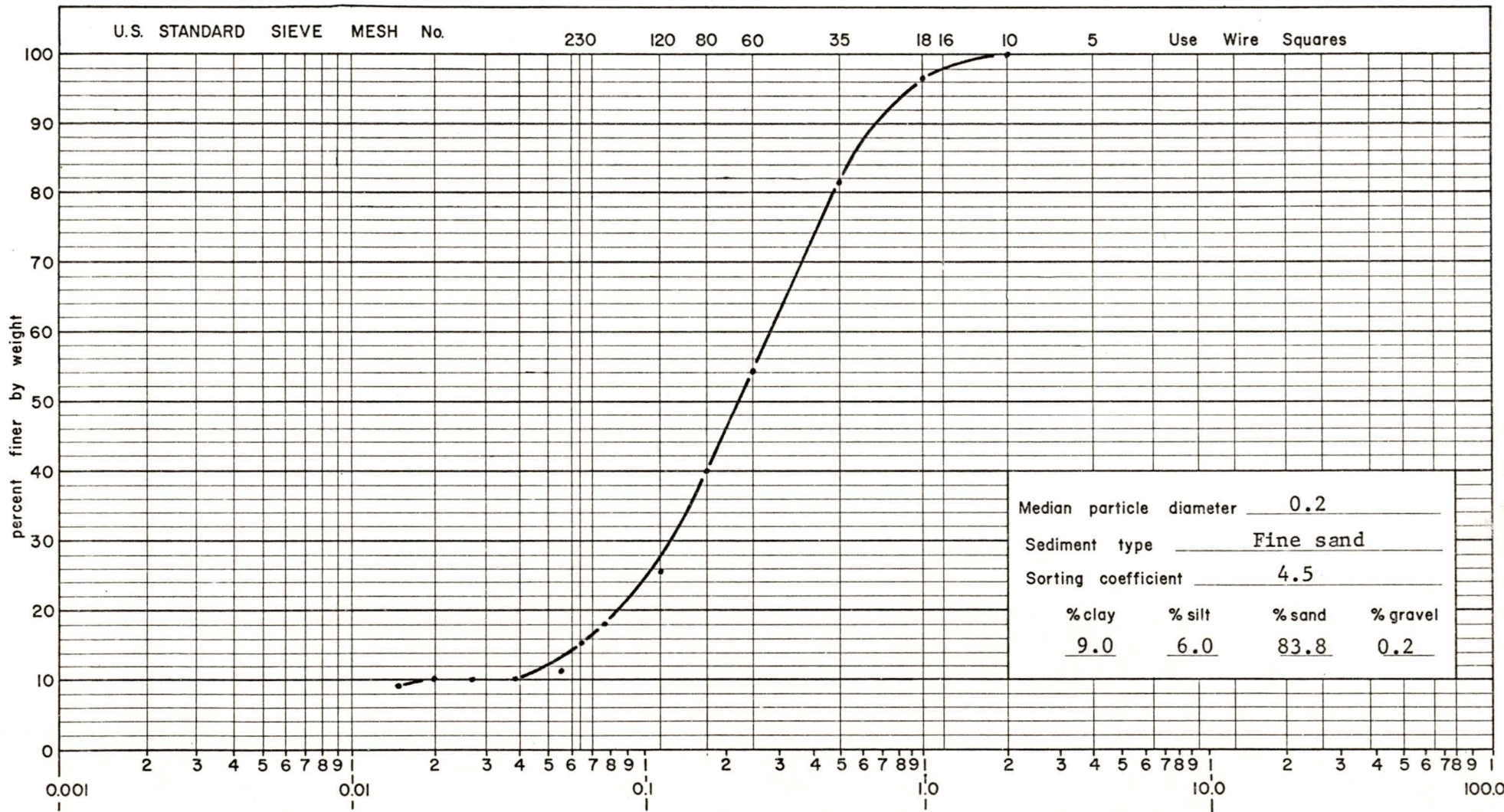
* Table of values (Appendix Table 9.3) cannot be extrapolated to such low hydrometer values.

CUMULATIVE CURVE

BASED ON WENTWORTH GRADE SCALE

TESTED BY	
LOCATION	Saanichton Bay
STATION No.	Sample 2
DEPTH	13 meters

DATE	1972
DATE TESTED	



CLAY	SILT				SAND					GRAVEL		
	WENTWORTH Size Class	very fine	fine	medium	coarse	very fine	fine	medium	coarse	very coarse	granule	pebble
PHI (φ)	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	-1.0	-2.0	-6.0
GRAIN SIZE (mm.)	.0039	.0079	.0156	.031	.0625	.125	.25	.50	1.0	2.0	4.0	

APPENDIX 11

BIOMASS OF *TRESUS CAPAX*AND OF *MODIOLUS RECTUS*

Biomass of *Tresus capax* and *Modiolus rectus*.

Two types of pumps were used in attempts to obtain specimens of *T. capax* and *M. rectus* from the sample sites for biomass determination. A centrifugal pump was coupled to 40 feet of 2 inch-diameter hose leading to a diver on the sea bottom. A strong jet of water from the hose was used to dig a hole into the sediment around a siphon of *T. capax* or *M. rectus*. Before the digging commenced, a small float was attached to the siphon by a length of twine. This allowed the siphon to be traced into the sediment. Holes could be dug to a depth of approximately 12 inches by this procedure. Greater depth was not possible because of sand sliding back into the hole. This method yielded no specimens of *T. capax* and only one specimen of *M. rectus*.

An alternative procedure utilized a diaphragm pump with a 3 inch-diameter suction hose, which sucked the sediment away from a tagged siphon. Holes of approximately 12 inches depth were produced by this method, but again, further depth was impossible because of sand sliding back into the hole. No specimens were obtained.

Biomass determination for *M. rectus* was therefore based upon a single specimen collected subtidally. No specimens of *T. capax* were obtained subtidally. Biomass determination was based upon nine specimens collected intertidally in Fulford Harbour on June 9, 1971. These are the only specimens available which were taken near to the sampling sites.

Appendix Table 11.1.

Biomass of *Tresus capax* - intertidal specimens from Fulford Harbour.

<u>Shell length</u>	<u>Wet weight</u>	<u>Dry weight</u>
13.5 cm.	559.3 gm.	36.9 gm.
13.0 "	455.2 "	30.0 "
13.8 "	632.6 "	41.7 "
11.8 "	392.5 "	25.9 "
lost "	431.6 "	28.5 "
12.8 "	498.6 "	32.9 "
11.2 "	347.1 "	22.9 "
lost "	142.6 "	9.4 "
15.1 "	559.7 "	36.9 "

Mean wet weight = 446.6 gm. \pm 145.0

Mean dry weight = 29.5 gm.

Biomass of *Modiolus rectus*.

Wet weight of one specimen = 400 gm.

APPENDIX 12

RANK ORDER OF SPECIES BY
PAMATMAT'S INDEX

Appendix Table 12.1.

Rank order of species by Pamatmat's Index (dry wt./m² x no./m² .
Fulford Harbour (1971).

<i>Lucinoma tenuisculpta</i>	519.80
<i>Acila castrensis</i>	300.98
Polychaetes unidentified	299.70
<i>Axinopsis sericatus</i>	57.92
<i>Tellina carpenteri</i>	35.28
<i>Tresus capax</i>	10.90
<i>Ninco gemma</i>	9.90
<i>Nephtys</i> sp.	9.25
Pelecypods unidentified	6.70
<i>Praxillella gracilis</i>	5.20
<i>Transenella tantilla</i>	2.25
<i>Pentamera</i> sp.	2.20
<i>Glycinde</i> sp.	1.45
<i>Onuphis</i> sp.	1.35
<i>Macoma nasuta</i>	1.26
<i>Venericardia ventricosa</i>	1.08
<i>Artacama conifera</i>	1.05
<i>Amphiodia urtica</i>	1.05
<i>Pinnixa</i> sp.	0.90
<i>Amage anops</i>	0.84
<i>Molpadia intermedia</i>	0.80
<i>Ampharete arctica</i>	0.40
<i>Solen sicarius</i>	0.40
<i>Onuphis elegans</i>	0.39
<i>Compsomyax subdiaphana</i>	0.30
<i>Macoma calcarea</i>	0.20
Polychaete A	0.15
<i>Polinices</i> sp.	0.12
<i>Protothaca</i> sp.	0.12
<i>Macoma elimata</i>	0.06
<i>Sternaspis fossor</i>	0.05
<i>Macoma alaskana</i>	0.04
<i>Macoma carlottensis</i>	0.04
<i>Thyasira gouldii</i>	0.02
<i>Nucula tenuis</i>	0.00
Amphipod A	0.00
Amphipod B	0.00
Amphipod C	0.00
Amphipods unidentified	0.00
Cumacea and copepoda	0.00
Decapod A (Maidae)	0.00

Index values of 0.00 result from a computer program convention of rounding off to two decimal places.

Appendix Table 12.2.

Rank order of species by Pamatmat's Index.

Fulford Harbour (1972).

<i>Lucinoma tenuisculpta</i>	1939.5
Polychaeta sedentaria	421.7
Nephtyidae	420.4
Other Polychaeta errantia	191.5
<i>Axinopsis sericatus</i>	150.5
Goniadidae & Glyceridae	113.1
Siphunculoidea	71.3
<i>Acila castrensis</i>	48.6
Nereidae	38.9
<i>Transenella tantilla</i>	34.5
<i>Tellina carpenteri</i>	15.4
<i>Cancer</i> sp. juveniles	14.8
<i>Solen sicarius</i>	11.9
<i>Amphiodia urtica</i>	9.9
<i>Macoma nasuta</i>	6.4
<i>Tresus capax</i> siphon tip	6.4*
<i>Modiolus rectus</i>	6.0
<i>Pentamera</i> sp.	2.4
<i>Venericardia ventricosa</i>	2.1
<i>Macoma</i> spp. juveniles	1.9
Lumbrinereidae	1.1
<i>Nucula tenuis</i>	0.7
<i>Clinocardium nuttallii</i>	0.3
Amphipod B	0.3
Relegpod A	0.2
<i>Macoma carlottensis</i>	0.2
Gastropoda	0.2
Amphipod A	0.0
Decapod juveniles	0.0
Other Arthropoda	0.0
<i>Macoma elimata</i>	0.0
Ophiuroid parts	0.0

* Based on assumed biomass of 400 gm./specimen.

Appendix Table 12.3.

Rank order of species by Pamatmat's Index.

Saanichton Bay (1972).

Polychaeta sedentaria	1293.6
<i>Lucinoma tenuisculpta</i>	263.2
Siphunculoidea	37.0
Lumbrinereidae	30.4
Nephtyidae	27.2
<i>Solen sicarius</i>	24.9
Goniadidae & Glyceridae	15.6
<i>Transenella tantilla</i>	13.5
Amphipod A	10.2*
<i>Modiolus rectus</i>	7.2
<i>Axinopsis sericatus</i>	6.7
Other Polychaeta errantia	6.6
Nereidae	2.2
<i>Clinocardium nuttallii</i>	1.2
<i>Cancer</i> sp. juveniles	0.8
<i>Macoma nasuta</i>	0.4
<i>Macoma</i> spp. juveniles	0.4
Amphipod B	0.3
<i>Tellina carpenteri</i>	0.1
Decapoda juveniles	0.0
Other arthropoda	0.0
<i>Venericardia ventricosa</i>	0.0
<i>Nucula tenuis</i>	0.0
<i>Thyasira barbarentis</i>	0.0
Ophiuroid parts	0.0
Holothuroidea	0.0

* Based on assumed biomass of 400 gms./specimen.

VITA

Surname: GODDARD

Given names: JAMES MARTIN

Place of Birth: CHEADLE HULME, ENGLAND Date of Birth: JULY 19, 1945

Education Institutions Attended, with Dates of Entering and Leaving:

UNIVERSITY OF SALFORD, SALFORD, ENGLAND 1963 to 1967

Degrees, Diplomas, etc., Awarded, with Dates and Names of Institutions:

B.Sc. 1967 University of Salford

Honors and Awards:

University of Victoria Scholarships 1969-1970, 1970-1971


Publications:

THE UNIVERSITY OF VICTORIA LIBRARY

MANUSCRIPT THESIS

AUTHORITY TO DISTRIBUTE

AUTHOR: This thesis may be lent or microfilm copies made available:

(a) Without restriction 

(b) With the restriction that, for a period of five years (until 1978) the written approval of the following is required:

(1) The Chairman, School of Graduate Studies _____

(2) The Author _____

(3) both the Chairman, School of Graduate Studies, and the Author _____

BORROWERS: The borrower undertakes, by signing below, to give proper credit for any use made of the thesis, and to obtain the consent of the author if it is proposed to make extensive quotations, or to reproduce the thesis in whole or in part.

Signature

Address

Date