BIOLOGICAL BASE-LINE TRIALS OF AN INTEGRATED PLANKTON PUMPING SYSTEM IN PLACE:..IA BAY, NEWFOUNDLAND

PHILIP W. PATEY

BIOLOGICAL BASE-LINE TRIALS OF AN INTEGRATED PLANKTON PUMPING SYSTEM IN PLACENTIA BAY, NEWFOUNDLAND.

A Thesis

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Master of Science

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by

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PREFACE

Johannes Müller to Ernst Haeckel

"There you can do much; and as soon as you have entered into this pelagic wonderland you will see that you can not leave it."

Haeckel 1893

Kofoid on the Hensen method

" Four places of decimals in a computed coefficient can hardly offer compensation for an error so fundamental as the variation in the straining capacity of the net."

Kofoid 1897

Frontispiece

M.V. Winnifred Shirley out of Arnold's Cove,

Placentia Bay, Newfoundland

ABSTRACT

Newfoundland's inshore waters continue to play an important role in the lives of many of its people. The shoreward portion may as a fishery reservoir influence species which contribute more than 70% of the landed value of commercial and sports fisheries. Yet the microbiota on which this reservoir is based has been a very neglected aspect of the island's marine biology. With the increase in coastal industrial development there is a greater potential for deterioration of this fragile and unfamiliar resource base.

In this social context a portable plankton pumping system was designed, assembled, and evaluated. The first module, a commercial diaphragm pump delivers sea water to a surge-tank where temperature, salinity, conductivity and dissolved oxygen measurements are made. In the third module the water is filtered by gravity flow through four Nitex plankton filters sequentially arranged after which the water's volume is determined.

Evaluation consisted of seventeen closely integrated field and laboratory experiments. Most of the field evaluation took place at Come by Chance adjacent to an oil refinery prior to its start-up operations. Several aspects of its operation and laboratory procedures were assessed.

Electronic environmental sensors were evaluated against alternate methods. Of these only the dissolved oxygen sensor yielded statistically significant variations. The water meter's performance was well within the value assured by the manufacturer. The filter-cleaning procedures

were satisfactory and sedimentation losses were not significant.

To evaluate zooplankton catching efficiency a conical net was tied below the pump's intake and both were pulled simultaneously through the same water column. There was little pump damage to plankton. The pump captured more of the smaller forms while the net retained more of the larger.

Together the net and the pump provided a means of gathering information on plankton numbers, diversity and their aqueous environment in a manner not previously demonstrated. Reduction of spatial and temporal displacement of the sampling devices increases the confidence one has in the conclusion that the numbers and diversity of plankton in the water column are more closely approximated by both devices together than by either operated singly.

ACKNOWLEDGEMENTS

The individuals, government agencies and commercial companies which have contributed directly or indirectly to this thesis are many. Each distinct participation was essential for the project's completion and is therefore singly appreciated. Without meaning ingratitude to those unnamed, I would like to especially thank the following:

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-Professor Howard J. Dyer, Faculty of Engineering and Applied Science,

-Mr. Roy Ficken, Department of Biology,

-Messrs. Llewllyn and George Allen Guy,

-and finally, Elizabeth.

DEDICATION

This thesis and whatever good it will serve is respectfully dedicated to the fisherman of Oderin and Harbour Buffet whose way of life will never be the same.

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1.0 INTRODUCTION

Briefly stated this thesis is an attempt to apply some recent technology and a few novel ideas to the use of a plankton pump in collecting zooplankton samples from an inshore area which is representative of a very neglected aspect of Newfoundland's coastal biota. The evaluation of the pumping system takes place at a site adjacent to a new oil refinery and projected petrochemical complex, prior to its start up. The data therefore constitutes base-line information within a social context.

1.1 Importance of inshore marine waters to Newfoundland and Labrador

The historical association of the Newfoundland people with marine fisheries resources since the island was first discovered is in great measure the story of their insular cultural evolution. Only with the building of the trans-island railway in the 1880's came the first major turning from the sea (McAllister 1965). Although the Province continues to seek new resources and new ways of using its resources, fish oriented industries still play an important role in the lives of many of its people. Statistical records indicate that possibly more than thirty per cent of the population depended directly of the fisheries in the last half of the twentieth century. The best records we have are those kept since 1957. Appendix 1 gives the fisheries dependent labour force for the primary and secondary sectors including part-time, casual and full employment as a percentage

of the total employed labour force for 1957 to 1972. The dollar value of the fishery to the Province's economy since 1958 is given in Appendix 2. An estimate of the annual contribution of this industry to the Gross Provincial Product can be made by applying the appropriate economic multiplier to the values given for each sector. For the primary sector the muliplier is 1.6, and 3.6 for the secondary sector, the fish products industry. For 1969 the input to G.P.P. by the fishing sector was in excess of $156 million, for example.

What cannot be made readily is a statement on the value of the coastal marine environment to the maintenance of this traditionally labour intensive industry. Although the continental shelf of the northeast coast of North America is world famous for its fishery resources, it is that portion closer to the Province which has had more value to Newfoundland and Labrador. The innermost portion of the neritic province is a zone of shallower water into which are deposited nutrients and freshwater by the hydrological cycle. Tidal oscillations, river mouth turbulence, wind, waves and coastal currents facilitate the mixing and dispersal of these. This zone provides a substrate for macrophytic algae and benthic invertebrates, and is a site for specialized fisheries having a proportionally high economic value, for example, the lobster, herring and salmon fisheries. Along the Atlantic seaboard of the United States nearly two thirds (63.7% by value) of the commercially important fish and shellfish species caught in the Atlantic and adjacent waters consist of species dependent on this inshore coastal zone for some phase of their life cycle (McHugh 1966 and Clark 1967). For those states bordering the Gulf of Mexico

this value runs to 90% because estuarial species such as shrimp, menhaden and oysters dominate the fisheries (Sykes 1968).

To what extent Newfoundland's commercial fish species utilize the inner portion of the neritic province is not clear because of the scarcity of scientific data for the majority of species. The limited scientifically based data on total inshore utilization consists of minor topics, footnotes and introductory sentences in papers more concerned with the occurrence, abundance, maturation, anatomical details and dispersal of the adult stages. Very occasional information exists for those growth stages not of commerical size. However, what is known can be a means for making a tentative statement about inshore utilization. For our purposes we accept as commercial those species for which Statistics Canada maintains records as publiahed in Landings, quantity and value by species and by area, Newfoundland, 1972. The commercial marine mammals normally listed are omitted. Only those species relevent to this project are given in Appendix 3.

The basis of a species' use of the inshore zone is derived from the suitability of the latter for some phase or phases of the life history or from the fact that it is a physical entity between the oceanic environment and the limnological. Part of this suitability relates to food production for the various consumer levels. Since there are no publiahed data on primary productivity for most of Newfoundland one must note what is known for adjacent similar sites. In St. Margaret's Bay, Nova Scotia, inshore primary productivity by macrophytes is among the highest levels for any natural populations, 1750 g C/m^2/year (Mann 1972). Zooplankters are a component of the

first and second order of consumers in the transfer of energy and are not directly used as food by most adult commercial fishes (herring, smelt and capelin are exceptions). Rather zooplankters are utilized by small vertebrate and invertebrate organisms which are themselves utilized by the commerical fish species.

Of the commercial species listed in Appendix 3, cod, mackerel and squid appear inshore mainly for feeding and maturation. Cod come right in after the spawning capelin. Squid increase in weight as much as six times while in Newfoundland inshore waters. Herring on the other hand overwinter, feed or spawn inshore depending on location, population and season (Hodder and Parsons 1971 a, b; Hodder, Parsons, Barbour and Chaulk 1972; and Wintera 1970). Other commercial species pass through the zone on their way to other sites; eel elvers, salmon as maturing adults or as smolts, brown trout, rainbow trout, arctic char and the anadromous form of the brook trout. Some species spend their life in the zone: smelt, clams, mussels and scallops whose food is planktonic. The early stages of several valuable species are components of zooplankton populations, including larval capelin, herring, and smelt; the veliger stage of clams, mussels and scallops; larval and juvenile lobsters, pink shrimp and queen crab. Although pink shrimp and queen crab are deep water organisms, their larval stages in Newfoundland are believed to develop in shallower water. The lobster and capelin make diverse use of the inshore zone. The former spawns, hatches, settles, molts and feeds there, while the latter spawns and undergoes early development.

Numerous individuals or entire populations of at least 22 of

the 44 species listed in Appendix 3 live in or frequent the near shore zone. Appendix 3 does not list a number of species of potential commerical value, for example, the sea urchin, *Strongylocentrotus droebachieneis* (Muller 1776) and the common dog whelk, *Buccinum undatum* L., nor does it incorporate the returns from the sports fisheries for salmon, trout and the blue fin tuna.

The Newfoundland inshore zone may as a fishery resource reservoir influence species which contribute more than 70% of the landed value of the commerical and sports fisheries.

1.2 Marine zooplankton research in waters adjacent to Newfoundland and Labrador

Plankton research in these waters has been mostly occasional and for the most part concentrated in the offshore waters above the continental shelf. Much of this data is but a minor component of projects involving a large geographical setting and having little bearing on local peculiarities. Several of the great oceanic expeditions sampled the ocean near the Grand Banks. Perhaps most notable among these were the Humboldt-Stiftung Expedition (Chun 1898), the Challenger Expedition (Thomson and Murray 1885), and the Michael Sars Expedition (Murray and Hjort 1910). The Canadian Fisheries Expedition of 1914-1915 and the Belle Isle Strait Expedition of 1923 were the basis for several plankton papers (Huntsman 1921 a and b, Davidson 1924, Pinhey 1927 a and b, Tattersall 1939, Kerswill 1940, Bousfield 1951, Huntsman *et al.* 1954 and Udvardy 1954).

Since 1959 Newfoundland has been a western terminus for the Continuous Plankton Recorder Programme in the North Atlantic

(Bainbridge 1961; Bainbridge and Jones 1962; Glover 1962, 1967; Henderson 1962; Robertson 1964; Jones 1969 and Gieskes 1971). European and Asian countries with fishing interests in the western North Atlantic have undertaken plankton research in this area (Alvarino 1956 a and b, Soulier 1965). Prior to the Soviet involvement hydrographic and biological studies were initiated in 1954. They are continuing (Marti 1963). Plankton research forms part of this endeavour (Pavshtiks *et al.* 1962, Drobysheva 1964, Vladimirskaya 1965, 1967 and Serebryakov 1965). In recent years plankton research has formed an important component of the studies done by member countries of the International Commission for the Northwest Atlantic Fisheries (ICNAF), (Bainbridge and Corlett 1968, Glover and Robinson 1968, and Colebrook 1972). Individual scientists have sometimes been interested in a specific planktonic group and have not been associated with an expedition as such but rather have worked with a single goal in mind (Bigelow 1909, Moore 1910, Mayer 1912, and Hulings 1967). Local contributions to our understanding of marine zooplankton are very scarce. Except for the work of the Newfoundland Government Laboratory 1930-1948 (e.g. Frost and Thompson 1932; Frost *et al.* 1933, 1934; Frost 1936 a, b, 1937, 1938; Templeman 1948; Thompson and Frost 1935, 1936), and a few recent papers (Mitchell 1964; Fraser 1969; Squires 1970) nothing has been published on offshore populations or on those inshore although research is now in progress.

Prior to the present study the only plankton research conducted in Placentia Bay and published is that of Templeman and Tibbo (1945) who towed for lobster larvae, although plankton samples have been taken

south of the Bay by various cruises of the Newfoundland Government Laboratory.

1.3 The pump as a plankton capturing device

1.3.1 Historical review

Although J. V. Thompson used some sort of a net to sample crab and barnacle larvae in 1828 (Fraser 1968), Johannes Müller, in 1845, made the first cone-shaped device from finely meshed cloth and towed it behind a boat (Fraser 1962). Thus the scientific study of plankton began and the obvious simplicity of the conical net hid its deficiencies. The progress and direction of plankton research has largely been the slow discovery and partial rectification of these weaknesses.

It was not until 1887 that Victor Hensen outlined his methods for the quantitative study of plankton (Hensen 1887, Jenkins 1901). He observed that surface plankton samples would eventually be best obtained by some sort of a tube and a pump carrying water to a filter (Gibbons and Fraser 1937). Although Hensen's conclusions about the pump may have periodically encouraged some to try it, his own greater interest in the net did not set the desired example. There is some justification for saying that it was frustration with the Hensen quantitative method which gave the needed encouragement.

Research in which the pump has been used is summarized in part by Gibbons and Fraser (1937) and in table form by Aron (1958, 1962). I have chosen to summarize in the manner of Aron (1962) those studies either overlooked or appearing since 1962. This updated summary is

presented in Appendix 4.

In the voluminous body of plankton literature it is clearly evident that the pump as a plankton collecting device has not been in popular use. The pump's application has been sporadic; the design and scope of both the equipment and the projects have been highly varied. The interplay of various circumstances has caused this. The status of applied pumping technology has had an important influence. Moreover the record of the use of the pump to capture plankton is also an account of the readiness of zoologists to apply unfamiliar technology to their research problems.

The first practical centrifuge pump was built in 1818 but it was not until about 1900 that it attained a high degree of commercial application when better rotative speed was available. It took another 37 years of popular use before zoologists applied the device to plankton collecting. The submersible centrifugal pump is widely used by the petroleum industry. The first use of the submersible centrifugal pump in plankton research was made in 1963 when O'Connell and Leong operated one 100 feet deep. The vacuum pump has been fairly well established commercially since the 1930's. It is only now that poasible application to plankton research is being explored (Lenz 1970).

Probably the most important factor in the application of pumps and pumping technology has been the availability of financial support to make commercial pumps more precise in function.

The kind of research undertaken as well as temporal and spatial restrictions have dictated the equipment one has had to use (Mathisen 1964 and Manz 1964).

Most of the studies summarized in Appendix 4 are based on a simple design (1, Fig 1.1) and vary only in the type of surface operating pump, its capacity, the size of the filtering net, its mesh size and the support facilities for sampling at a specific depth.

The incorporation of simultaneous hydrographic sampling procedures was first made by Cleve (1904). It was not until 50 years later (Banse 1955) that another effort was made to simultaneously obtain zooplankton samples and hydrographic data (Aron 1962). Cassie (1958) introduced electronic sensors for temperature and salinity determination. Since then there are only three other published accounts of the use of physical and chemical sensors (Beers *et al.* 1967, Whaley and Taylor 1968, Lenz 1970).

The simultaneous use of a sequential series of plankton nets or filters was first made by Held in 1961 (Aron 1962). Since that time less than half a dozen other workers have followed this procedure but of these only Beers *et al.* (1967), Whaley and Taylor (1968) and Lenz (1970) have constructed an integrated sampling system from the pump, electronic sensors and sequentially arranged plankton filters.

A feature which increases the complexity of a system while greatly broadening its scope is the capability of sampling while underway. Only one system has yet been built which can sample underway at 100 meters deep (Beers *et al.*, 1967). It is foreseeable that devices for deeper sampling will result as a technological spin-off from the present effort of the oil industry to locate and bring into production oil resources in the continental shelf.

Clearly the pump's significant historical value is that it has increased our understanding of the conical plankton net, the major plankton collecting tool. Using a simple pumping system and a net together Kofoid (1897) demonstrated that the "coefficients of a net", which were later called the filtration coefficients, calculated by Hensen as fixed values for a series of towing velocities, could not be static or rigid. They were, in fact, shown to vary significantly because of progressive clogging of the meshes.

Through the use of a plankton pump certain hitherto unknown ecological phenomens have been observed. Banse, (Aron 1962), was able to describe sharp biological stratifications that could not have been detected by standard tow net sampling. Cassie (1959, 1960) found high correlation between the distribution of some species and the temperature and salinity data which would have been unknown had the usual tow net and water bottle cast-sampling been done. Barnes (1949) began to unravel the phenomonon of non-random distribution in plankton using a plankton pump.

Kofoid (1897) demonstrated that all organisms are not retained by the finest silk bolting cloth thus proving erroneous one of Hensen's basic assumptions. Interest in the problem of plankton losses continues to motivate studies. Beers and Stewart (1969) have shown, using a plankton pumping system (Beers *et al.* 1967), that organisms small enough to pass through a 35μ mesh cloth constitute as much as 95% of the total number of micro-zooplankton present in the euphotic zone of the area studied. Their average volume was 17% of the average total microzooplankton volume. It can be tentatively

speculated that the contribution of ciliated Protozoa to energy flow pathways and biomass in the marine environment is greater than earlier thought.

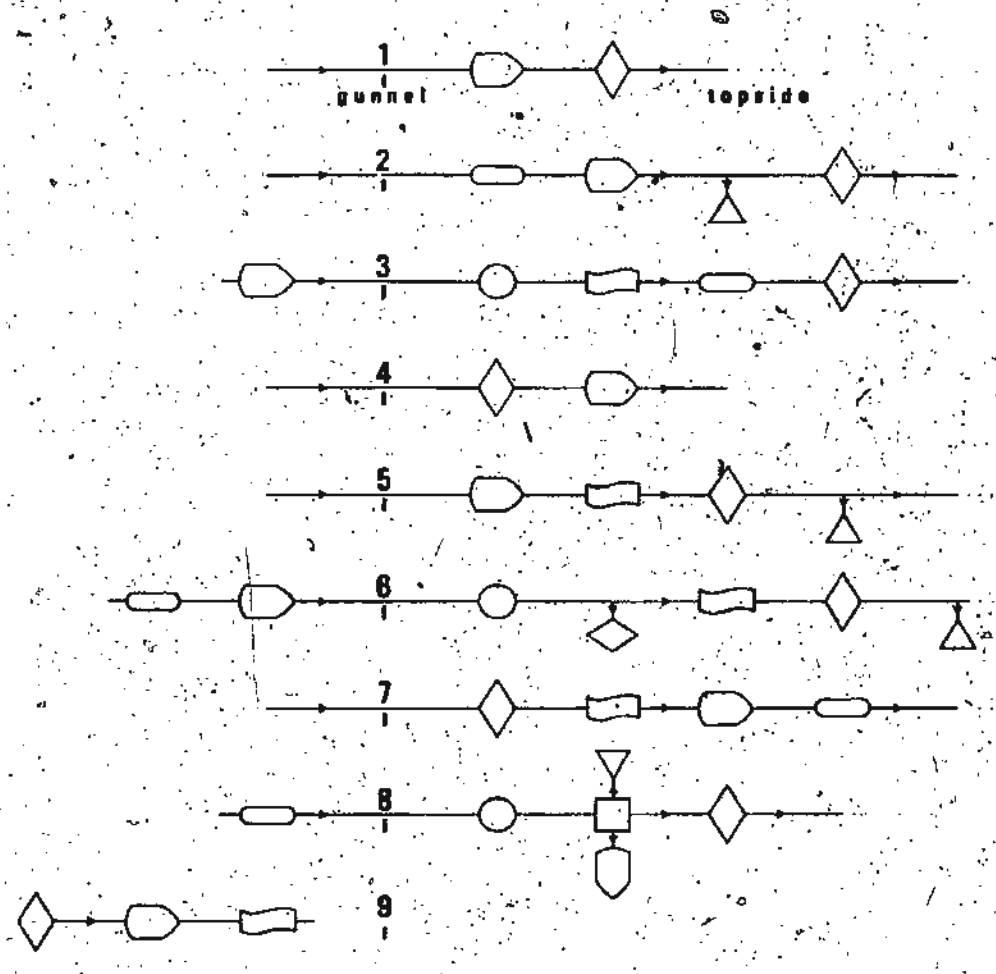
1.3.2. Hydrodynamics of the pumping method

It is evident that the manner of the sequential arrangement of components within the constraints of fluid mechanics is a major determinant to the successful design of a pumping system. A summary of the component arrangement of previous systems (Appendix 4) is given by Fig. 1.1. Equations which relate to this aspect are given in Appendix 5.

Figure 1.1 Diagrammatic layout of previous plankton pumping systems.

(See Appendix 4)

1. Various
2. Cassie 1958
3. O'Connell and Leong 1963
4. Manz 1964
5. Mathisen 1964
6. Beers *et al.* 1967
7. Whaley and Taylor 1968
8. Lenz 1970
9. Langford 1953



Legend

- pump
- hose winch
- filtering surface
- water meter
- sensors
- by-pass
- sub-sample point
- reservoir

2.0 MATERIALS AND METHODS

2.1. Research Locations

2.1.1 Marine Sciences Research Laboratory

The Marine Sciences Research Laboratory of Memorial University of Newfoundland has several land based facilities which were used extensively. The workshop area was the site for most of the construction of the pumping system. The running fresh sea water which is piped to the individual research laboratories was utilized for the laboratory aspects of design and evaluation. Other laboratory space was used to analyse the data.

2.1.2 Study Areas

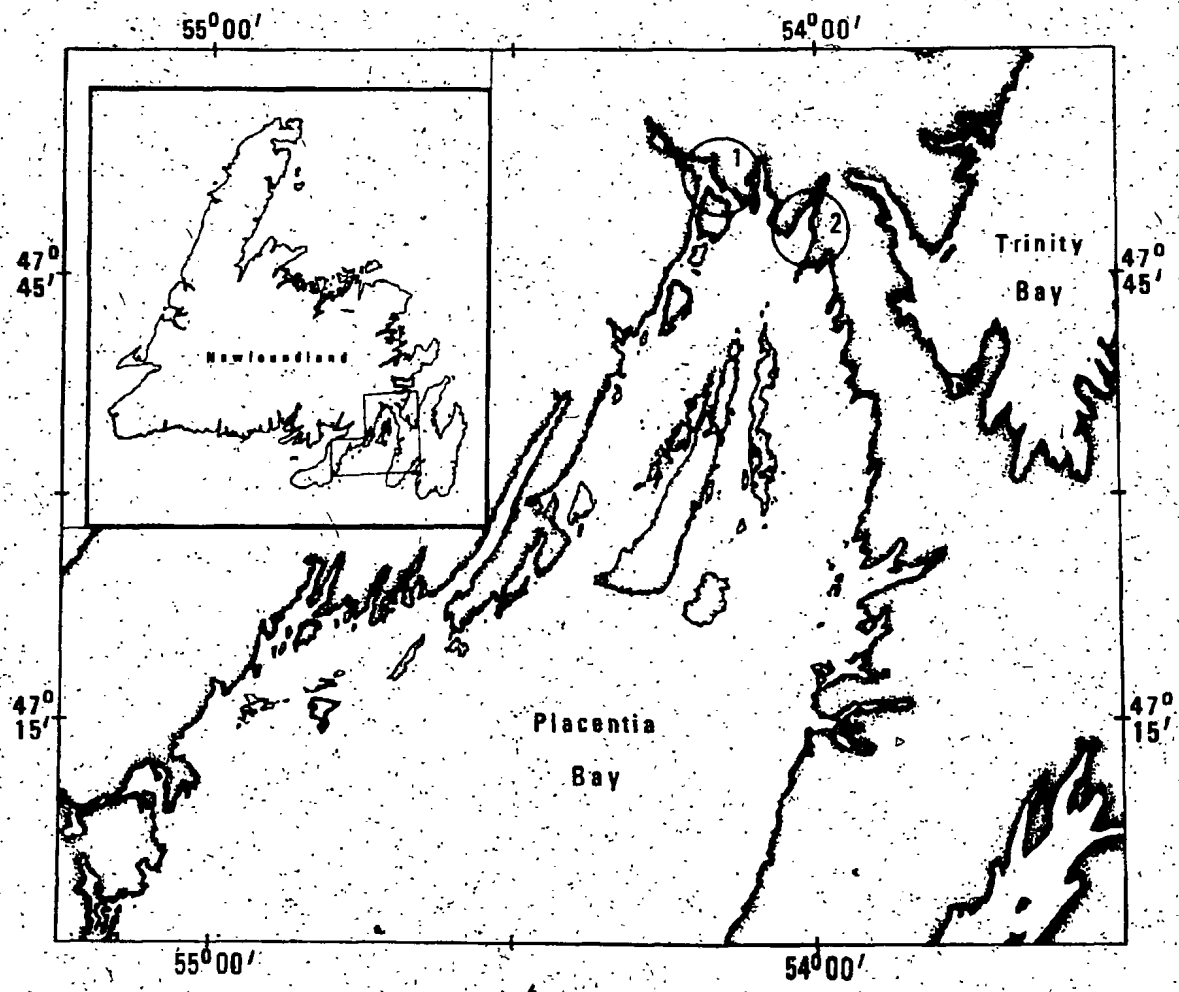
The field location for this project could have been any marine or freshwater body large enough to accomodate the operation. That selected was a very deliberate choice. Initially motivated by the absence of scientific literature on the estuarine zooplankton of this island, I decided to select an unpolluted estuary for a quantitative and qualitative study.

After an extensive survey of the island's rivers and estuaries through the use of topographic maps, hydrographic charts and the Stream Inventory of the Department of Environment, twenty-five estuarine systems were selected for more detailed study. Of these the Swift Current - Black River estuary met the criteria adequately and was selected as the prime study area (Map 2.1). Preliminary samples were taken by net in April 1969. However the unfolding drama of the

Map 2.1 Location of study areas

1 Swift Current – Black River

2 Come by Chance


55°00′
54°00′
47°
45′
47°
15′
Newfoundland
1
2
Trinity
Bay
Placentia
Bay

elemental phosphorus (P_4) disaster at Long Harbour, Placentia Bay, (Jangaard 1972) cast grave doubts on the undefiled quality of the prime study area, for "red" herring were caught nearby. This and the increasing certainty of an oil refinery complex at Come By Chance were major influences in the decision to change the prime study area to Come by Chance and use the Swift Current - Black River estuary as a secondary study area. Since base-line biological investigations were not in progress at that time, it was recognized that even evaluation of the pumping system then being constructed would provide some information against which any environmental change at Come by Chance might be judged. A dual purpose would therefore be served by conducting the field evaluation at Come by Chance. The qualitative and quantitative evaluation of the pumping system would also contribute to an understanding of base-line conditions at sea before the refinery started production.

Little has been published on the geomorphology and hydrography of Placentia Bay in spite of the growing hydrographic documentation on the offshore water on the Province's east coast (Smith *et al.* 1937, Hachey 1961, Templeman 1970, Dickson and Lamb 1972, Rodewald 1972, Alekseev *et al.* 1972). Canadian Hydrographic Service, Bathymetric Chart 802 shows it to be a deep bay with some prominent shoals. Protruding from the mouth is a 200 meter deep trough, bound to the south by St. Pierre Bank, Green Bank and Whale Bank, all of which are less than 100 meters deep. Placentia Bay is deeper than most of the continental shelf adjacent to Newfoundland's south-east coast. Of the few submarine channels adjoining these banks the deepest approach to

the central basin is through Halibut Channel. The effect of this topography on water circulation is not entirely clear. An inshore portion of the Labrador Current follows the Avalon Channel and enters the Bay at the southeast (Templeman 1966). Surface waters move in a counter-clockwise direction, entering from the east, passing in around the islands and going out at the west (Hodder, Parsons and Pippy 1972). The effect of the prevailing southwest winds on western surface water is not known. How much this acts against Coriolis Force is not clear. Since the trough is bound by shallow banks, Coriolis Force should create a giant eddy in the deeper waters. South of this cold water mass the Gulf Stream sweeps eastward along the southern slopes of the Grand Banks. Under specific conditions there is the possibility that giant masses of this water may spin off the major current and intrude into Placentia Bay over the colder Arctic waters. Winter water temperatures in 1966 and 1969 indicate at that season all the water in Placentia Bay was of Arctic origin. The range of temperature in the water column was -1.0°C to 0.6°C (Hodder, Parsons and Pippy 1972). Squires (1970) states that the trough in Placentia Bay is almost always full of water of very low temperature (about -1°C). In addition to physical data, the presence of more southern planktonic would indicate the occurrence of a warm water mass intrusion.

2.2 Sampling Equipment

2.2.1 Portable Aquatic Environmental Data System

The Portable Aquatic Envirnonmental Data System (PAEDS) was designed and built locally so that the advantages of the pump as a means of collecting suspended particles from water were maximized. Components of the PAEDS were built as functional units or modules. Because these are portable, the system is portable.

The Pump Unit

This component consists of an Edson "Bone Dry" Diaphragm Pump Model 120 G.W.B., with a capacity to handle 9.84 cubic meters of liquid per hour (Photograph 2.1). The motor, a Brigge & Stratton air cooled engine, develops 3.0 horsepower at 3600 rpm. The unit has a suction lift to 7.62 meters. The pump body, the valves and diaphragm are resistent to sea water corrosion.

The Surge-Tank Unit

This, the largest module, consists of a $0.108m^3$ fiber-glassed plywood tank elevated on a plywood base (Fig. 2.1). The bulkhead fittings are of schedule 80 PVC fittings. The outermost fitting, to which a hose coupling is attached, is bronze since it has the greatest probability of being damaged during repeated assembly of the PAEDS. The unit has three distinct functions. Water from the pump unit enters at b, Fig 2.1 and Fig 2.2, directly opposite which is c, the exit to the filter-stack unit. As the water rises in the tank it reaches an enlarged upper portion where its surface area increases. This modulates the pulsing action of the pump unit and insures a more constant head to the filter-stack unit.

Photograph 2.1 The pump-unit

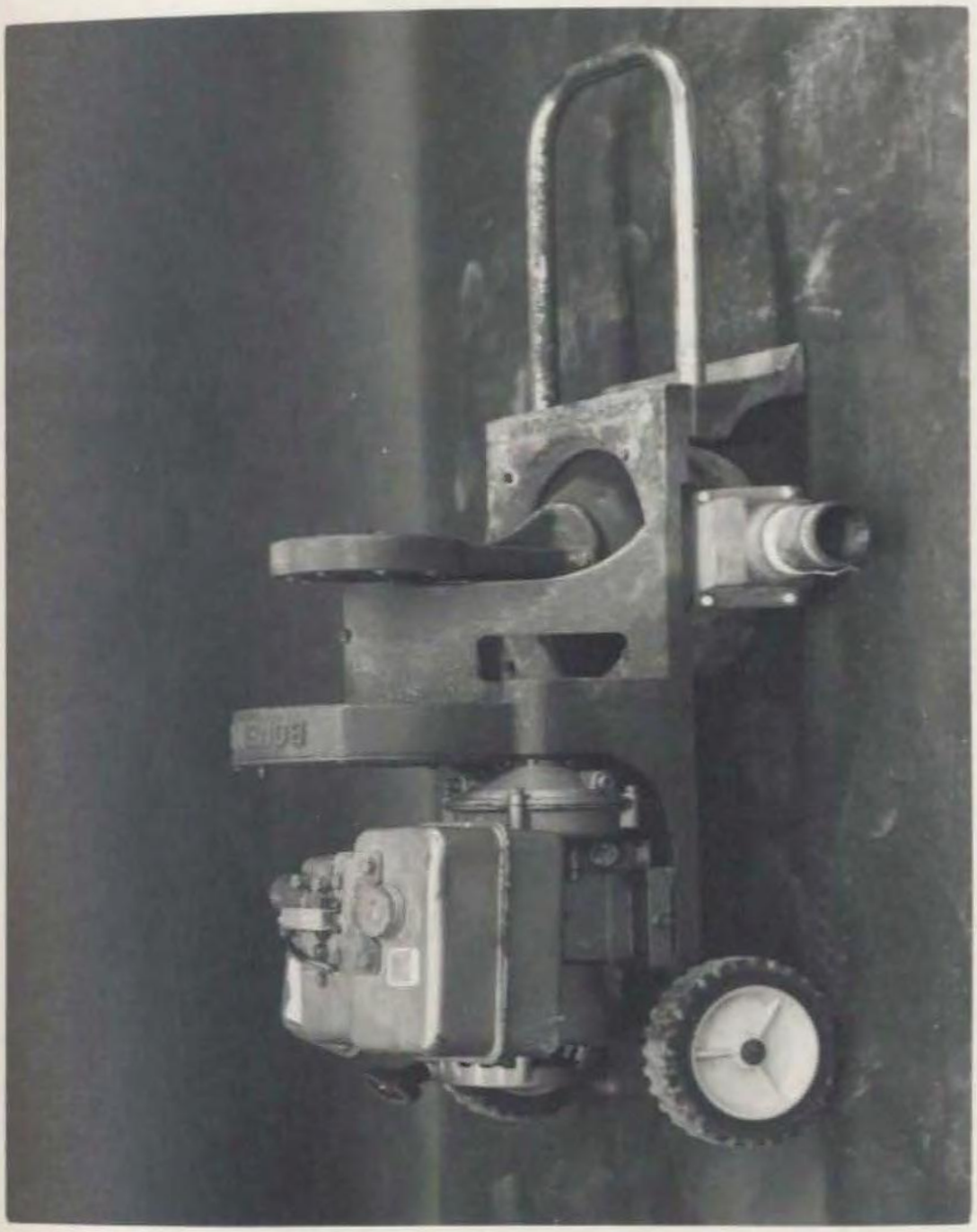


Figure 2.1 A side view of the surge-tank

a excess discharge outlet

b inlet from pump unit

c exit to filter-stack unit

d maximum head level

e minimum head level

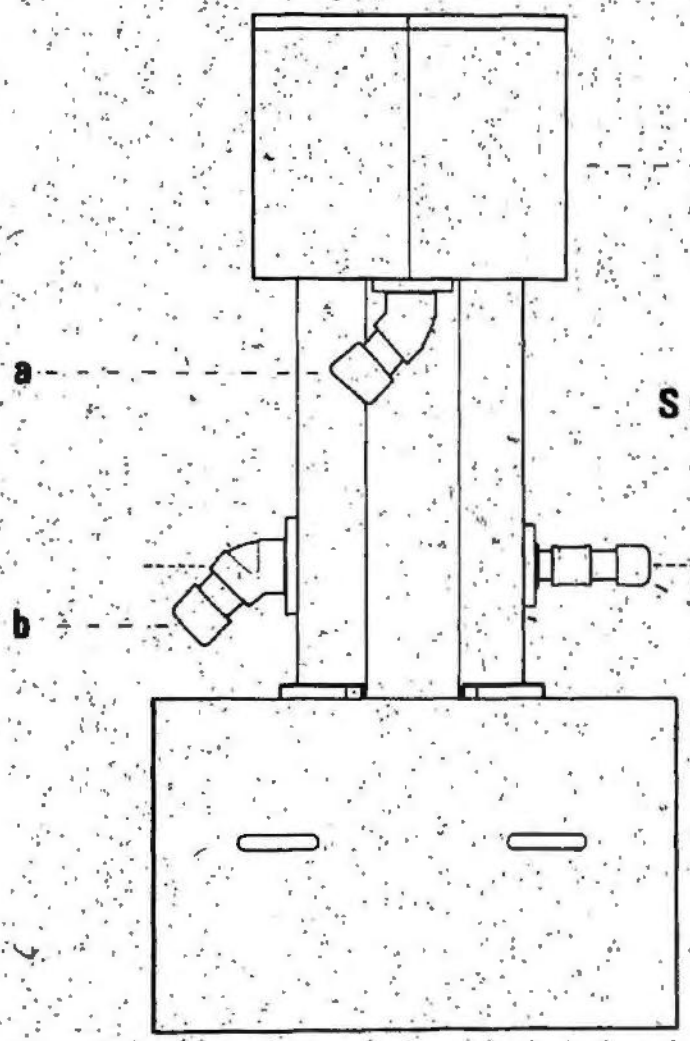

d
a
Surge-tank
e
b
c
Surge-tank
Base
25 cm

Figure 2.2 Top-view of surge-tank with cover removed

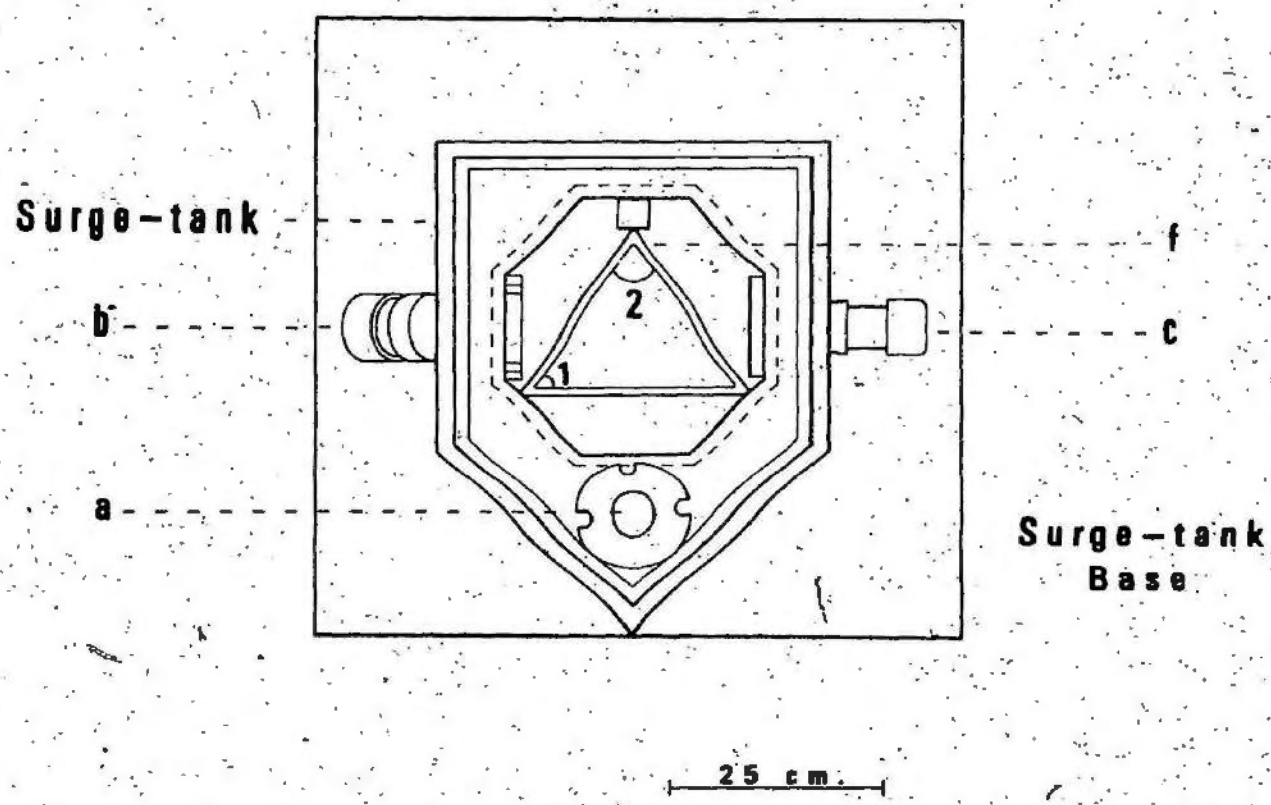
a excess discharge outlet

b inlet from pump motor unit

c exit to filter-stack unit

1 position of oxygen meter probe

2 position of salinometer probe


Surge-tank
b
a
f
c
2
1
Surge-tank
Base
25 cm.

This is the first function of the surge-tank.

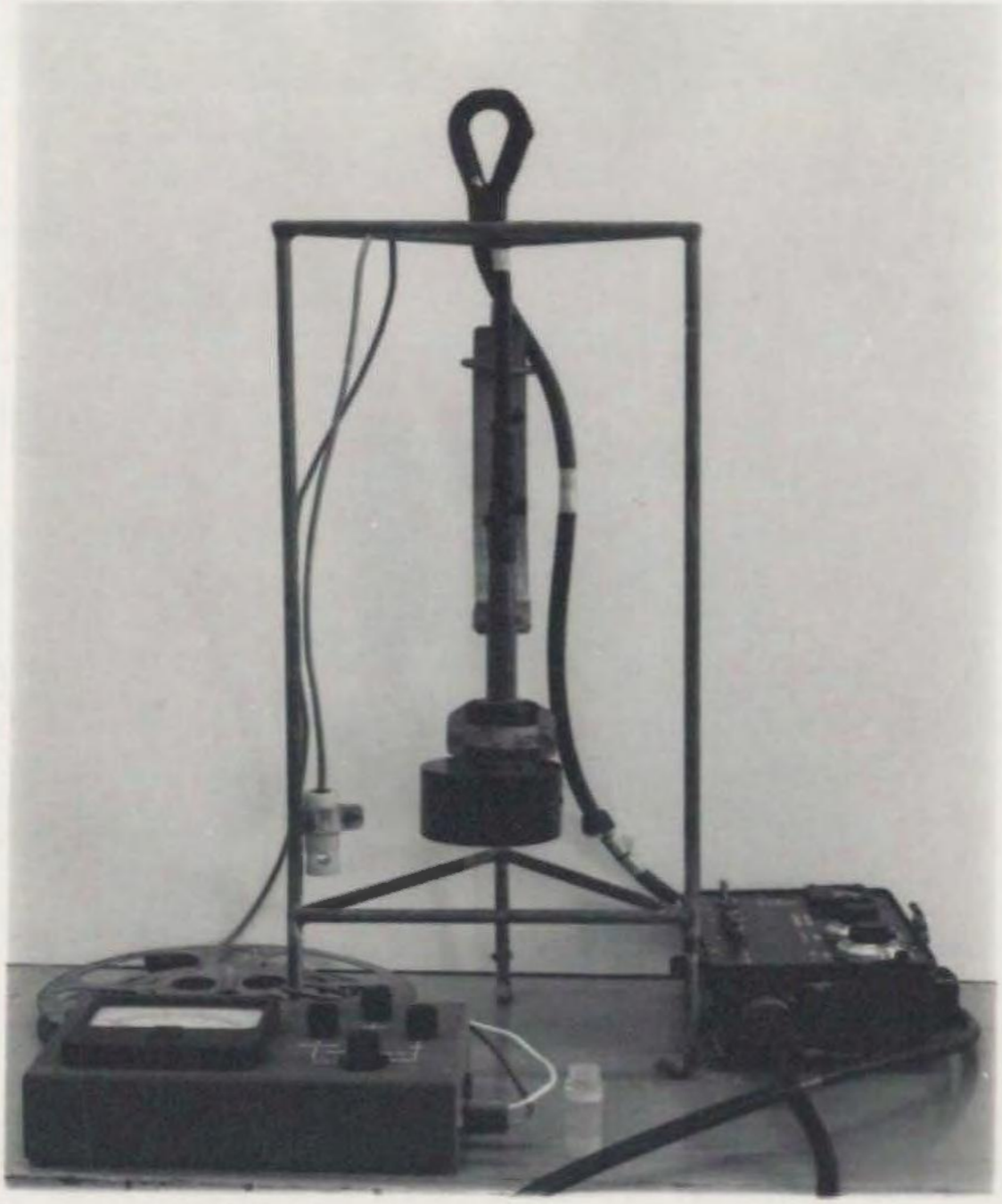
Located in the upper section of the tank is the excess discharge outlet a, Fig 2.1 and Fig. 2.2. Since water can discharge here it permits one to have the pump unit operating properly without affecting the filter-stack unit. This is also important because the water column which enters the intake hose as it is lowered must first be removed to avoid contaminating the sample with water from nearer the surface.

The third function comes from the fact that water pumped from below the surface is not normally exposed to atmospheric conditions. The tank, therefore, serves as a water bath for electronic physical and chemical sensors as well as a site for collecting water samples.

Environmental Sensors

Historically quantitative zooplankton studies have necessitated handling numerous, predominantly microscopic organisms one individual at a time. To insure a greater portion of time for zooplankton identification and counting, electronic sensors were used to provide direct read-out of temperature, salinity, dissolved oxygen and conductivity, rather than the standard chemical or mechanical methods. An RS5-1 induction salinometer from Industrial Instruments, Inc. was used to measure salinity, temperature and conductivity. A Model 54 BP Yellow Springs oxygen meter monitored dissolved oxygen. Both instruments are Hg battery powered. Photograph 2.2 and Fig. 2.2 show how the probes were supported. In Fig 2.2 the salinometer is at 2, the YSI, at 1. They are at the same level as the minimum head level, e, Fig. 2.1.

Photograph 2.2 Instrument probe rack with probes in position

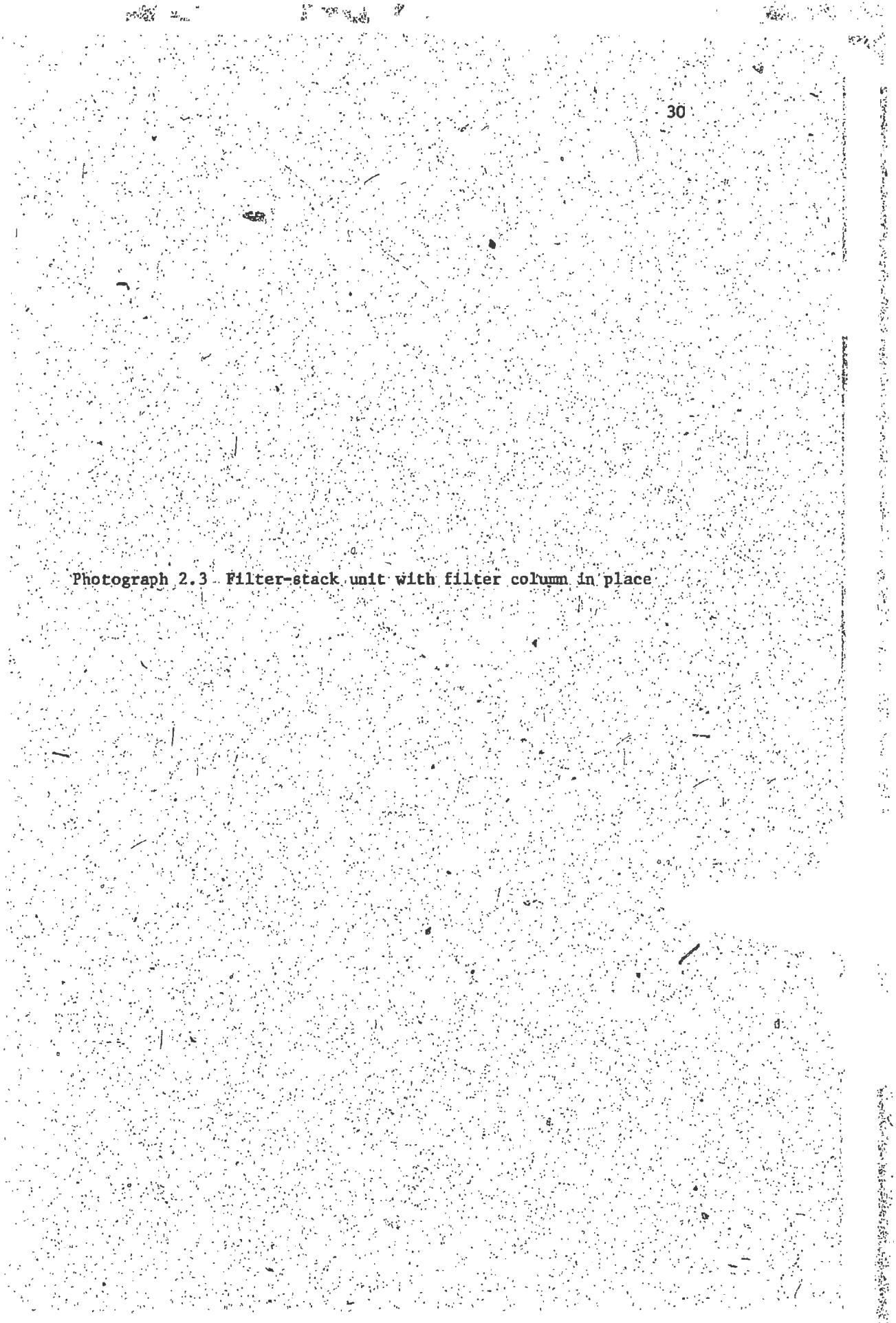


The Filter-Stack Unit

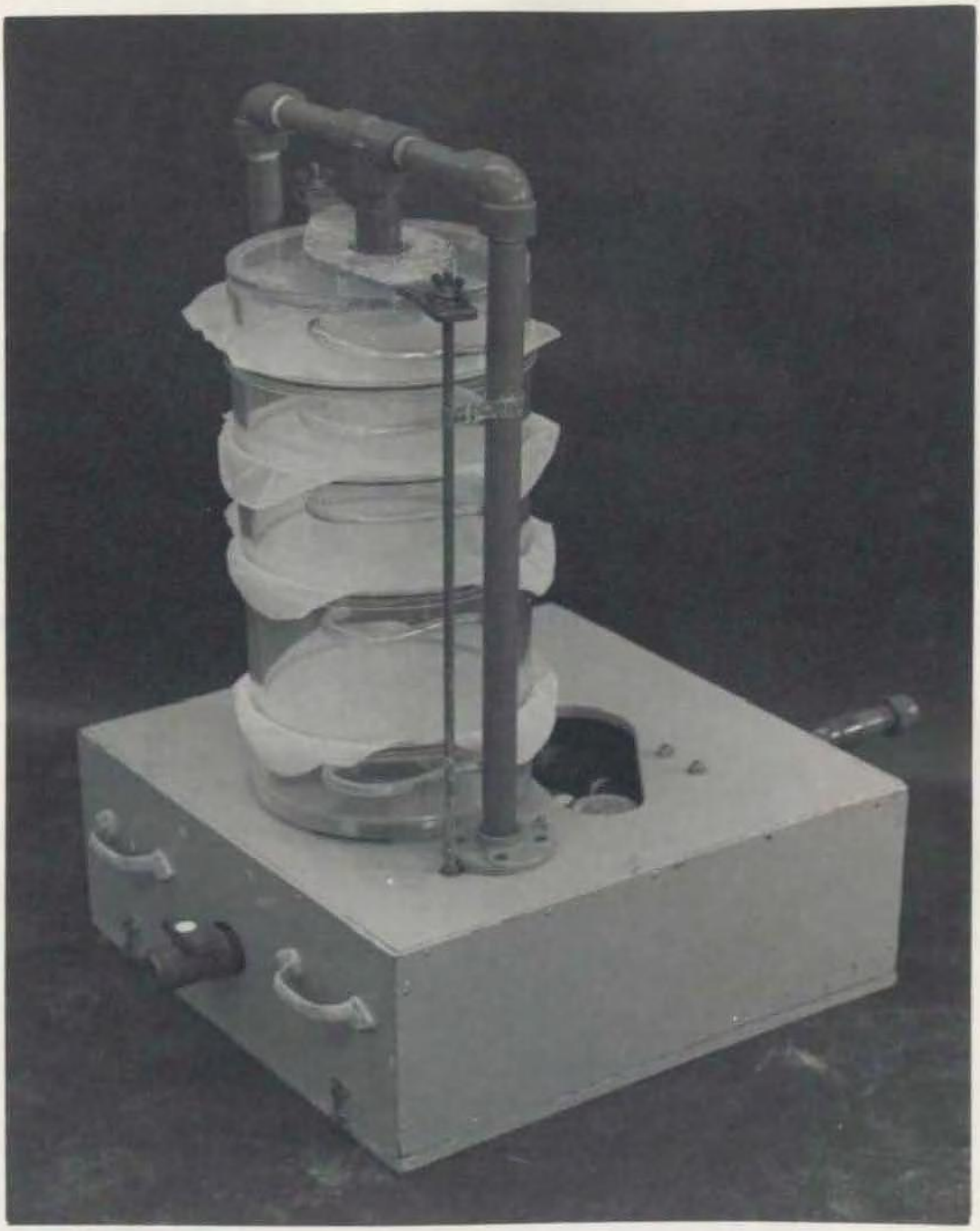
Perhaps the most important of the four functions of this modular component is collecting and sorting plankton on a sequential series of filters placed across a stream of water. The cylindrical column (Photograph 2.3) is the filtering device. The plywood base houses an arrangement of PVC pipe and fittings. The filter column (Photograph 2.4) constructed of 1.27 cm. clear acrylic can accomodate four filters (Fig. 2.3). Because it is a relatively fragile item the filter column is carried in an insulated case.

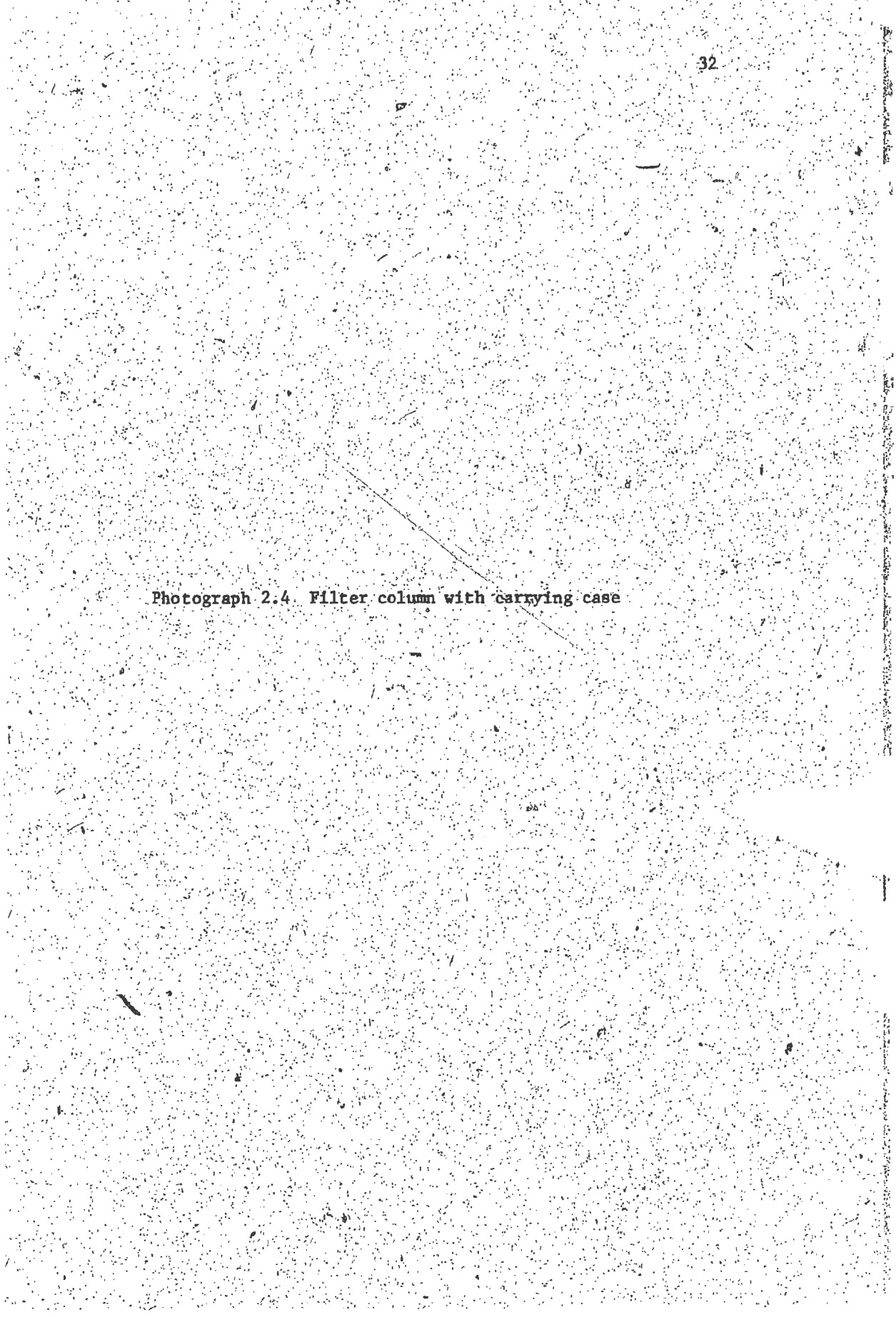
The filters of Nitex nylon bolting cloth were made as sets in each of which the 233μ filter has a plain weave, while the other three, 153μ, 80μ, 64μ, are monofilament with a simple locking weave. After some experimenting Dow Corning silicone sealant effectively bound the margin of the filter, thereby preventing fraying and distortion of the meshes. The sealant was flexible and salt water resistant. Each filter was colour coded by a small paint spot for easy recognition (Photograph 2.5).

To assemble the filter column the bottom section is placed on a rubber gasketed mounting around i, Fig 2.4 and is supported by rubber pads at j. This is followed by a filter and a section until all are in position. By tightening the winged-nuts on the filter clamp, e, each section firmly holds a filter in place. Installation of the filter column is completed when the coupling, f, Fig 2.4 is screwed down. The rubber ring at c. and e. Fig 2.3 with the gasket mounting around i, Fig 2.4, make water tight connections.



Photograph 2.3 Filter-stack unit with filter column in place





Photograph 2.4. Filter column with carrying case

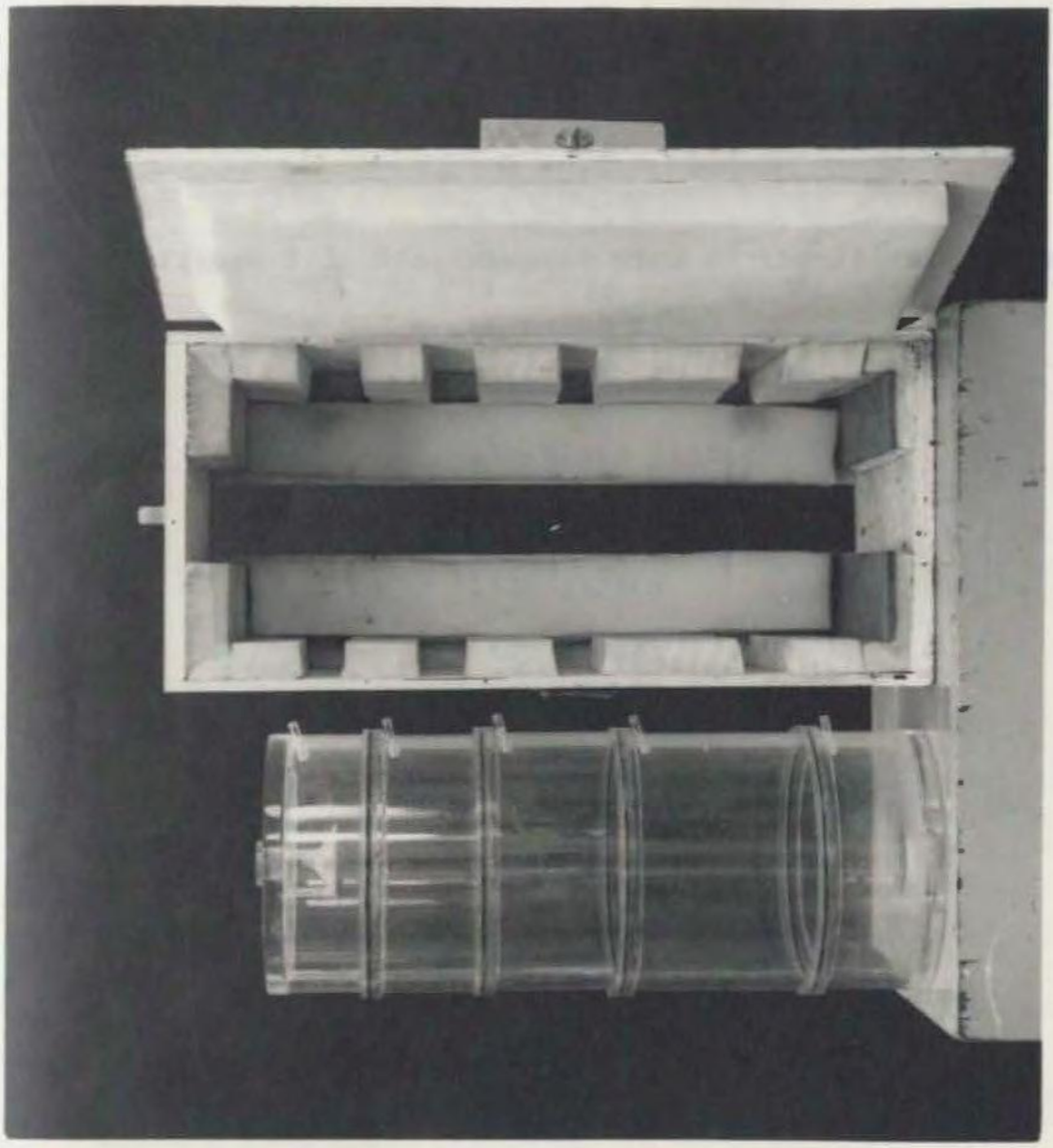
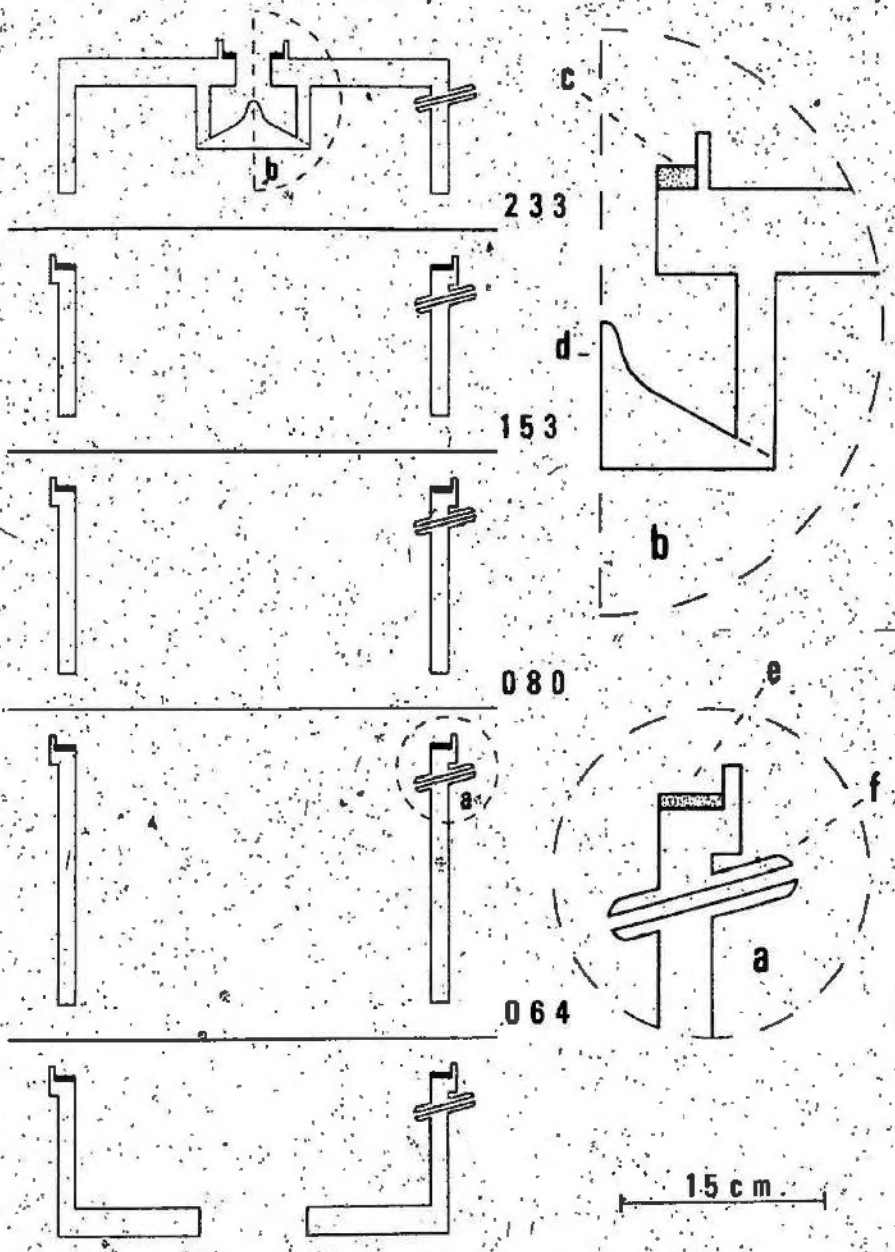
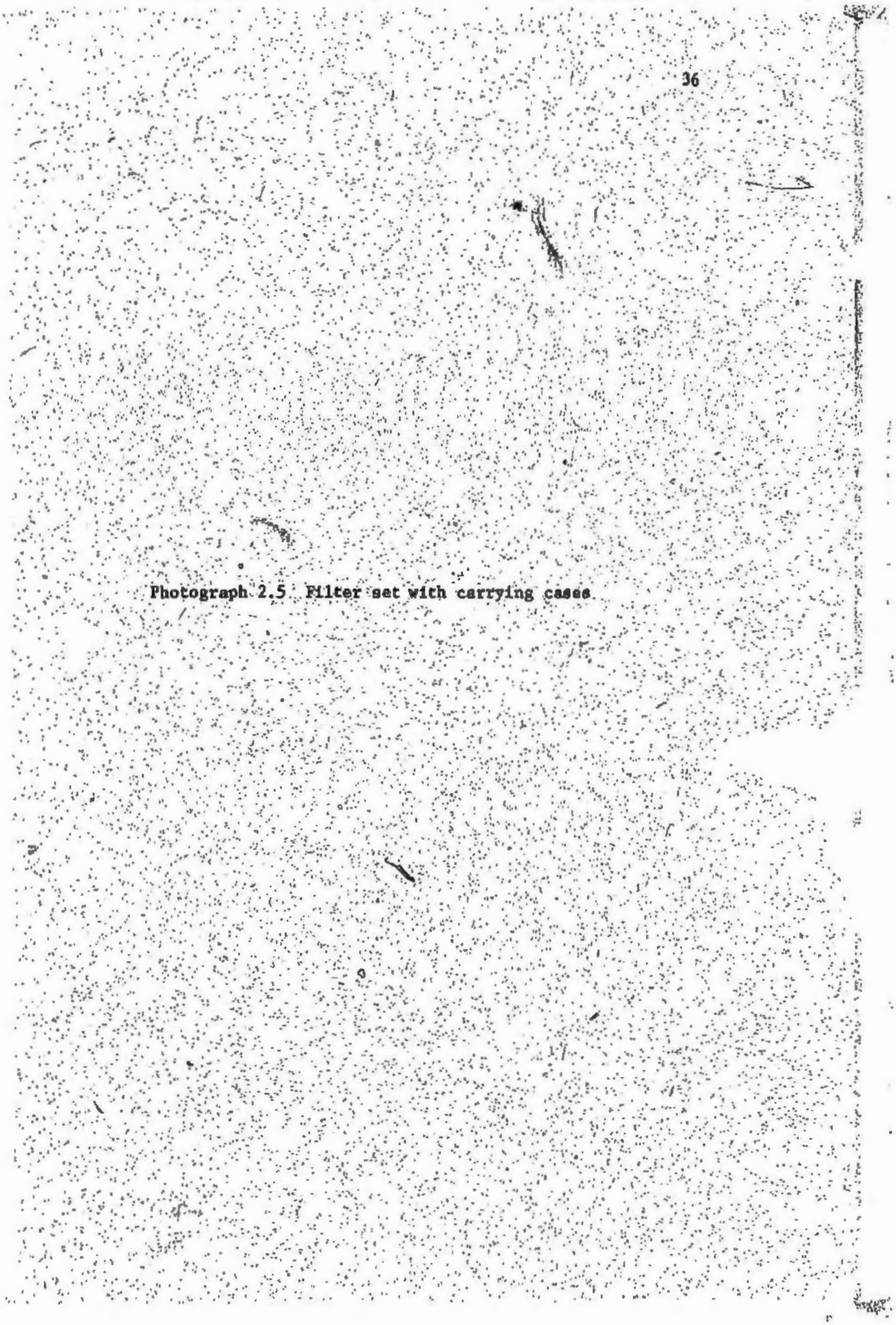


Figure 2.3 Diagrammatic view of the filter column

c and e	neoprene rings
d	deflector cone
f	air-bleed link
233	233μ filter
153	153μ filter
080	80μ filter
064	64μ filter


c
b
233
d
153
b
080
e
f
a
064
15 cm.



Photograph 2.5 Filter set with carrying cases

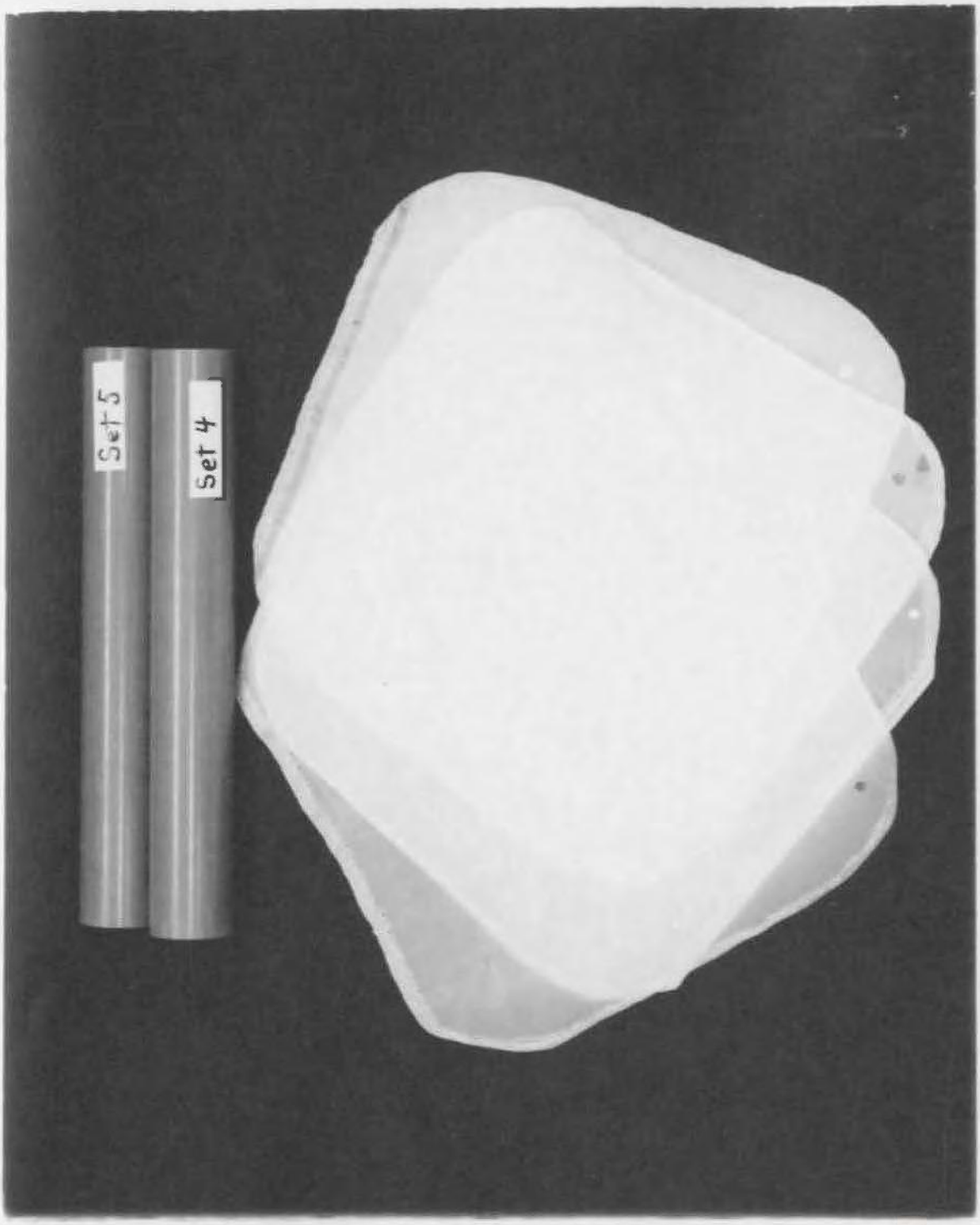

Set 5
Set 4

Figure 2.4 Scale drawing of filter-stack unit

a inlet

b water conduit

c internal plug

d air bleed conduit

e filter clamp

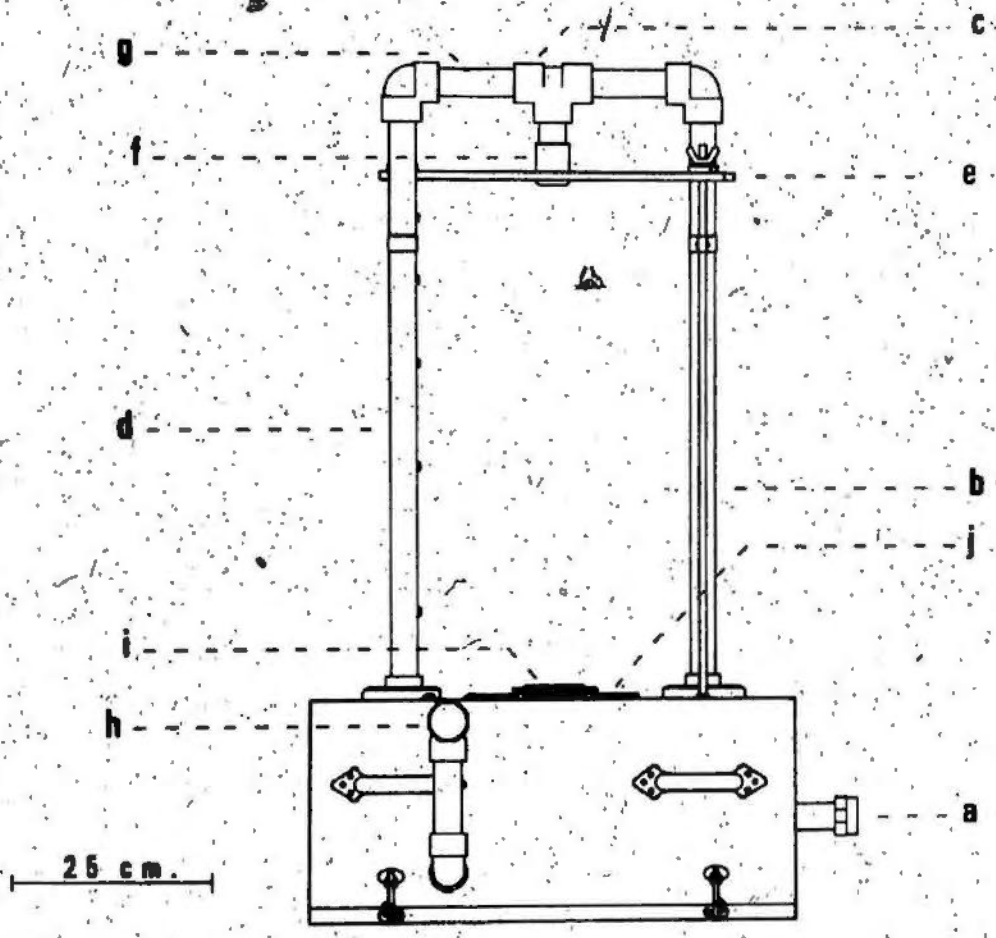
f coupling

g air bleed opening

h exit

i exit from filter column

j neoprene mat


g
c
f
e
d
b
j
i
h
a
25 cm.

Water enters at a, Fig 2.4. Until the pump unit, the surge tank unit, and the environmental sensors are working properly and the system has been flushed the valves at l and k, Fig 2.5, are closed. To make the filter-stack unit operational only the valve k is opened. Water then passes through k to rise up through the vertical pipe, b, (Fig 2.4). A plug at c, Fig 2.4, in the tee diverts water down through f to the filter column and the deflector cone d, Fig 2.3, distributes it over the first filtering surface. After passing through the filters, it exits via i, Fig 2.4, and passes through the water meter at m, Fig 2.5, to exit from the unit at h, Fig 2.4.

While the right hand pipe, b, Fig 2.4, carries water, the opposite one, d, is part of an air bleed linkage. It is connected to each section of the filter column by a short piece of detachable flexible tubing. A small opening at g, Fig 2.4, maintains atmospheric equilibrium in the column and allows the filtering to proceed by gravity flow. This is the second function of the filter-stack unit.

The third function, measuring the volume of water filtered, is accomplished by the water meter. It is a Neptune, Type S, cold brine industrial meter, bronze, with a simple horizontal totalizing non-resettable register. To avoid trapping air which would cause incorrect registration the meter is seated lower than the rest of the plumbing. Additional care was taken during transportation. In winter antifreeze was added to the water to prevent ice damage to the meter's mechanism.

The fourth and final function of the unit is provided by a ball valve at n, Fig 2.5. This allows one to take a subsample of filtered water for phytoplankton analysis.

Figure 2.5 Diagrammatic scale drawing of underside of filter-stack unit

a inlet

b water conduit

d air bleed conduit

h exit

i exit from filter column

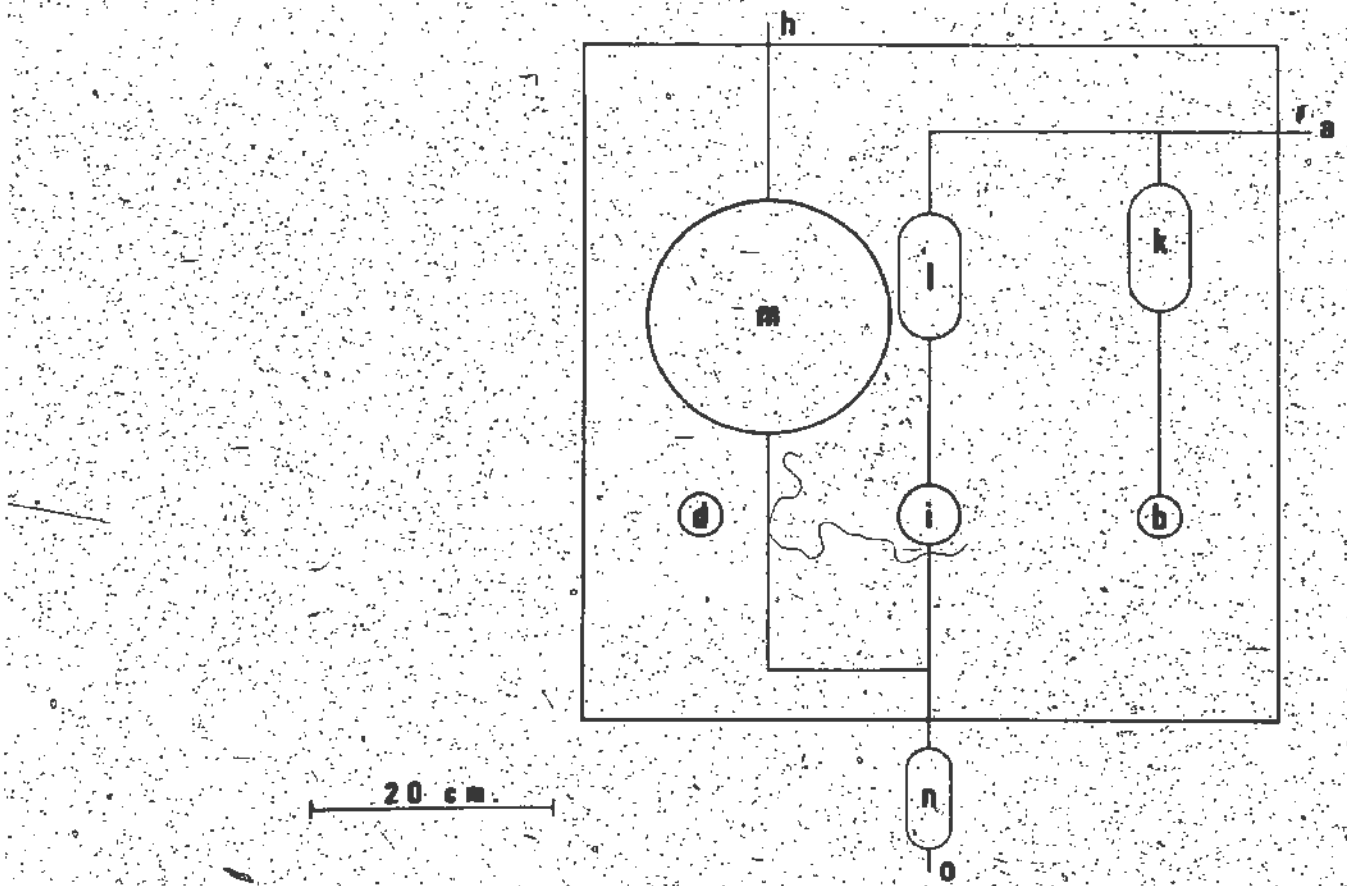
k inlet valve

l by-pass valve

m water meter

n sub-sampling valve

o sub-sampling outlet


h
a
m
l
k
d
i
b
n
o
20 cm.

Just how these three units and the environmental sensors form the core of the PAEDS is perhaps best explained by Fig 2.6. The specifications of each hose section connecting the three units are given in Appendix 6.

The Air Spray Unit

The air-spray unit (Photograph 2.6) was used to clean the filters and to wash remaining plankton from the net after each sampling. A 6.5 m^3 capacity cylinder, d, supplies air to a CGA 501 DeVilbiss Spray Gun, c. Air passes into the reservoir, e, and forces filtered sea water up into the gun where water and air mix to form a spray. Long hoses allow the operator to work away from the pressurized vessels.

The reservoir, an experimental pressure vessel, consists of a 22.7 litre, polyethylene, Nalgene carboy fiberglassed inside a discarded chemical shipping container. Although the reservoir withstood a test pressure of 2.8 kilograms per square centimeter, the best spray pattern was produced at 1.4 kilograms per square centimeter. In its present form it does not meet this Province's standards code for either metal pressure vessels or fiberglass-reinforced plastic pressure vessels.

After sampling, the top filter was attached to the holder, a, and then inverted over the filter cleaning stand, b. The plankton were washed off the filter by back-spraying. Before each section of the filter column was removed, the filter below it was attached to the filter holder, and the balance of the operation for each filter was as described for the first.

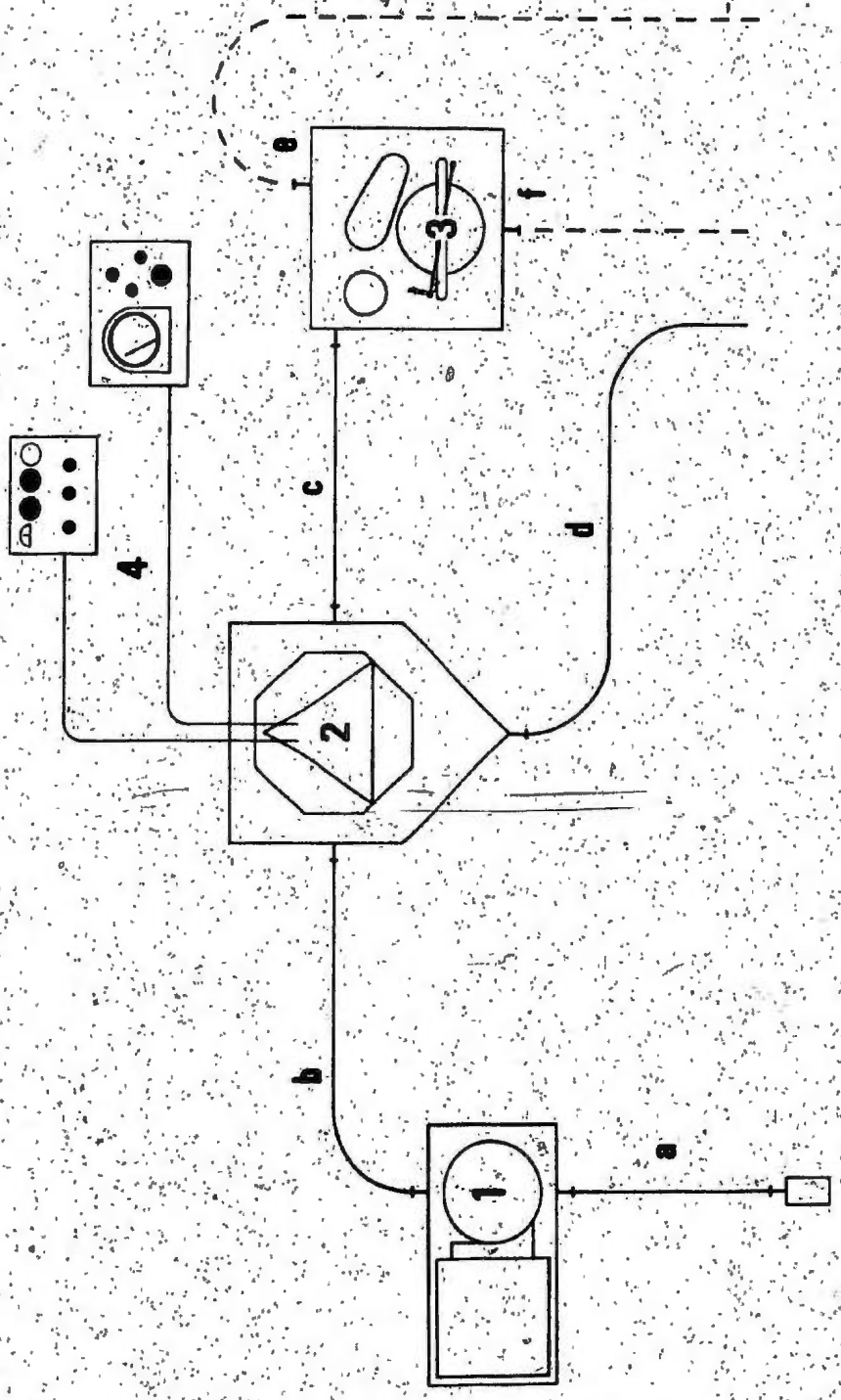
Figure 2.6 PAEDS Flow diagram

1 Pump unit

2 Surge-tank unit

3 Filter-stack unit

a-f hoses (See Appendix 6)


a
f
3
4
c
d
2
b
1
a

Photograph Number 2.6 Air-spray unit.

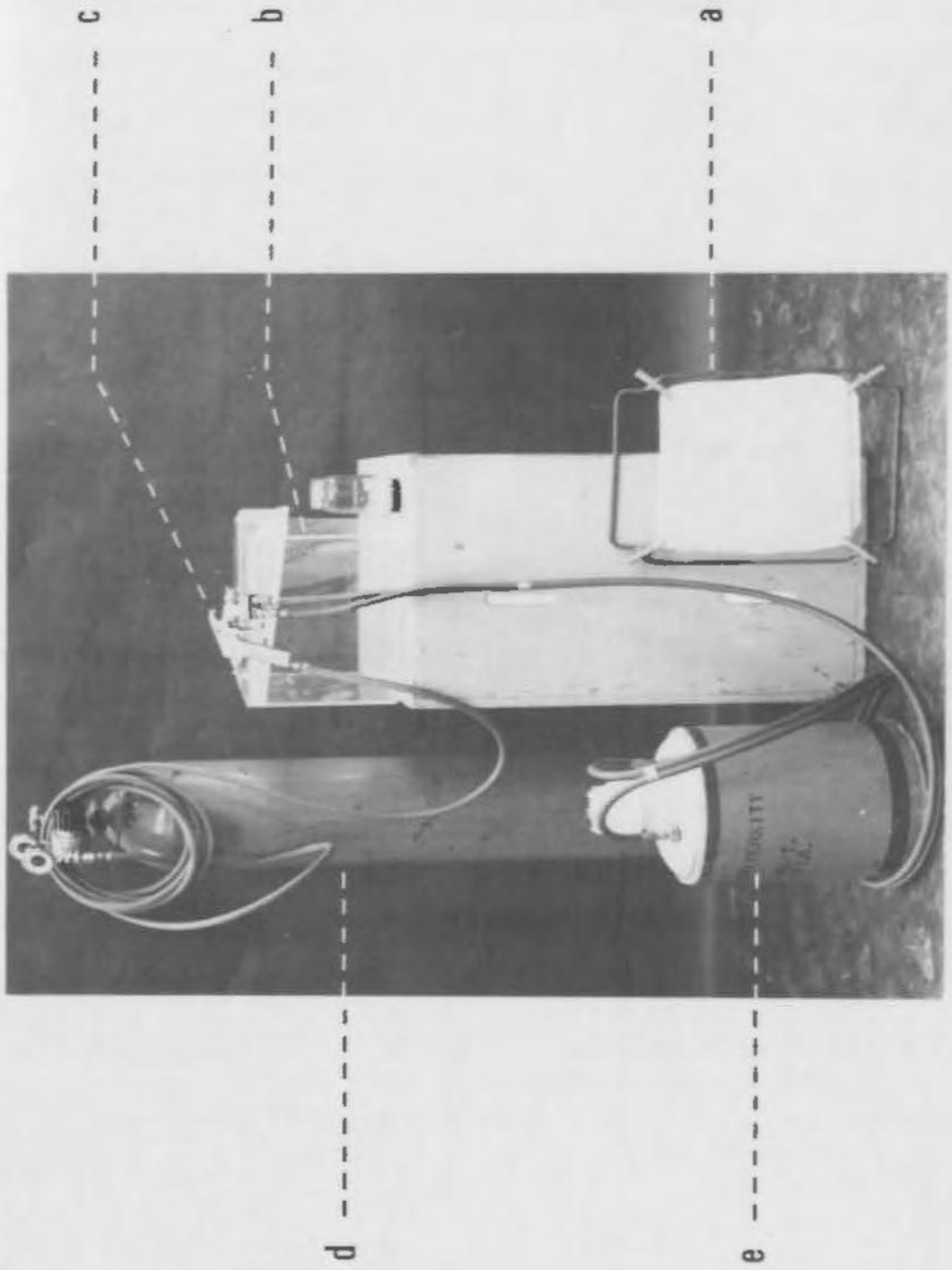
a filter holder

b filter cleaning stand

c spray gun

d air cylinder

e water reservoir


c
b
a
d
e

Prior to a field trip the reservoir was filled with filtered sea water. Coastal water from a sea water tap was passed through a Honeycomb Filter Tube W17R10-AV which has a nominal particle removal rating of 15μ, much smaller than the smallest mesh filter used in the filter column. This insures that the zooplankton samples to be taken will not be contaminated.

Support Components

The quality of portability in the PAEDS depends on its modular construction, the means of land transport and the sea transport. The first has been described. Transportation to Arnold's Cove was accomplished through use of the Biology Department's vehicles and rented vehicles. Of these the Econoline type was the best. The M.V. Winnifred Shirley (Frontispiece), a long-liner fishing boat out of Arnold's Cove, Placentia Bay, provided sea transport. Its afterdeck provided ample room for the pump unit, surge-tank unit, and hoses.
The encloaed work area behind the pilot house provided protection for the filter-stack unit, the instrument packs and the filter-cleaning operation.

The field equipment utilized to monitor electronic sensors was: for temperature, a total immersion thermometer with accuracy to 0.1°C; for salinity and conductivity, water samples were collected in numbered hard glass, 8 oz. prescription bottles, and for dissolved oxygen, water samples were collected in 300 ml. B.O.D. bottles.

A checklist of all the items required for operation of the PAEDS is given in Appendix 7.

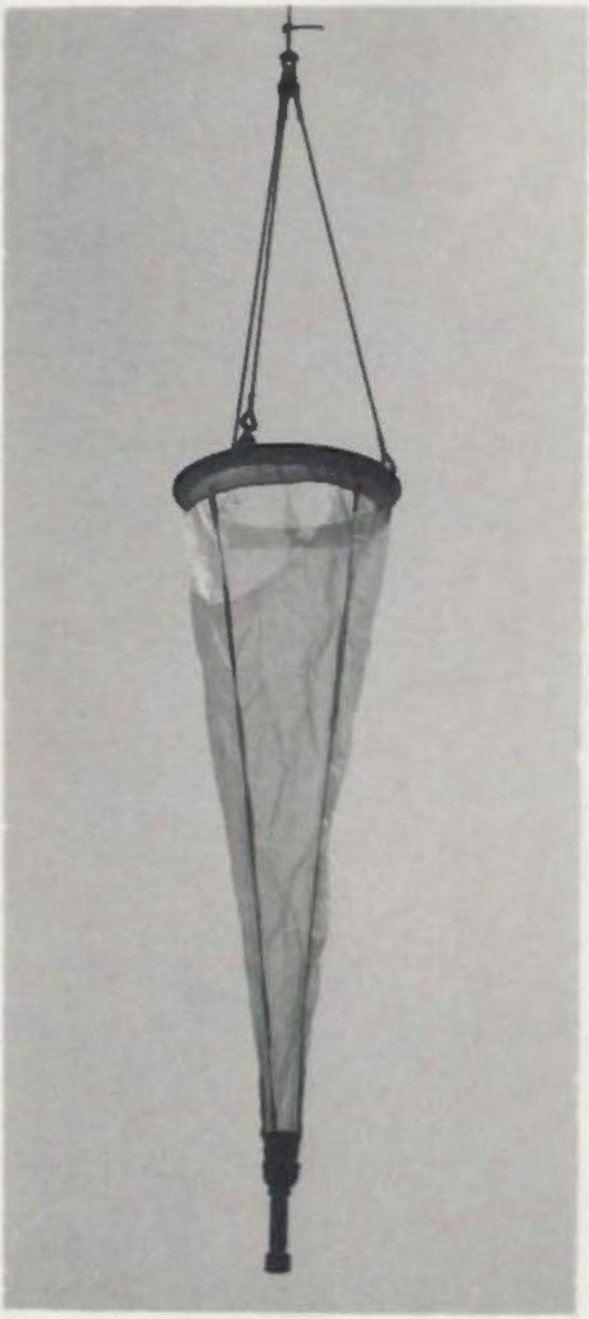
PAEDS Hydrodynamics - Theoretical Aspects

Based on the pump's rated hourly capacity of $9.84m^3$, the minimum required size of the surge-tank is $2.73 \times 10^{-3}\ m^3$. Its final size was determined by the need to provide a water bath for the electronic sensors. Water enters it at $2.73 \times 10^{-3}\ m^3$/ sec. and exits through ports capable of handling $4.73 \times 10^{-3}\ m^3$/sec. In the equation for relative roughness (Appendix 5, Equation 3), ε is assumed to be equivalent to that of copper pipe, that is, $\varepsilon = 5.0 \times 10^{-6}$ (Diagram A-2, Giles 1962) and the kinematic viscosity, $\gamma = 1.664 \times 10^{-5}$, the value for fresh water at 40°F (Table C.1, Streeter 1966). If the flow of water is $2.73 \times 10^{-3}\ m^3$/sec., the head loss for the 55.23 meters of intake hose (Appendix 6, a) is 12.02 meters. At 75% efficiency the theoretically required horsepower is approximately 0.75. The motor supplied with the Edson "Bone Dry" Pump is therefore quite adequate for maintaining a flow of sea water to the surge-tank. Throughout other units of the PAEDS water flows by gravity.

2.2.2 Half-meter net

A 0.5m diameter, conical net (Photograph 2.7) with the filtering portion made of 233μ mesh size Nitex nylon bolting cloth was manufactured locally. Except for the bolting cloth the required materials were obtained locally. This version of a standard plankton capturing device has mesh area 1.4 sq.m. and a radius to length ratio 0.124 (Smith *et al.* 1968)

Photograph No. 2.7 0.5m. Plankton Net.



2.3 Evaluation Procedures

Assessment consisted of an integration between the laboratory and field phases. One phase was designed to compliment the other. The laboratory evaluation began before the field evaluation and continued afterwards. The field aspects consisted of eleven field trials during any one of which two or more experiments were in progress.

2.3.1 Physical Parameters

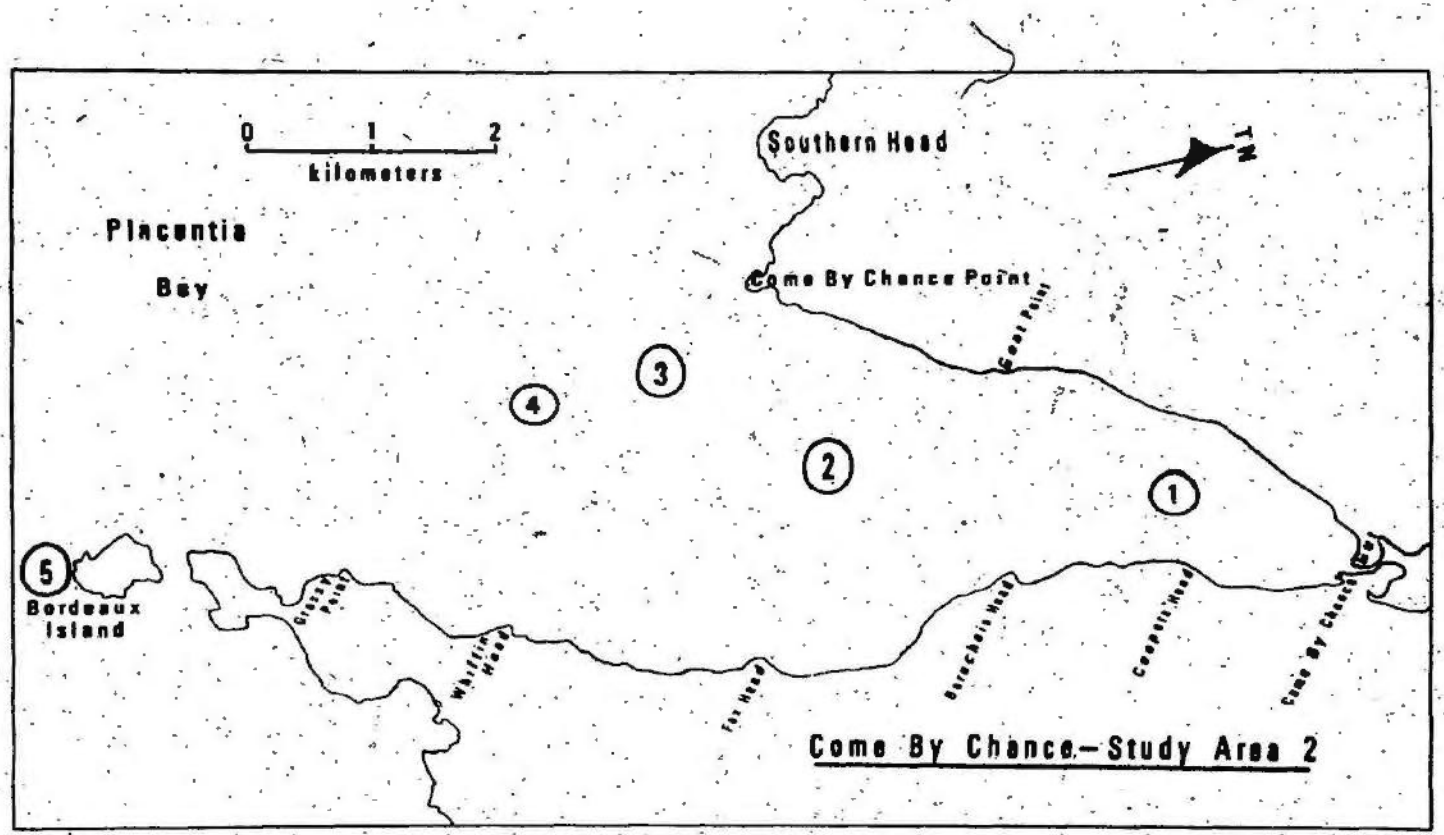
Selection and marking of sampling stations

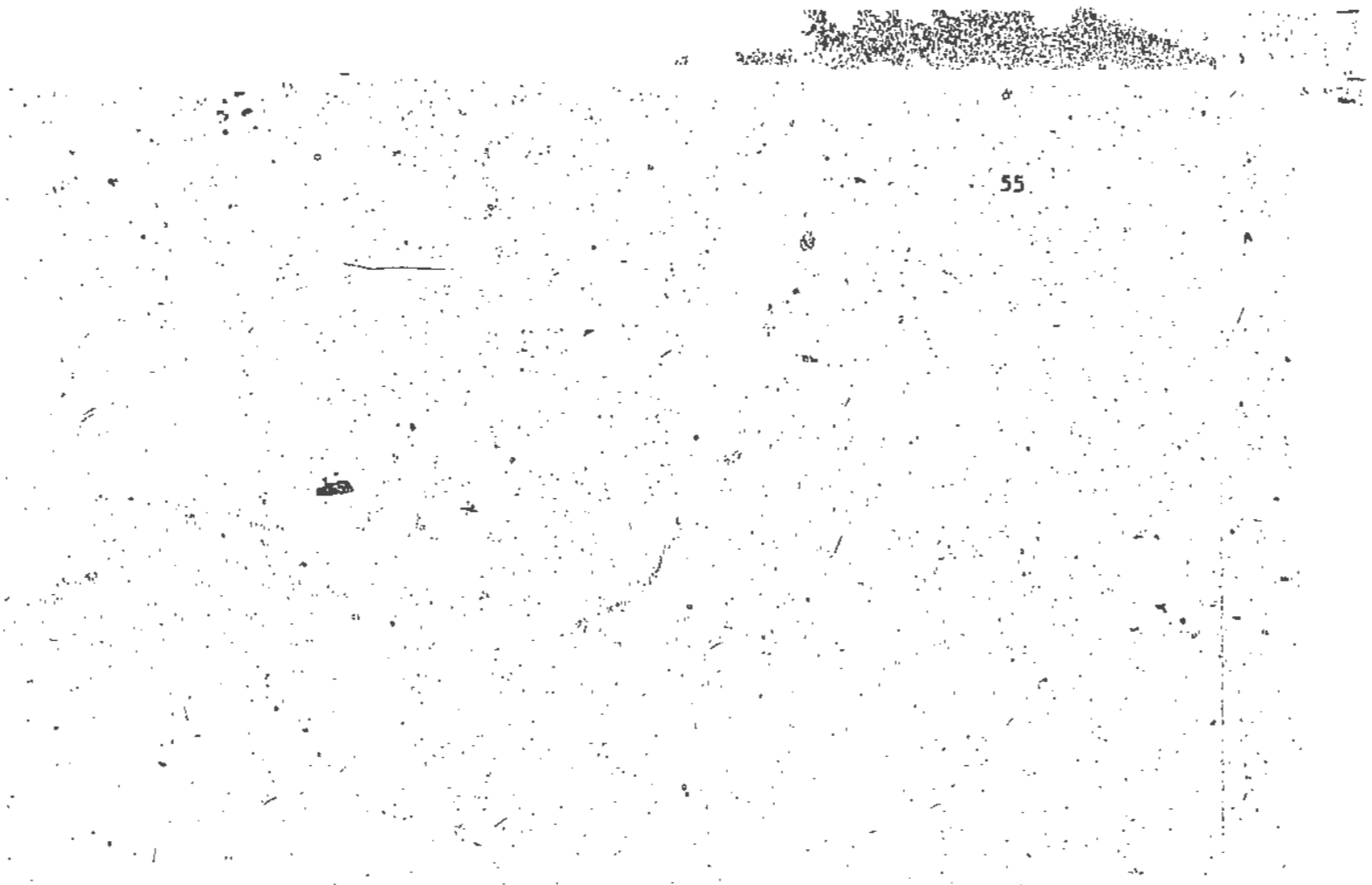
At Come by Chance (Map 2.2) five stations were selected in seaward order using the ship's compass and depth sounder. By tying the stations in with prominent landmarks, locating them thereafter involved bringing the boat to the points of intersection. Stations 1, 2, 3 and 5 were occupied during the PAEDS field trials. At the Swift Current-Black River estuary (Map 2.3) only Stations 12 and 15 were sampled for this project.

Sensor evaluation - Conductivity/Salinity

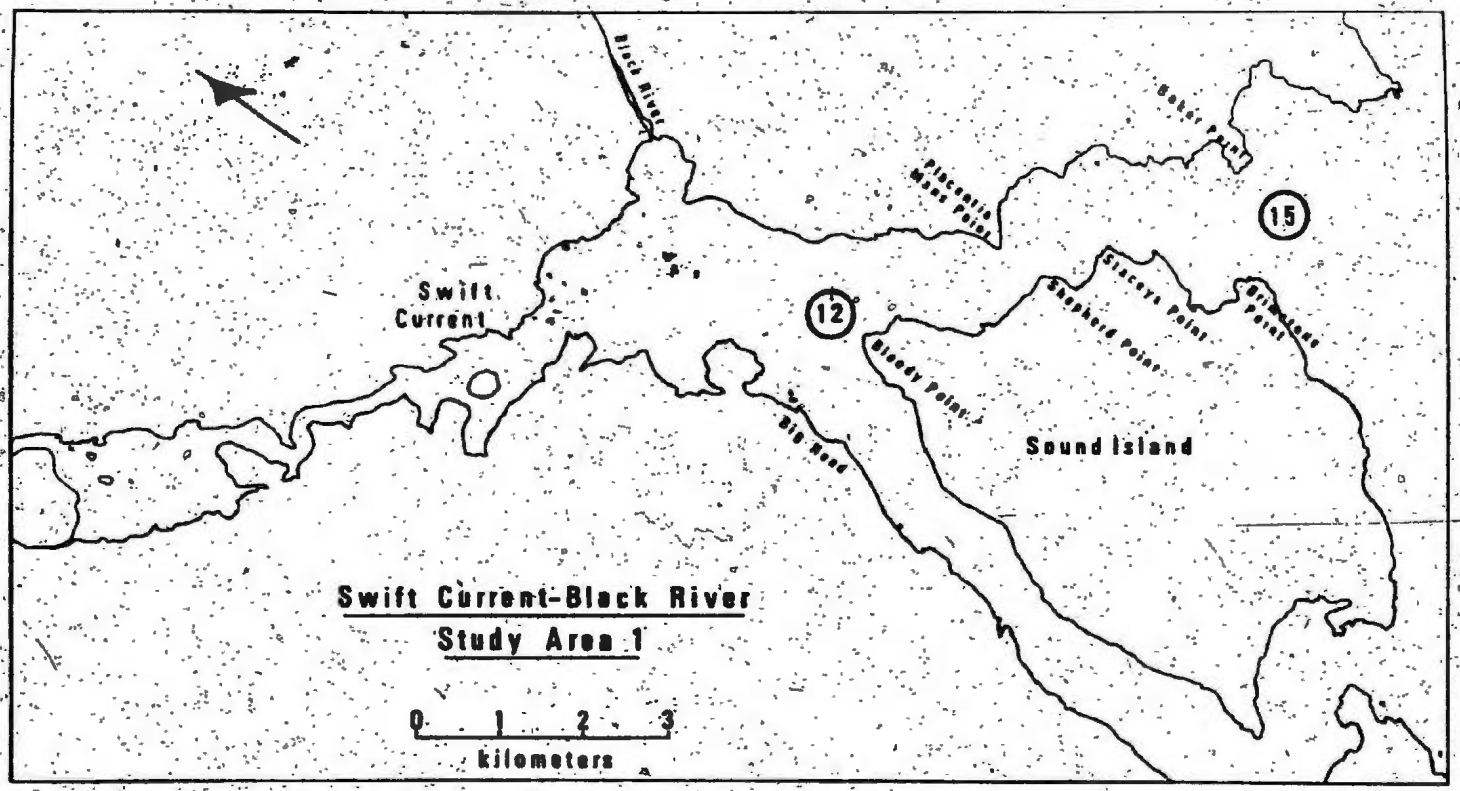
The use of an induction salinometer in a confined place such as the surge-tank can result in interference in the sea conductivity loop. Water turbulence in the tank necessitated securing the sensor probes. The instrument probe rack introduced another possible source of interference. However since the surge-tank was of plywood and fiberglass construction, it was hypothesized there would be negligible hinderance in the operation of the salinometer in the PAEDS. To test the validity of this assumption four laboratory experiments (Experiments C/S-1L to C/S-4L) and two field experiments (Experiments

Map 2.2 Come by Chance sampling stations


0 1 2
kilometers
Placentia
Bay
Southern Head
Come By Chance Point
Goat Point
3
4
2
1
5
Bordeaux
Island
Gravelly Point
Whitten Head
Fox Head
Burrchois Head
Cooper's Head
Come By Chance
Come By Chance—Study Area 2



Map 2.3 Swift Current-Black River sampling stations


Black River
Placentia Head Point
Baker Point
15
Swift Current
12
Shepherd Point
Slacora Point
Bloody Point
Big Head
Sound Island
Swift Current-Black River
Study Area 1
0 1 2 3
kilometers

C/S-1F and C/S-2F) were completed. In the laboratory the surge-tank was kept full with a continuous flow of sea water, at ambient temperatures, with one exception. The conductivity sensor of the salinometer was tested against a Radiometer CDM 2e conductivity meter. In Experiment C/S-1L the salinometer probe was attached to the instrument probe rack, calibrated with a known resistance and placed in position in the surge-tank, with the conductivity meter probe. Conductivity values for Experiment C/S-2L were recorded under the conditions given in Table 2.1.

Table 2.1

Conditions for Experiment C/S-2L

Data Set No.	Description
	Salinometer
A1	The probe in position on the instrument probe rack in the surge-tank.
A2	The probe in a plastic bucket supplied with a continuous flow of sea water.
	Conductivity Meter
B1	The probe in the surge-tank.
B2	The probe in a sample of water from the surge-tank.
B3	As in A2.
B4	The probe in a sample of water from the plastic bucket.

Experiment C/S-3L was like Experiment C/S-1L except that the conductivity meter's readings were for water samples from the surge-tank. The last

laboratory experiment, Experiment C/S-4L, was designed to test for possible interference over a temperature gradient and an electrolyte gradient. A hot freshwater line was introduced in the sea water line to the surge-tank.

The field evaluation of the salinometer in the PAEDS involved two experiments. The first, Experiment C/S-1F followed Experiment C/S-1L and was designed to explore interference under field conditions. The procedure consisted of taking a conductivity reading with the salinometer probe in position in the surge-tank and then with it held adjacent to the submerged hose intake valve. In the second field experiment (Experiment C/S-2F) water samples were collected during the eleven field trials. In the laboratory the specific conductivity of each was measured using the conductivity meter. Salinometer readings recorded under variable field conditions were standardized using the chart Electrical conductivity of sea water produced by Martek Instruments Inc., California.

Sensor Evaluation - Dissolved Oxygen

The laboratory evaluation of the Yellow Spring Instruments oxygen meter consisted of one experiment, Experiment DO-1L, to test the instrument against the classical Winkler procedure. After calibration the instrument's probe was placed in a 1000 ml beaker containing the testing medium. The testing media were as given in Table 2.2. When the YSI reading was completed a sample was collected for Winkler analysis (Strickland and Parsons, 1968).

Table 2.2

Testing Media for Experiment DO-1L

Observation pair	Characteristics
1	Filtered sea water at room temperature
2	Cold fresh water at room temperature
3	Fresh water at room temperature
4	Cold fresh water at room temperature

To facilitate use of this instrument the probe was prepared prior to each field trip. Upon completion of the manufacturer's instructions for preparation, a small acrylic cylinder was attached, filled with distilled water, capped and the sensor guard was attached (Photograph 2.8; a, b, c, respectively).

Two experiments were done to evaluate the field accuracy. In the first, Experiment DO-1F, a comparison was made between the YSI reading at the surge-tank and at the hose intake. In the second, Experiment DO-2F, B.O.D. bottle samples collected from the surge-tank during PAEDS field trials 5,7 and 8 and "pickled" in the field were titrated by the Winkler method (Strickland and Parsons 1968).

Sensor Evaluation - Temperature

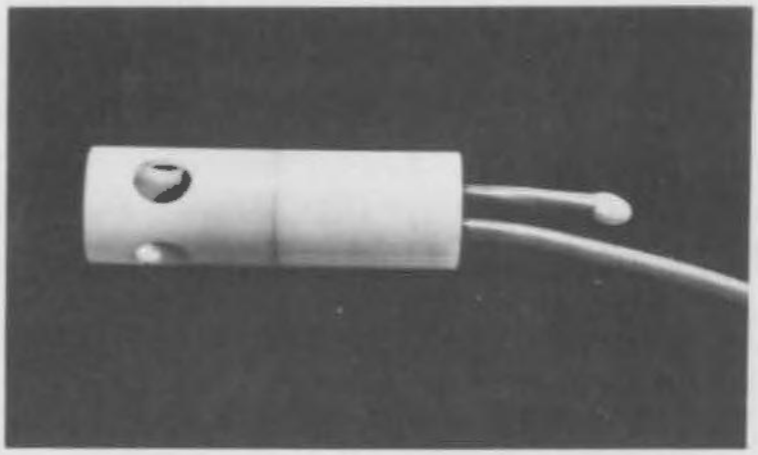
Since the salinometer and the dissolved oxygen meter are capable of recording temperature, assessment of this aspect entailed comparison of one with the other and verification with a hand-held thermometer. The laboratory evaluation, Experiment T-1L, was run simultaneously with Experiment C/S-1L. The field experiment,

Photograph 2.8 Oxygen meter probe and adapter

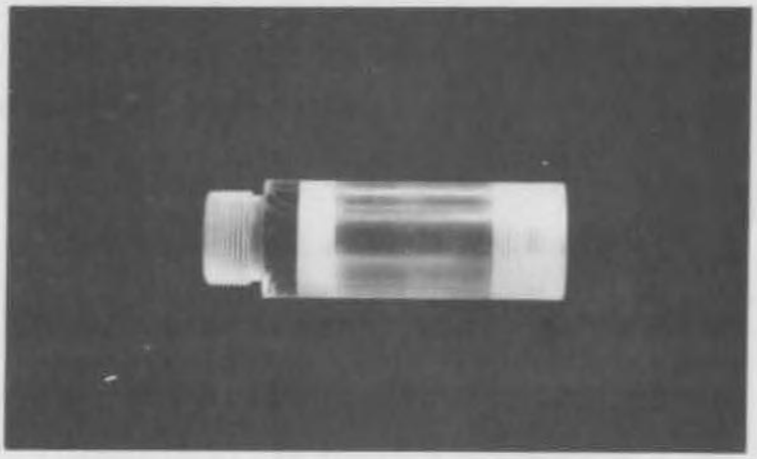
a probe

b adapter

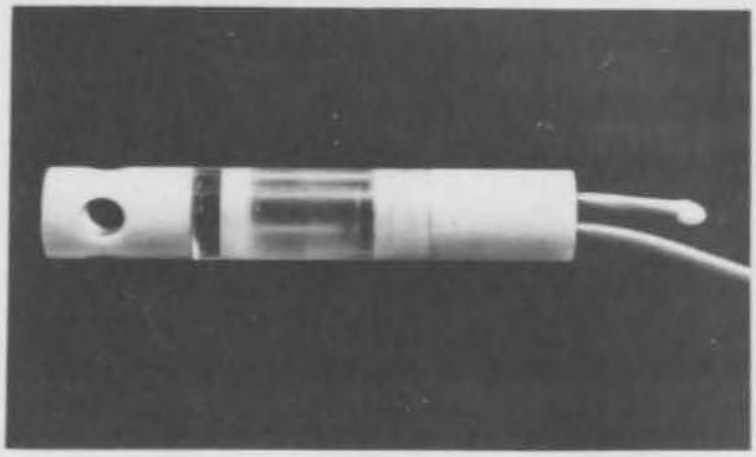
c probe with adapter in position



a



b



c

Experiment T-1F, consisted of 10 pairs of field observations. In it the YSI is compared with the salinometer only.

Meter Calibration

Although the manufacturer's agent stated that the accuracy of the Neptune industrial meter was well within 1%, it was tested against a known volume of water to determine its accuracy in the PAEDS. In this experiment, Experiment MC-1L, the filter-stack unit was coupled to the surge-tank and the latter was repeatedly filled and drained by gravity thus duplicating conditions in the field for operation of the meter.

Air-spray Unit Assessment

The air-spray unit described earlier was a second attempt, the first being very ineffective. To evaluate the present design Experiment AS-1F was completed during the last five field trials. Three unused filter sets were employed for routine sampling. After normal back-spray cleaning, each filter when returned to the laboratory was placed, filtering surface side up, over a board in which eighty 4.6mm diameter holes had been drilled and numbered consecutively. Twenty fields were selected by a random numbers table. Each of the selected fields was examined and the number of plankton remains seen was recorded. The plankton count for each filter in a set is compared with the total plankton count for the PAEDS field trial in which it was used. Since plankton counts were not made of the PAEDS field trial 7 for reasons given later, no values are available for Set 2 and partial values are given for Set 1, however, those for Set 3 are complete. This experiment was designed to test two hypotheses. It is generally

observed the more often a filtering surface is used the more plankton will be entangled in it. If the method of filter cleaning here used is not effective it should be evident from this experiment. Furthermore the number of planktonic organisms retained should be insignificant in relation to those in the entire station plankton sample.

PAEDS Station Procedure

The procedure for collecting physical data with the PAEDS was varied because of the evaluation experiments. However these modifications were imposed on a series of steps. These steps are given in Appendix 8, the standard PAEDS sampling procedure. Table 2.3 lists the PAEDS field trials during which this format was followed.

Table 2.3

Stations sampled by standard PAEDS sampling procedure

PAEDS Field Trial	Study Area	Station Number	Sampling Depth
1	1	1	surface
3	1	5	surface
4	1	1	surface
4	1	1	5 meters
5	1	1	surface
5	1	1	5 meters
7	2	12	surface
7	2	12	5 meters

2.3.2 Biological Parameters

Field Zooplankton Sampling and Handling Procedures

As stated earlier modifications were imposed on some stages of the standard PAEDS sampling procedure. The variations were necessary to determine the zooplankton sampling efficiency of the system and are embodied in three field experiments. The first, Experiment Z-1F, was completed during PAEDS field trial 4 and sought to determine if there were any major differences in the numbers and kinds of planktonic organisms retained by the 233μ mesh filter in the filter stack unit and the 0.5m, 233μ mesh plankton net held beneath the excess discharge hose. Experiment Z-2F compares the 233μ mesh filter of the filter-stack unit with the 233μ mesh plankton net when both are simultaneously pulled through the same water column. This experiment was completed during PAEDS field trials 5 and 6. Experiment Z-3F completed during PAEDS field trials 8, 9, 10 and 11 compares the net with a full complement of filters. The standard PAEDS sampling procedure is therefore rewritten as Appendix 10, the modified PAEDS sampling procedure.

After each filter was cleaned and each zooplankton sample flushed into a bottle, 40% commercial formaldehyde (100% formalin) buffered by sodium borate was added to make a 10% formalin (4% formaldehyde) preservative seawater solution. The net samples had to be atored in more than one numbered sample bottle.

Laboratory Zooplankton Handling Procedure

The usefulness of the PAEDS theoretically depends on its suitability to perform several operations adequately, the most important of which is the collection of the planktonic organisms in an accessible body of water. On this premise proficiency might be assessed in terms of a comparison with a traditional sampling tool, the conical plankton net. Plankton biomass, diversity or relative abundance might serve as a basis for comparison. However, it was hypothesized that a criterion and an experimental design based on a comparison between the size and shape of meshes and the size and shape of planktonic organisms would bring evaluation to a more precise focus on some of the problems of plankton sampling. Within this context it was decided to base efficiency on the number and size of individuals retained by each filtering surface and to reduce variation by the specific design of equipment and procedure. Rather than use the physical dimensions of an organism as the basis for sizing, maturation stages were selected. This is especially feasible in these northern waters since the dominant planktonic forms are copepods (Hardy 1956; Fraser 1962, Mitchell 1964).

During the eleven field trials 54 zooplankton samples of varying size were collected. However only those from which most could be learned about the efficiency of the system as a plankton collecting device had any immediate priority, namely, those from the field zooplankton experiments outlined in the previous section. The samples were brought back to the laboratory for concentration by settling or sedimentation. Since this procedure varies with planktologists, that followed here is given in Appendix II, and is evaluated by Experiment

SE-1L to be outlined shortly.

Total counts were made of organisms retained on the 233μ mesh filter and the 153μ mesh filter and for the smaller samples retained by the 0.5 m, 233μ mesh net. Estimate counts were made of the large net samples because of the number of organisms in each. The 80μ and 64μ samples consisted of small stages usually accompanied by detritus. Individual handling was not feasible therefore estimate counts were made of these as well.

The equipment used to handle the individual zooplanters consisted of the following:

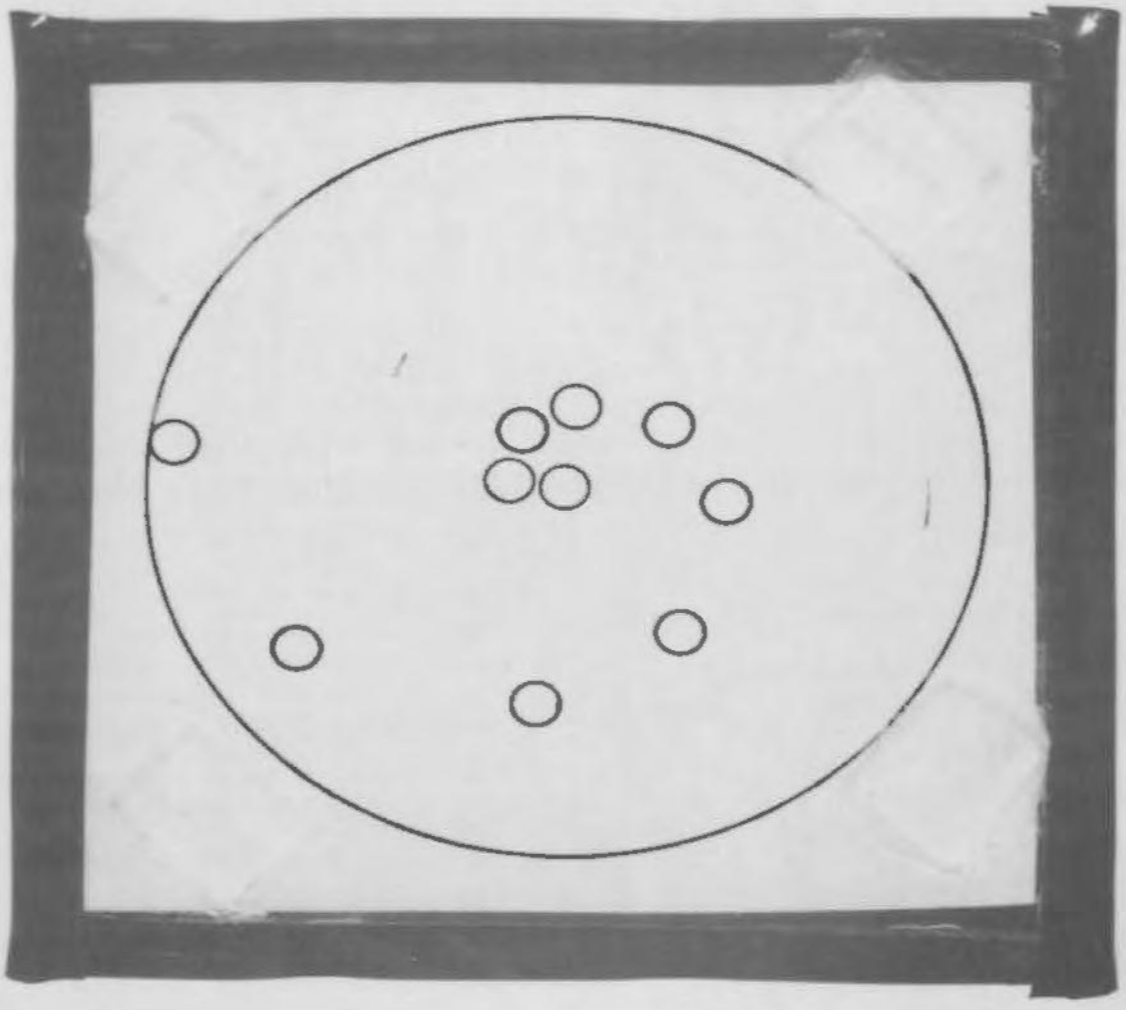
(a) The counting dish for total counts was a petri dish on the outside bottom surface of which parallel lines 0.5 cm. apart were etched with a carborundum stylus.

(b) Estimate counts were made using the average of ten counts from circular fields 0.5 cm. diameter distributed on a logarithmic spiral (Kramer 1955). The spiral traced on acetate was placed between two pieces of clear glass which were blocked to hold a petri dish (Photograph 2.9).

(c) A Carl Zeiss Stereomicroscope IV fitted with 25X and 10X eyepieces sufficiently magnified both 0.5 cm. wide fields to make identification.

(d) Tools for maintaining organisms consisted of a pair of small tweezers to which two pig's eye lashes were cemented, two glass tubes each drawn to a fine tube into which a pig's eye lash was cemented and two insect pins attached to the handles of small paint brushes.

Photograph 2.9 Logarithmic spiral counting block



(e) An array of seven Denominator tally counters and a Clay-Adams gang counter were used to record counts.

(f) Total counts, estimated counts and numbers per cubic meter was recorded on a zooplankton analysis sheet (Appendix 12).

The procedure for counting and identification is given in Appendix 13. Fiches d'Identification du Zooplankton (1939-1971), Sars (1903, 1918), Brodskii (1950), Davis (1955), Hyman (1955), Barnes (1963) and Meglitsch (1967) were guidea for identification. Shih et. al. (1971) was a very helpful source book.

Special effort was made to reduce the number of times the samples were handled and divided. Lack of access to a suitable plankton splitter led to the design of the device shown in Photograph A.1. It was assumed that the size of the bore would not interfere with the even distribution of the plankton in the four beakers. As a precaution however, two portions were counted and values averaged.

Sedimentation Procedure Evaluation

From the literature on plankton methods it is evident that the step by step procedure of settling or sedimentation varies greatly. That being so it was important the methods followed here (Appendix 11) be appraised with respect to plankton losses in the supernatant preservative. Such losses could be an important source of error in the comparison of the PAEDS with the half-meter net. In Experiment SE-1L three sets of ten field samples bottles were selected for analysis of the supernatant. All supernatant from each set was collected and filtered through the 064μ filter. Each container used was flushed with

filtered sea water using the air-spray unit. Any organisms on the filter were flushed into a numbered sample bottle. Sets 2 and 3 were counted by method A, Appendix 13 while for Set 1, both methods A and B were followed because of the nauplii and copepodid stages present.

2.3.3. Statistical Methods

Most of the physical data consists of pairs of observations about an environmental factor. One member of each pair was determined by a component of the PAEDS, the other, by an alternate device. In any experiment the purpose was not to compare the pairs of observations because the pairs will vary since they were recorded under varying environmental conditions. Rather the purpose was to establish that the difference between the members of a pair was a consequence of chance and not the result of an inherent weakness in the design and function of the PAEDS.

In this particular instance one could use any one of three statistical tools: the non-parametric rank sum test, the traditional "students" t-test for paired comparisons or matched pairs, or a two-factor analysis of variance for paired comparison. The first was not selected because it is generally regarded as a low power statistic test since it operates on the median rather than the mean. Since the results of the other methods are the same (Sokal and Rohlf, 1969), for paired observations on conductivity, dissolved oxygen and temperature, I chose the t-test for paired comparisons.

In Experiment MC-1L, the t-test for the difference between two sample means determined by independent sampling was employed.

Statistical tests were not applied to the zooplankton data of Experiments Z-1F, Z-2F and Z-3F because conclusions relevant to the project's objectives are obvious.

Sokal and Rohlf (1969) and Hoel (1966) were the references for the statistical methods.

3.0 RESULTS

3.1 Sensor Evaluation

3.1.1 Conductivity/Salinity

Detailed statistics of the six experiments on the operation of the salinometer and its comparison with the conductivity meter are given in Appendices 14 to 20. The field experiments and most of those done in the laboratory show there was no significant interference in the operation of the conductivity sensor.

3.1.2 Dissolved Oxygen

Appendices 21 to 23 contain the detailed results of the three experiments on the operation of the Yellow Springs Instruments oxygen meter in the PAEDS. In the laboratory this instrument gave results comparable to those obtained by the Winkler method, but in the field experiment the difference between its operation and the Winkler analysis was significant.

3.1.3 Temperature

Detailed records of the outcome of the two experiments on temperature sensor evaluation are given in Appendices 24 and 25. In both field and laboratory experiments the null hypothesis was accepted.

3.2 Meter Calibration

Detailed statistics for the results of Experiment MC-1L are given in Appendix 26. Acceptance of the null hypothesis demonstrates

the degree of accuracy of the water meter. Furthermore, the percent variation between the known volume and the metered values is 0.5%.

3.3 Air-spray Unit Evaluation

The three sets of filters in Experiment AS-1F were utilized as shown in Table 3.1 The number of plankton remains found in twenty random fields on each filter is given in Table 3.2. and is expressed as a percent of the total plankton count for the related PAEDS field trials in Table 3.3. Seventy-five percent of these values are less than 0.5%.

3.4 Sedimentation Appraisal

The total plankton count for the field sample bottles which form each set in Experiment SE-1L is presented in Appendix 27. Appendix 28 gives the plankton count on the supernatant collected from each of these sets. An approximation of the percent of plankton lost in each set is recorded in Table 3.4.

3.5 Zooplankton Sampling

The number of zooplankters per cubic meter for the three experiments (Experiment Z-1F, Z-2F and Z-3F) obtained during PAEDS field trials 4,5,6,8,9,10 and 11 is recorded by Tables 3.5 to 3.10 inclusive. Table 3.11 shows the relative importance of the copepods in these trials and Table 3.12 gives a listing of the major species encountered. A summary of the progress of the field trials is given in Appendix 29. How these relate to and are integrated with the

Table 3.1

Air-spray unit assessment - Filter set utilization

Experiment: AS-1F

Set Number	PAEDS Field Trial	Study Area	Station Number	Sampling Level
1	7	1	12	05
1	8	1	15	50-00
1	9	2	3	50-00
2	7	1	12	00
3	10	2	3	50-00
3	11	2	3	50-00

Table 3.2

Number of plankton remains retained by each set of filters.

Experiment: AS-1F

Set	Filter mesh size (μ)				Total
	64	80	153	233	
1	1	10	1	1	13
2	14	22	5	3	44
3	22	14	6	13	55

Table 3.3

Plankton remains retained as a percent of the total plankton count for the relevant PAEDS field trials.

Experiment: AS-1F

	Filter mesh size (μ)			
	64	80	153	233
1	<0.058 (1708)	<0.094 (10584)	<0.042 (2377)	<0.070 (1419)
2	--	--	--	--
3	0.521 (4220)	0.269 (5190)	0.307 (1950)	0.889 (1462)

Note: The numbers in parentheses are the total plankton counts for the relevant PAEDS field trials.

Table 3.4

Percent of plankton lost in supernatant

Experiment: SE-1L

Set	$\Sigma_{1,m}$	$\Sigma_{2,n}$	% $\left(\frac{\Sigma_{2,n}}{\Sigma_{1,m} \quad \Sigma_{2,n}}\right)$
1	14852	678	$\leq$4.36
2	114611	173	$\leq$0.15
3	87757	397	$\leq$0.45

Table 3.5

Zooplankton per cubic meter

Experiment Z-1F — Come by Chance

PAEDS Field Trial 4 — Station 3, March

Group	PAEDS 233μ	PAEDS 153μ	PAEDS 80μ	PAEDS 64μ	NET* 233μ
Gastropod larvae	19	0	0	0	0
Polychaeta adults	0	1	0	0	0
Calanoids 6 male	5	0	0	0	10
Calanoids 6 female	20	1	0	0	13
Calanoids 4	0	0	0	0	1
Calanoids 3	18	1	0	0	10
Calanoids 2	19	9	0	0	3
Calanoids 1	25	26	0	0	0
Undetermined Calanoids	0	0	0	0	6
Harpacticoids	3	8	0	0	7
Cyclopoids 6 male	87	0	0	0	24
Cyclopoida 6 female	54	0	0	0	44
Cyclopoids 3 - 5	90	38	0	0	17
Cyclopoids 2	0	21	0	0	0
Cyclopoids 1	0	40	0	0	0
Undetermined Cyclopoids	0	0	0	0	1
Copepod nauplii	41	312	2270	593	13
Undetermined Copepods	0	0	0	0	11
Cirripede nauplii	5	0	0	0	8
Undetermined crustaceans	1	0	0	0	0
Others undetermined	1	0	0	140	1
TOTALS	370	457	2270	733	169

*Total Count. Water passing through the excess discharge hose is not metered.

Table 3.6

Zooplankton per cubic meter

Experiment Z-2F — Come by Chance

Station 3, June and August

Group	PAEDS Field Trial 5		PAEDS Field Trial 6	
	PAEDS 233μ	NET 233μ	PAEDS 233μ	NET 233μ
Cnidarians	0	7	0	151
Gastropod larvae	0	0	45	121
Polychaeta adults	0	4	0	0
Other annelids	0	0	0	91
Acarines	0	0	6	0
Cladocerans	120	226	6	590
Calanoids 6 male	110	516	246	1014
Calanoids 6 female	40	654	452	1665
Calanoids 5 male	10	47	84	318
Calanoids 5 female	0	118	110	348
Calanoids 4	50	967	498	939
Calanoids 3	40	589	271	257
Calanoids 2	0	55	13	30
Calanoids 1	0	15	0	0
Undetermined calanoids	0	0	0	76
Cyclopoids 6 male	20	139	26	212
Cyclopoids 6 female	90	578	155	61
Cyclopoids 3 - 5	30	70	39	136
Copepod nauplii	10	0	0	0
Cirripede nauplii	0	4	0	0
Decapod larvae	0	0	6	0
Chaetognaths	0	4	6	15
Copelatans	0	7	0	30
Fish eggs	0	4	0	0
TOTALS	520	4004	1963	6054

Table 3.7

Zooplankton per cubic meter

Experiment Z-3F — Swift Current-Black River

PAEDS Field Trial 8 — Station 15, August

Group	PAEDS 233μ	PAEDS 153μ	PAEDS 80μ	PAEDS 64μ	NET 233μ
Cnidarians	11	0	0	0	111
Ctenophores	0	0	0	0	19
Gastropod larvae	16	16	0	0	32
Bivalve larvae	22	255	2178	0	26
Polychaete adults	0	11	0	0	25
Other annelids	0	0	0	0	5
Cladocerans	11	0	0	0	114
Calanoids 6 male	244	5	0	0	608
Calanoids 6 female	531	0	0	0	1148
Calanoids 5 male	0	0	0	0	67
Calanoids 5 female	92	5	0	0	134
Calanoids 4	704	22	0	0	1458
Calanoids 3	504	493	0	0	428
Calanoids 2	87	981	0	0	1
Calanoids 1	43	1078	184	0	0
Undetermined calanoids	0	0	0	0	6
Harpacticoids	173	81	547	0	0
Cyclopoids 6 male	114	81	0	0	26
Cyclopoids 6 female	309	87	0	0	66
Cyclopoids 3 - 5	845	4226	1089	0	161
Cyclopoids 2	16	87	1089	0	0
Cyclopoids 1	0	5	1268	0	0
Copepod nauplii	27	396	16514	2541	13
Decapod larvae	0	0	0	0	13
Chaetognaths	0	0	0	0	19
Echinoderm larvae	0	0	0	0	13
Copelatans	38	0	0	0	52
TOTAL	3787	7829	22869	2541	4545

Table 3.8

Zooplankton per cubic meter

Experiment Z-3F — Come by Chance

PAEDS Field Trial 9 — Station 3, August 23, am:

Group	PAEDS 233μ	PAEDS 153μ	PAEDS 80μ	PAEDS 64μ	NET 233μ
Cnidarians	45	0	0	0	91
Ctenophores	0	0	0	0	6
Nematodes	0	64	0	0	0
Trochophore larvae	0	0	0	0	0
Gastropod larvae	51	32	0	0	85
Bivalve larvae	58	641	641	212	55
Polychaete adults	0	0	0	0	79
Polychaete larvae	6	0	0	0	12
Cladocerans	52	0	0	0	384
Calanoids 6 male,	423	0	0	0	609
Calanoids 6 female	359	6	0	0	992
Calanoids 5 male	109	0	0	0	177
Calanoids 5 female	64	0	0	0	189
Calanoids 4	372	0	0	0	871
Calanoids 3	398	231	1289	0	304
Calanoids 2	103	398	2578	0	19
Calanoids 1	51	596	5156	0	0
Harpacticoids	173	71	0	0	0
Cyclopoids 6 male	301	263	0	0	104
Cyclopoids 6 female	327	314	0	0	49
Cyclopoids 3 - 5	1565	2867	0	0	201
Cyclopoids 2	0	19	0	0	0
Cyclopoids 1	0	6	0	0	0
Copepod nauplii	19	366	31143	7734	0
Chaetognaths	32	0	0	0	0
Echinoderm larvae	13	0	0	0	24
Copelatans	19	0	0	0	67
Fish eggs	0	6	0	0	6
Others undetermined	64	96	0	0	0
TOTALS	4617	5976	40807	7946	4324

Table 3.9

Zooplankton per cubic meter

Experiment Z-3F — Come by Chance

PAEDS Field Trial 10 — Station 3, August 23, noon

Group	PAEDS 233μ	PAEDS 153μ	PAEDS 80μ	PAEDS 64μ	NET 233μ
Cnidarians	27	0	0	0	95
Ctenophores	0	0	0	0	7
Gastropod larvae	0	0	260	0	50
Bivalve larvae	19	711	260	0	22
Polycheate larvae	0	0	0	0	7
Cladocerans	31	0	0	0	381
Calanoids 6 male	268	8	0	0	376
Calanoids 6 female	315	4	0	0	1011
Calanoids 5 male	23	0	0	0	67
Calanoids 5 female	27	0	0	0	130
Calanoids 4	311	12	0	0	963
Calanoids 3	152	23	0	0	390
Calanoids 2	31	260	128	0	37
Calanoids 1	0	380	128	0	15
Harpacticoids	78	23	128	0	0
Cyclopoids 6 male	249	175	0	0	66
Cyclopoids 6 female	253	198	0	0	89
Cyclopoids 3 - 5	750	2643	521	0	90
Cyclopoids 2	0	19	128	0	0
Cyclopoids 1	0	0	388	0	0
Copepod nauplii	16	268	7419	8461	0
Decapod larvae	0	0	0	0	22
Chaetognaths	0	0	0	0	22
Echinoderm larvae	4	0	0	0	0
Copelatans	0	0	0	0	43
Fish eggs	4	0	0	0	7
Others undetermined	27	0	0	0	0
TOTALS	2585	4674	9360	8461	3890

Table 3.10

Zooplankton per cubic meter

Experiment Z-3F — Come by Chance

PAEDS Field Trial 11 — Station 3, August 23, pm:

Group	PAEDS 233µ	PAEDS 153µ	PAEDS 80µ	PAEDS 64µ	NET 233µ
Cnidarians	35	0	0	0	64
Gastropod larvae	23	6	0	0	45
Bivalve larvae	29	480	983	0	45
Polychaete adults	0	6	0	0	7
Polychaete larvae	0	0	0	0	7
Cladocerans	170	0	0	0	296
Calanoids 6 male	310	12	0	0	456
Calanoids 6 female	439	0	0	0	1227
Calanoids 5 male	35	0	0	0	116
Calanoids 5 female	105	0	0	0	302
Calanoids 4	714	0	0	0	1169
Calanoids 3	351	123	0	0	398
Calanoids 2	70	234	0	0	7
Calanoids 1	47	328	199	0	0
Harpacticoids	129	29	0	0	0
Cyclopoids 6 male	228	18	0	0	90
Cyclopoids 6 female	146	41	0	0	32
Cyclopoids 3 – 5	1784	2715	3528	0	148
Cyclopoids 2	0	88	1960	0	0
Cyclopoids 1	0	6	0	0	0
Copepod nauplii	18	287	9600	11952	0
Decapod larvae	6	0	0	0	7
Bryozoan cyphonautes	6	0	0	0	0
Chaetognaths	0	0	0	0	7
Echinoderm larvae	6	0	0	0	0
Copelatans	12	0	0	0	45
Fish eggs	0	0	0	0	19
TOTALS	4663	4373	16270	11952	4487

Table 3.11

Percent of copepoda in field trial samples

PAEDS Field Trial	Percent of Copepoda
4	96.0
5	91.7
6	86.7
8	92.8
9	95.5
10	93.1
11	98.9

Table 3.12

Unconfirmed identification of major copepods

Phylum Arthropoda
Class Crustacea
Subclass Copepoda
Order Calanoida
Acartia longiremis (Lilljeborg, 1853)
Bradyidius similis (G. O. Sars, 1903)
Calanus finmarchicus (Gunnerus, 1765)
Calanus helgolandicus (Claus, 1863)
Centropages hamatus (Lilljeborg, 1853)
Centropages typicus Kroyer, 1849
Metridia longa (Lubbock, 1854)
Pseudocalanus minutus (Kroyer, 1849)
Eurytemora sp.
Temora longicornis (O. F. Müller, 1785)
Tortanus discaudatus (Thompson and Scott, 1898)
Order Harpacticoida
Oncaea borealis G. O. Sars, 1918
Order Cyclopoida
Oithona similis Claus, 1866
Oithona spinirostris Claus, 1863

laboratory experiments can be seen by comparing this Appendix with Appendix 30. Absolute values of zooplankton sampling details are given in Appendix 31.

4.0 DISCUSSION

4.1 Environmental Sensors

4.1.1 Conductivity/Salinity

Acceptance of the null hypothesis in Experiments C/S-1L, C/S-4L and C/S-2F supports the conclusion that there is no significant difference between the use of the salinometer in the PAEDS and the conductivity meter in both laboratory and field measurements of conductivity and hence salinity. The results of Experiment C/S-4L, especially, strongly support this conclusion for in it specific conductance is determined against changes in both temperature and electrolyte concentration. In Experiment C/S-2L rejection of the null hypothesis for pooled specific conductivity (Appendix 15) contradicts its acceptance when pairs are not pooled (Appendix 16). Repeated acceptance of the null hypothesis (Appendix 16) supports the conclusion there is no difference between the effectiveness of the conductivity meter and the salinometer in the surge-tank or out of it. That pooled pairs should lead to rejection of the null hypothesis likely results from an inappropriate pooling of the pairs of observations. But this is questioned because the members of each pair of observations are the same for both pooled or un-pooled evaluation. In the first instance (Appendix 15) all psirs are taken collectively while in the second (Appendix 16) only pairs relating to a specific test are grouped.

The results of Experiment C/S-3L although contradictory for a similar experimental condition (A1-B2, page 57 and Appendix 16)

may be interpreted as supporting the premise here. At a probability $\alpha = 0.025$, the critical value is ±2.6850 for which we could accept the null hypothesis.

In the initial field evaluation, Experiment C/S-1F (Appendix 19) there was no obvious major variation in the operation of the salinometer in the surge-tank and at the hose intake.

That there would be no interference from the surge-tank is supported by Whaley and Taylor (1968) who utilized a Chesapeake Bay Institute conductivity temperature indicator (CBI-CTI) (Schiemer and Pritchard 1957) in a wooden tank.

4.1.2 Dissolved Oxygen

The operation of the Yellow Springs Instrument, Model 54BP, oxygen meter in the PAEDS was not satisfactory during the field trials. In the laboratory where experimental conditions were carefully controlled (Experiment DO-1L) results were similar to the Winkler Test, (Appendix 21). On this basis field evaluation was not initiated until PAEDS Field Trial 5. At that time consideration was given to the problems arising during field calibration of the instrument. The manufacturer's calibration tables are for fresh water and for sea water with a chloride ion concentration of 20000 mg/l. Field conditions were estuarine, therefore neither table was appropriate exclusively. In the absence of any instructions for such a circumstance, estimate calibration values were used. The YSI for the most part underread dissolved oxygen as determined by the Winkler method.

There are other possible causes for the results of Experiment DO-2F (Appendix 23). The modified preparation of the probe prior to

each field trip is not considered to be one. The electrolytic cell does not function until a polarizing current activates it. Obviously salting out phenomena (Horne 1969) contributes; compensation values for this could not be determined from the information supplied (APHA-AWWA-WPCF) 1971. That dissolved oxygen measurements were made on water in the surge-tank from depths to 50 meters might be regarded as a source of error. In surface waters the dissolved oxygen concentration is a function of ambient temperatures, and the partial pressure of oxygen in the air. Both the YSI samples and the Winkler samples were taken from the surge-tank and were therefore subject to the same turbulence and pressure changes. Theoretically then, the difference should be insignificant. The source of error that might be encountered here is no greater than that faced in determining the dissolved oxygen content of water samples collected by Van Dorn, Kemmerer or Nansen water bottles which are also brought to the surface. Because the results of Experiment DO-2F were not consistent with those in the laboratory, the YSI was not used for the last three field trials.

4.1.3 Temperature

The temperature sensors functioned very well in the laboratory and the field. This conclusion is based on the accepted null hypothesis of Experiments T-1L and T-1F (Appendices 24 and 25). No effort was made to determine if there were any changes in water temperature between intake and the surge-tank. J. H. Allen (Faculty of Engineering and Applied Science, Memorial University of Newfoundland) (personal communication) did not observe significant changes while pumping water from similar depths.

4.1.4 Practical Comments on Sensor Operation

The ease with which the YSI meter operates, its compactness and portability are desirable qualities for its use in the PAEDS. However, the effects of salting out over the range of estuarine salinities needs to be determined. Furthermore, if it is to be used in the surge-tank a compensation factor for partial pressure changes over depth is required. The alternative is to locate the probe at the hose intake, that is, at the sampling level. Its capability of measuring temperature below 0°C is an asset beyond that of the salinometer. For this reason measurements made during PAEDS field trials 3 and 4 are not considered in Appendix 20. Calibration of the salinometer presents another problem. This can only be done with the probe removed from the surge-tank. A self-calibrating device would have permitted easy calibration prior to each observation.

4.2 Evaluation and Implications of PAEDS Hydrodynamics

Because the previously calculated loss of head (Page 49) for the pump is in excess of that possible, we must now determine the significance of this in the operation of the PAEDS. If we include the frictional head loss from joining two hose sections of different diameters together on the suction side of the pump, the theoretical head loss is 12.25 meters, most of which results from the 3.175 cm. inside diameter hose section (Appendix 6). Since the pump has a maximum suction lift to 7.62 meters, we can determine a closer approximation to the true velocity of water in the smaller hose by using the Darcy-Weisbach equation (Equation 1, Appendix 5). The

approximate velocity then is 2.7m/sec. which is 78.89% of the theoretical. We can compare this value with approximations determined for several other pumping systems (Appendix 32).

Although the pump-motor unit is theoretically capable of delivering one cubic meter of sea water in six minutes the frictional head loss reduced efficiency, resulting in longer time on station. Station time was also extended because all the water delivered by the pump was not filtered, only that which flowed by gravity to the filter stack unit. However in these field trials the extended station time was necessary to complete the various experiments.

When the ancillary problems discovered in the first three trials were resolved no further delays in the system's operation were experienced.

4.3 Operation of the Water Meter

With respect to the operation of the water meter in the field there were no problems. The results of Experiment MC-1L (Appendix 26) are further support to its efficiency. The percent variation is well within the value of 1% stated by the manufacturer's agent and generally observed for positive-displacement meters (Streeter 1966).

4.4 Operation of the Air-spray Unit

Although the results of Experiment AS-1F are incomplete there is clear evidence to show that the air-spray unit functioned satisfactorily. There is no apparent relationship between the number of times a filter was used and the number of planktera retained (Tables 3.1 and

3.2). Furthermore there does not appear to be any relationship between the total plankton count for a specific filter and the number of plankters retained on the filter after cleaning with the air-spray unit.

4.5 The PAEDS- a Plankton Sampling Device

4.5.1 The Choice of Methods

The rationale for designing a portable plankton sampling system was presented earlier. The manner of its usage as a plankton capturing device and the significance of the findings must now be considered.

Sample Size

The decision to filter one cubic meter of water is based on Cassie (1958). For the range of organisms being sampled, that is, the microplankton (Lenz 1970), this size sample can be used to statistically assess the population.

Minimum Pump Capacity and Intake Velocity

Since Wiborg (1948) stated that 200 liters a minute should be the minimum capacity of a plankton pump, scientists have reacted in various ways. Some chose to accept this without question; others have designed systems to handle more than this amount, some less (Appendix 4). Why this specific amount and not another should be the minimum is not discussed by Dr. Wiborg, however, he does give two hypotheses. Firstly, fast moving organisms can succeed in avoiding the suction currents at the mouth of the hose. Secondly rarer organisms will not be sampled if a smaller volume is filtered. O'Connell and Leong (1963) question the required minimum. Concerning the second premise, they show that

for a delivery rate of 92 liters per minute they collected adequate data in a California fall survey for precise statistical analysis on *Calanus helgolandicus*, euphausids and chaetognaths. Schram (1968) reports 200/min. is well above that assumed to be sufficient for collecting representative samples of invertebrate larvae. It might be fair to say for a specific sampling device there has always been rarer organisms. The uncommon organism is not exclusively a geographical phenomenon (Ahlstrom *et al.* 1969).

While there may be limited justification for Wiborg's second premise, the first can be questioned because of the difference expected in the suction zone's efficiency when sampling while stationary and that to be observed while underway (O'Connell and Leong 1963). Furthermore a pump's capacity has little bearing on the type of organisms captured. It is not the quantity of water pumped per minute that collects plankton. Rather it is the velocity in the intake that captures plankton and in the conduit that retains them. For a specific volume of flow there is a reciprocal relationship between the size of the conduit and the velocity of a liquid in it (Equation 4, Appendix 5). Comparing the approximate water velocity of the PAEDS, that is, 2.7m/sec. with those of Appendix 32, it ranks fourth. Yet for this, the approximate volume of flow is 129.3 l/min., one of the lower volumes compared to those of Appendix 4 and Aron (1958, 1962).

By far the majority of previous pumping systems employed the centrifugal pump which theoretically maintains a steady flow at a constant velocity. In the pump motor unit the water velocity went from zero to maximum to zero during the suction portion of each stroke

of the diaphragm. The suction zone would therefore be expected to vary in size, shape and duration as the velocity changed. Other than the observation made by O'Connell and Leong (1963) that a clearly defined bulbous shaped suction zone about 5.08 cm. in diameter was located ahead of the 1.9 cm. pump intake orifice in their system, there is no information in the plankton pumping literature on the configuration of this zone for various velocities and intakes nor on the behaviour of planktonic forms when in the zone. Wiborg's first premise has yet to be demonstrated experimentally.

Pump Damage to Plankton

Pump damage to plankton has been a real source of concern for those who would choose this type of sampling device. This is expected to be especially true for those selecting high speed centrifugal pumps yet here the evidence varies. Leong (1967), Aron (1958), Tester and Stevenson (1948), Pyefinch (1949), Banse (1955) and Collier (1957) all report varying degrees of damage. Beers *et al.* (1967) using a 1750 r.p.m. six atage centrifugal pump had damage to copelatans (Appendicularia), severe damage to chaetognaths and quite a difference in the counts of *Noctiluca miliaris* Suriray, a fragile dinoflagellate, as compared with those taken by net. Yet a pump in the range of 1800 r.p.m. caused no damage to organisms less than 5.08cm. long (Gibbons and Fraser 1937). Schram (1968) was able to study live samples taken by pump.

In the PAEDS field trials clear evidence for damage was seen in Experiment Z-1F (Table 3.5). Although the net values are total counts rather than counts per cubic meter, we can compare the 233μ mesh net

with the corresponding mesh size PAEDS filter. A larger volume of water went through the net than through the filter and should have resulted in a larger net count. It is unusual for the 233μ PAEDS filter to have counts greater than the 233μ mesh net (Tables 3.7 to 3.10). It is concluded that variation in Experiment Z-1F results from plankton damage and destruction. This however did not result from the pump. The 0.5m, 233μ mesh net was suspended above the water's surface at the side of the boat while the excess discharge hose emptied into it. The turbulence of falling water is suspected to have destroyed some and mutilated others. Organisms with missing appendages were observed in the net samples counted. It is surprising that Gibbons and Fraser (1937) did not have extensive plankton damage for their filtration procedure for the net was very much the same as above. Furthermore their pump was of a higher capacity. Perhaps the fine mesh silk net retained water longer resulting in less abrasion of organisms against the netting. In Experiments Z-2F and Z-3F the proportionally lower counts for soft-bodied forms, cnidarians, chaetognaths, copelatans and echinoderm larvae may be attributed to pump damage although contradictory counts are shown for these forms in Tables 3.6 to 3.10.

Filtration Efficiency of the Half-meter Net

Here as in Aron (1958) and Beers *et al.* (1967) it is assumed the 0.5m net fished at 100% efficiency. Although metering devices were not installed there is sufficient evidence in the literature to demonstrate that this assumption is not correct. The terminology followed is that of Smith *et al.* (1968).

1. Mesh area. The total area of the completed net including mesh apertures and filaments (expressed in square meters).

2. Porosity. That fraction of the mesh area that is open.

3. Filtering area. The product of porosity times mesh area (expressed in square meters).

4. Filtering area ratio. The ratio of filtering area to mouth area.

5. Filtration efficiency. The percentage of the water encountered which is filtered after passing through the mouth of the net.

Porosity for a variety of Nitex plankton gauze has been demonstrated to be in the range of 0.39 to 0.46 (Hagmeier 1968, Smith *et al.* 1968 and Mahnken and Jossi 1967). If we assume the Nitex 233μ mesh plankton gauze used in the 0.5m net has a porosity in this range then the filtering area ratio is between 3.05 and 3.61. It had a side angle of 82° and a length to diameter ratio of 3.55. The towing velocity was from 6.5m/min to 12.8m/min. Based on its probable porosity, the side angle, its conical form and the towing velocity the percent filtration efficiency of the half meter net was between 80 and 85 (Smith *et al.* 1968).

Sedimentation

Sedimentation continues to be widely used for concentrating phytoplankton and the smaller zooplankton (Weber 1966, Dickman 1968,

Marshall 1968, Shomura and Nakamura 1969) often with modifications to the techniques proposed by Allen (1930) and Utermöhl (Lund *et al.* 1958).. In this procedure plankton losses are influenced by settling time and by the size and shape of organisms. The choice of this method together with filtration was based on the hypothesis that organisms of the size to be sampled would respond to this procedure. Although there is variation in the literature on the limits of sedimentation and centrifugation, they do overlap and one has to balance what will be gained by one procedure against what will be lost by another. Centrifugation is commonly used for phytoplankton and nanoplankton (Raymond 1937, Littleford *et al.* 1940, Moore 1952, Haertel *et al.* 1969, Wood *et al.* 1969). Caution must be exercised with this procedure although it is regarded as the most rapid and efficient means of concentrating even the smallest nanoplankton (Kutkuhn 1958). Some of the problems are, losses through adhesion to apparatus, compactness (Kutkuhn 1958), and differential settling (Wood *et al.* 1969). Sedimentation on the other hand takes time. Davis (1973) allowed 200ml. nanoplankton samples to settle for a minimum of 72 hours. Conover, as reported by Wood *et al.* (1969), permitted 250ml. phytoplankton samples to settle for at least 48 hours and then concentrated them by siphoning off the supernatant, again allowing settling and then again removing the supernatant. She reported a loss of 0.2% on these samples. For the size of organisms to be handled here it was considered that so extended a settling time would not be required. The validity of such a conclusion is verified by the results of Experiment SE-1L, Table 3.4. The high percent for Set 1 results from the presence of copepod nauplii

(Appendix 28) which would be least expected to respond to limited sedimentation because of their buoyancy.

Systematic Counts Versus Random Counts

Because concentrated samples are often too dense or too large for total counting they must be divided or sub-divided (Wiborg 1962). This procedure is likely to precipitate several events. Each stage of handling increases the probability and opportunity for human error; it decreases opportunity for quantitative analysis of the rarer forms; it increases opportunity for creation of non-randomness and gives an artificial statistical importance to the subsample of the subsample. When a sample is divided it becomes a statistical population.

The Stempel pipette or an equivalent suction pipette is often used to select subsamples or aliquots (Ricker 1938, Haertel and Osterberg 1967 and Herman and Beers 1969). The oldest and most common device for quantitative analysis of phytoplankton is the Sedgewick Rafter counting chamber (Chandler 1937, Haertel *et al.* 1969, and Wood *et al.* 1969). It is also widely used for counting zooplankton (APHA-AWWA-WPCF 1971). Use of both these items is based on the assumption that the plankton in an aliquot placed in each is randomly distributed. Frolander (1968) has demonstrated that variability in using the Stempel pipette is caused by the non-random distribution of zooplankton while the aliquot is being extracted. Notably his conclusions are derived from ten aliquots taken from each sample. Non-random distribution of plankton in the Sedgewick Rafter counting chamber has also been demonstrated by Serfling (1949) and Kutkuhn (1958). Therefore the non-randomness inherent in the population from which a sample

is extracted becomes compounded by that in the calibrated pipette and this in turn by the non-randomness in the counting dish.

The most powerful tools of statistics have been applied to plankton research especially in recent years (Cassie 1963, 1967, 1969 and Colebrook 1965). Ricker (1937) and Cassie (1962) review the more common statistical devices, one of which is the Poisson distribution. Both Serfling (1949) and Kutkuhn (1958) found that the distribution of some species in the Sedgewick Rafter counting chamber approach a Poisson distribution, while others did not; the latter group did not meet the uniform distribution assumption required by the Poisson function. Kutkuhn (1958) found that a majority of those not fitted by the Poisson distribution were adequately fitted by the negative binomial distribution. Both authors concluded that the size of sub-sample necessary, to assure reasonably precise estimates for the numbers of each microplankton species and to reduce variance in a given sample concentrate would be too large to be of practical value.

Because of the statistical problems created by non-randomness in the field and in the laboratory, the systematic counting procedure outlined in B, Appendix 13 was followed for estimate counts. The device used was described on page 66.

Temporal and Spatial Displacement

Several scientists chose to compare their pumping systems with a plankton net (Gibbons and Fraser 1937, Wiborg 1948, Pyefinch 1949, Aron 1958, Beers *et al.* 1967). In all these instances there are varying amounts of temporal and/or spatial displacement between net sampling

and pump sampling. For example, Pyefinch (1949) and Wiborg (1948) made horizontal net tows but collected pump samples from fixed stations. Gibbons and Fraser (1937) made collections simultaneously but with vertical and horizontal displacement. The pump collected discrete samples at 12 meters and at the surface while the net made vertical tows down to 50 meters.

Plankton patchinees is a generally recognized phenomenon. However, distributional variations exist on a very small scale (Cassie 1959) as well as on a large one (Cassie 1968, Wiebe 1970, 1971). Therefore in Experiment Z-2F and Z-3F the mouth of the net was secured within 1.6 meters of the hose intake. The net bridle was attached to the foot valve. The vertical variation is compensated for by the vertical tow. By this procedure the possibility of variation because of displacement has been reduced to a greater degree than previously demonstrated.

Although both devices sampled the same water column simultaneously in Experiments Z-2F and Z-3F, there was a lag in what was happening to the water samples (Appendix 10). When the filtering phase for both devices began water reaching the PARDS filter first was from the 50 m level having been previously pumped up during measurement of abiotic parameters. That passing through the net was also from the 50 m level. As the hose was raised water entering the hose intake was replaced by adjacent water which was filtered by the net. It is assumed that the water filtered by the net is most similar to that taken by the pump since both samples were proximal. Since the diaphragm pump only took quantities of water during the intake stroke its sampling was intermittent. In

contrast, the net sampled water in a continuous uninterrupted manner. Each plankton sample is therefore representative of the entire water column sampled. For this reason there was no need to be concerned about the effect of the mixing of water from different levels. Such "smearing" would be important if continuous discrete sampling were proposed. To use the PAEDS for profiling one must repeat items 4 to 14, Appendix 8, The Standard PAEDS Sampling Procedure, for each level sampled Continuous profiling would require modification to the surge-tank unit and a second filter stack unit.

One must distinguish between simultaneous sampling and simultaneous filtering. For evaluation of the PAEDS it was considered essential that samples be taken simultaneously so as to reduce the possibility of variability caused by time and space. What happens after the sample is captured then serves to demonstrate differences in the sampling devices rather than in the sample.

Filtration Losses

Some who have compared the pumping method with the net method have expressed disappointment with the pump (Collier 1957 and Wiborg 1948). This arises from the fact that when only one filtering surface is used in the pumping system, the net, in most instances, is a much more efficient plankton catching device. Experiment Z-2F clearly demonstrates this (Table 3.6). Comparing the net catch with that of its corresponding PAEDS filter in Experiment Z-3F (Table 3.7-3.10) for most taxonomic groups the same is true. Where the pump has given a higher count than the net (Gibbons and Fraser 1937 and Aron 1958) other factors are evident including clogging, mesh size, plankton gauze material, water velocity and pump capacity. When comparing a net with a pump only one other system (Beers *et al.* 1967) used more than one filtering surface simultaneously. The significance of filtration losses on the catch of these

two devices can be demonstrated dramatically. For example, if we exclude from consideration the plankton counts for the PAEDS 153μ, 80μ and 64μ filters (Tables 3.7-3.10) a very different picture of the plankton results. What is retained by a smaller meshed filter is filtration losses for the proceeding filter. Such losses resulting through use of only one filter have been an important consideration in evaluating several previous systems (Gibbons and Fraser 1937, Wiborg 1948, Pyefinch 1949, Aron 1958 and Leong 1967). To determine their losses O'Connell and Leong (1963) collected water samples from the filtrate. The organisms lost through the filter are remarkably similar in taxonomic group, growth stage and number to those retained by the smaller meshed PAEDS filters.

No attempt was made during the PAEDS field trials to determine the nature of plankters which passed through all four filters although there is provision in the filter unit to take water samples (Valve n, Fig. 2.5).

Catch Efficiency of the Half-meter Net

That the 0.5m net captures more of the larger and more motile forms but less of the smaller forms than does the PAEDS is evident from the results of Experiments Z-2F and Z-3F (Tables 3.6-3.10). This may result from a number of phenomena. Since it filters a large volume of water there is a greater probability of encountering more organisms. Avoidance of the small pump intake by active organisms would emphasize those taken by the net. Wiborg (1948) noted the Clarke Bumpus sampler took more of the larger copepods, fish larvae and decapods than did the pump and credited it to avoidance phenomenon. Yet avoidance of the net

can also be expected (Vannucci 1968). That smaller forms do not occur in large numbers may result from escapement or extrusion through the meshes. Hagmeier (1968) demonstrates varying amounts of mesh deformation in nylon plankton gauze. However as filtering proceeds so does clogging of the meshes. This increases the capacity of the net to retain smaller organisms. Since the direction of water flow is not perpendicular to the filtering surface a more efficient flushing action is expected in the net thus reducing the effects of clogging. Patchiness could hardly have been a major cause for catch variation, for reasons already discussed.

4.5.2 The Plankton

As expected the copepods dominated the PAEDS field trials (Tables 3.11 and 3.12). Those present were typically neritic and boreal. All have been previously reported for the outer continental shelf waters around Newfoundland (Pinhey 1927 a and b, Vladimirskaya 1965, Pavshtiks *et al.* 1962). Three species were reported by Mitchell (1964) at Salmonier River estuary; *Calanus finmarchicus, Centropages hamatus,* and *Temora longicornis*. Copepod presence compares with that of adjacent shelf waters in St. Margaret's Bay, Nova Scotia, (Paranjape and Conover 1973) and in the Gulf of Maine (Sherman 1966 a and b, 1968, 1970). In view of their abundance the copepods constitute a very important link in energy transfer from primary producers to higher level consumers in Come by Chance and Placentia Bay.

4.6 Reappraisal of the Pumping Method

The ideal quantitative study of plankton begins with the removal

of only the necessary organisms from a volume of water whose size and location is known. It may also be necessary to know something of related biotic and abiotic phenomena. How close one comes to achieving this goal is determined by the strategy employed to accommodate to the characteristics of the plankton and of their environment, the limitations of the sampling equipment and the logistics of a given project. Plankton is so varied in kind, size, shape, activity, number and distribution of species that it is obvious no single device is remotely suitable to sample all forms. But given a set of circumstances one device will be more efficient than another. The suitability of the pumping method for collecting phytoplankton is recognized (Robert 1922, Kokubo and Tamura 1931, Whaley and Taylor 1968, Wood *et al.* 1969). For sampling the euphotic zone it has been demonstrated that the plankton pump has several advantages over the plankton net (Aron 1962 and Leong 1967). These are summarized in Table 4.1. Like any other sampling device the pump has its limitations. It is not the device to sample all plankton any more than a butterfly net can be used to catch elephants. By the use of procedures for measuring environmental parameters and a series of filters the PAEDS exceeds the capabilities of the 0.5m conical net in several spheres. However, more important conclusions resulted from the field trials. Together the net and the pump have provided a novel means of gathering information on plankton numbers and diversity. The efforts to reduce spatial and temporal displacement increases the confidence one has in the conclusion that the numbers and diversity of plankton in the water column are more closely approximated by both devices together than by either considered singly.

Table 4.1

Comparison of the Pump Method and Net Method of Plankton Sampling

Sampling Feature	Pump	Net
Plankton size group sampled: (Lenz 1970)		
nanoplankton (< 20 μ)	Yes.	No.
microplankton (20 - 200 μ)	Yes.	Yes.
mesoplankton (0.2 - 2 cm.)	Difficult	Yes.
macroplankton (> 2 cm.)	No.	Yes.
Discrete multiple simultaneous plankton samples.	Yes.	No.
Possible method of sampling:		
vertical	Yes.	Yes.
horizontal	Yes.	Yes.
oblique	Yes.	Yes.
fixed spot (discrete sampling)	Yes.	No.
Filtration losses.	Few.	Many.
Exact determination of sampling depth.	Not difficult.	Sometimes difficult.
Exact measurement of volume filtered.	Yes.	No.
Integrated simultaneous sampling of zooplankton and phytoplankton.	Yes.	No.
Integrated simultaneous collection of biological, physical and chemical data.	Yes.	No.
Mesh selection.	Problematic.	More so.
Clogging problems.	Few.	Many.
Shallow water sampling.	Yes.	No.
Degree of avoidance.	Greater?	Less?
Volume sampled per unit time.	Small.	Large.
Maximum sampling depth (practical).	About 300 m.	Unlimited.

Had a plankton pumping device been used during the Northwestlant Surveys (Bainbridge and Corlett 1968) a more comprehensive knowledge of North Atlantic plankton would most certainly have been obtained.

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6.0 APPENDICES

Appendix 1

Fishery dependent labour force (Primary and Secondary Sectors) as compared with employed portion of the Total Labour Force

Year	Total Labour Force X1000[1]	Employed X 1000[1]	Fisheries based employment		Total X1000	Fisheries Labour Force as a % of Employed Labour Force
			Primary Sector X 1000[2]	Secondary Sector X 1000[3]		
1957	109	98	16.3+	2.4	18.7+	19.1
1958	108	88	18.2+	2.4	20.6+	23.4
1959	111	89	18.3+	2.4	20.7+	23.3
1960	111	91	18.3+	2.8	21.1+	23.2
1961	113	91	18.0+	2.9	20.9+	23.0
1962	117	97	19.9	3.0	22.9	23.6
1963	126	108	21.4	3.3	24.7	22.9
1964	126	112	22,6	3,3	25.9	23.1
1965	133	119	21.7	4.0	25.7	21.6
1966	139	127	20.3	4.5	24.8	19.5
1967	143	131	19.8	4.4	24.2	18.5
1968	144	130	19.3	4.9	24.2	18.6
1969	146	131	17.8	5.1	22.9	17.5
1970	148	133	17.8	5.4	23.2	17.5
1971	158	139	15.8	5.1	20.9	15.0
1972	165	145	14.5	5.3	19.8	13.7

[1]Obtained from Table C-1, Historical Statistics of Newfoundland and Labrador and Table 3, Chartbook of Selected Economic Statistics for Newfoundland and Labrador.

[2]Obtained from Tables K-8 to K-11, Historical Statistics of Newfoundland and Labrador and Fiscal Policy Division, Department of Finance, Newfoundland and Labrador.

[3]Obtained from Table N-3, *Ibid* and Fiscal Policy Division, Department of Finance, Newfoundland and Labrador.

Appendix 2

Census Value Added for Primary and Secondary Fishing Sectors as compared with that of the Total Commodity Producing Sector

Year	Primary Sector (Fishing) ($ Millions)	Secondary Sector (Fish Products Industry) ($ Millions)	Total Fishing Sector ($ Millions)	Total Commodity Producing Sector[1] ($ Millions)	Fishing as a % of Total Commodity Producing Sector (%)
1958	11.4	6.6	18.0	190.2	9.5
1959	14.6	5.6	20.2	207.1	9.8
1960	15.9	6.9	22.8	241.4	9.4
1961	15.0	8.4	23.4	245.1	9.5
1962	17.5	9.8	27.3	262.9	10.4
1963	20.5	9.6	30.1	281.4	10.7
1964	22.9	12.2	35.1	320.3	11.0
1965	24.1	17.1	41.2	333.7	12.3
1966	26.6	18.0	44.6	419.9	10.6
1967	28.9	14.6	43.5	414.6	10.5
1968	28.8	17.9	46.7	459.6	10.2
1969	30.8	29.9	60.7	521.1	11.6
1970	36.3	33.0	69.3	684.3	10.1
1971	36.7	..	..	713.2	..

..Not available.

[1]Includes Primary Forestry (logging), Primary Fishing, Mining, Electric Power, Manufacturing (including fish and fish product processing), and Construction. Conceptual changes in Census Value Added in certain commodity producing industries makes the total column inconsistent within itself. However, the Primary Fishing component has not changed conceptually.

Appendix 3

Newfoundland and Labrador Commercial Fish and Shellfish

Groundfish	
Cod	*Gadus morhua* Linnaeus 1758
Haddock	*Melanogrammus aeglefinus* (Linnaeus) 1758
Redfish	*Sebastes marinus* (Linnaeus) 1758
Halibut	*Hippoglossus hippoglossus* (Linnaeus) 1758
Flounder	*Hippoglossoides platessoides* (Fabricius) 1780
	Glyptocephalus cynoglossus (Linnaeus) 1758
	Limanda ferruginea (Storer) 1839
	Pseudopleuronectes americanus (Walbaum) 1792
Turbot	*Reinhardtius hippoglossoides* (Walbaum) 1792
Pollock	*Pollachius virens* (Linnaeus) 1758
Hake	*Urophycis tenuis* (Mitchill) 1815
	Merluccius bilinearis (Mitchill) 1814
Catfish	*Anarhichas lupus* Linnaeus 1758
	Anarhichas minor Olafsen 1774
Tomcod	*Microgadus tomcod* (Walbaum) 1792
Pelagic and Estuarial	
Herring	*Clupea harengus harengus* Linnaeus 1758
Mackerel	*Scomber scombrus* Linnaeus 1758
Eels	*Anguilla rostrata* (LeSueur) 1817
Salmon	*Salmo salar* Linnaeus 1758
Skate	*Raja radiata* Donovan 1807
	Raja laevis Mitchill 1817
	Raja spinicauda Jensen 1914
	Raja ocellata Mitchill 1815
	Raja senta Garman 1885

Appendix 3 (Continued)

Smelts	*Osmerus mordax* (Mitchill) 1815
Capelin	*Mallotus villosus* (Muller) 1777
Trout	*Salvelinus fontinalis* (Mitchill) 1815
	Salvelinus alpinus (Linnaeus) 1758
	Salmo trutta Linnaeus 1758
	Salmo gairdneri Richardson 1836
Other	*Lamna nasus* (Bonnaterre) 1788
	Squalus acanthias Linnaeus 1758
Molluscs and Crustaceans	
Clams	*Mya arenaria* Linnaeus 1758
	Macoma balthica (Linnaeus) 1758
	Spisula solidissima (Dillwyn) 1817
Mussels	*Mytilus edulis* Linnaeus 1758
	Volsella modiolus Linnaeus
Scallops	*Placopecten magellanicus* (Gmelin) 1792
Squid	*Illex illecebrosus* (LeSueur) 1821
Lobster	*Homarus americanus* Milne-Edwards 1837
Shrimp	*Pandalus borealis* Kroyer 1838
	Pandalus montagui Leach 1814
Crabs	*Chionoectes opilio* Fabricius
Other	
Lumpfish	*Cyclopterus lumpus* Linnaeus 1758

Appendix 4

Updated summary of previous plankton pumping research. (After Table 3, Aron 1962)

Investigator	Year	Type of pump	Capacity	How used	Where used
Frenzel (Gibbons and Fraser 1937)	1897 (?)	Not stated	100 liters per minute	With an especially reinforced hose collected samples through the ice; a minimum of 500 liters per sample.	Lakes-
Kramer, Herdman, Wolf, Steuer, Murray and Blackman (Gibbons and Fraser 1937)	1895 to 1903 (1)	Steamship's pump	Not stated	Filtered surface waters from the pump.	Marine-
Lohmann (Dakin 1908) (Gibbons and Fraser 1937)	1903	Hand pump.	Not stated	Operation of the pump also controlled depth of lower end of hose which sampled down to 100 meters.	Marine- Mediterranean
"Dana" Expedition	1929 to 1930 (1)	Ship's pump	Not stated	Surface waters filtered through plankton net.	Marine- 36 stations on route.
Wiborg	1948 (1)	Centrifugal pump driven by ship's engines.	About 43 liters per minute.	One inch armed rubber suction hose 38 meters long; 500 liters per sample; No. 8 and No. 11 silk nets.	Marine- West Fjord, Norway

Appendix 4 (Continued)

Investigator	Year	Type of pump	Capacity	How used	Where used
Anraku	1956	Hand pump	About 13.2 liters per minute.	A 2 cm. diameter hose fixed 2 meters below surface; 20 liters per sample.	Marine-Hokkaido, Japan
Aron	1958 (1)	Centrifugal pump, gasoline powered.	1500 liters per minute	544 micron mesh size net in an especially designed drum.	Marine-Elliott Bay, Puget Sound, Washington
Wibaut-Isebree	1958 (1)	Hand pump	Not stated	Samples of 20 liters each collected and filtered through No. 24 plankton gauze; 15 meters deep.	Marine-Noordzeekanaal and Ymuiden Harbours, Netherlands
Whaley	1958	Submersible centrifugal pump	3 to 4 gallons per minute with hose 195 feet deep.	Initial tests for collecting dissolved oxygen samples.	Not stated.
O'Connell and Leong	1963 (3)	Submersible centrifugal pump	About 92 liters per minute	With ship underway at 9 knots, 100 feet of hose samples at 5 to 6 meters deep.	Marine-California

Appendix 4 (Continued)

Investigator	Year	Type of pump	Capacity	How used	Where used
Manz	1964 (4)	Centrifugal pump	28000 gallons per	A 3 inch suction hose intake attached to a sled sampled near the bottom at depths from 5 to 40 feet.	Lakes- Lake Erie
Mathisen	1964 (5)	Centrifugal pump	1500 liters per minute	10.2 cm. diameter hose at 22.9 meters delivered water to 3 filters with mesh sizes No. 6, 12 and 20 respectively.	Marine- Rongelap Atoll
Quayle and Terhune	1967	Centrifugal	About 57 liters per minute	Surface waters samples from 0 to 8 feet.	Marine- Pendrall Sound, British Columbia
Beers, Stewart and Strickland	1967 (6)	Submersible 6 stage, centrifugal pump	About 150 liters per minute	Hose retrieval system can sample down to 100 meters while underway at 3 to 4 knots; sample sorted on four filters; depth sensor.	Marine- Off Del Mar, California and Gulf of Santa Catalina
Whaley and Taylor	1968 (7)	Centrifugal pump	Not stated	Three nets with mesh sizes 570 μ, 75 μ, and 65 μ, sensors for conductivity and tempersture; sampled surface waters.	Marine- Chesapeake Bay

Appendix 4 (Continued)

Investigator	Year	Type of pump	Capacity	How used	Where used
Schram	1968 (1)	Mono-pump	200 liters per minute	Vertical samples at select depths.	Marine- Inner Oslofjord, Norway
Lenz	1970 (8)	Vacuum pump	With intake at 40 meters and 50% vacuum, 40 liters per minute.	Preliminary evaluation	Marine- Western Baltic
Bernard and Laguex	1970	Hand pump	Not stated	Not stated	Lakes- Quebec

The number in parenthesis in the column "Year" refers to the type of sequential arrangement used and illustrated in Figure 1.1.

Appendix 5

Some equations of fluid mechanics which relate to the design and construction of plankton pumping systems

Nomenclature	
A	area in ft.^{2}
d	pipe inside diameter in feet.
f	dimensionless frictional factor.
g	gravitational acceleration, 32.2 ft./sec.^{2}
h_f	head loss due to friction, in feet.
HP	horsepower.
h_p	head of the pump in feet.
L	length in feet.
n	efficiency expressed as a decimel.
P	pressure in pounds/sq. in.
Q	volume in rate of flow cu.ft./sec.
R_E	Reynolds Number, dimensionless.
R_r	relative roughness.
V	mean linear velocity in ft./sec.
v	linear velocity.
z	liquid height in feet.
ϵ (epsilon)	surface roughness in faet.
ν (nu)	kinematic viscosity in ft.^{2}/sec.
ρ (rho)	density in slugs/ft.^{3} or lb./cu.ft.
Δh	total head in feet.

Appendix 5 (Continued)

The Darcy-Weisbach equation is defined as

$$h_f = f \frac{L}{d} \frac{V^2}{2g} \qquad \text{Equation 1}$$

(Giles 1962)

The frictional factor, f, is commonly determined by use of the Moody Diagram, American Society of Mechanical Engineers, (Figure 5.32, Streeter 1966). This diagram gives the relationship between f, Reynolds Number, R_E, and the relative roughness R_r. The Reynolds Number represents the ratio of the inertia forces to the viscous forces (Streeter 1966) and is expressed by the equation

$$R_E = \frac{Vd}{\nu} . \qquad \text{Equation 2}$$

(Giles 1962)

Relative roughness is a ratio of the surface imperfections to the diameter of the circuit and is stated as

$$R_r = \frac{\varepsilon}{d} . \qquad \text{Equation 3}$$

The mean linear velocity, V, may or may not be given and can be determined from the equation for Q, the flow volume in cu.ft./sec. which is stated as

$$Q = \rho A V . \qquad \text{Equation 4}$$

The algebraic expression for horsepower may be stated as

Appendix 5 (Continued)

$$HP = \frac{Q\rho h_p}{550n} \qquad \text{Equation 5}$$

The Bernoulli equation may be stated as

$$\left(z_2 + \frac{P_2}{\rho g} + \frac{v_2^2}{2g} \right) - \left(z_1 + \frac{P_1}{\rho g} + \frac{v_1^2}{2g} \right) = \Delta h - h_f \qquad \text{Equation 6}$$

(Holland and Chapman 1966)

Appendix 6

PAEDS hose specifications

The PAEDS flow diagram indicates where each section fits

a Lower Portion

30.5 m. (100 ft.) x 3.175 cm. dia. (1¼ in dia.), UniRoyal Royaline gas and oil hose fitted with one male and one swivel female brass Compression Spring coupling.

Upper Portion

2 sections, each 12.2 m. (40 ft.), X 5.08 cm. dia. (2 in. dia.), Aeroquip Republic interwoven wire suction hose, RBW 26, smooth bore. Each length is fitted with one male and one swivel female brass long shank coupling which is attached with two Punch-Lok clamps per coupling.

Foot Valves

Two brass valves, 3.175 cm. (1¼ in.) and 5.08 cm. (2 in.) When assembled the intake hose section a, Fig. 2.2.6 is 55.23 meters long, (181.19 ft.). It is colour coded for the sampling depths of 0, 5, 15, 25, and 50 meters.

b Pump to surge-tank hose. 3.7 m. (12 ft.) X 5.08 cm. dia. (2 in. dia.), B. F. Goodrich Super Highflex water discharge hose fitted with two swivel female, brass long shank couplings each attached with two Punch-Lok clamps.

Appendix 6 (Continued)

c Surge-tank to filter-stack hose. 6.1 m. (20 ft.) X 3.175 cm. dia. (1¼ in. dia.) UniRoyal Royaline gas and oil hose with two swivel female brass Compression Spring couplings.

d Excess discharge hose. 11.6 m. (38 ft.) X 5.08 cm. dia. (2 in. dia.), B. F. Goodrich Super Highflex water discharge hose fitted with one swivel female brass long shank coupling attached with two Punch-Lok clamps.

e Filter-stack discharge hose. 15.2 m. (50 ft.) X 2.54 cm. dia. (1 in. dia.), Goodyear Red Ray water hose fitted with one swivel female brass long shank coupling attached with one Punch-Lok clamp. In this study the hose was not used so the water flowed off the deck via the scuppers.

f There is no hose section here. A ball valve allows one to take the desired amount of water for phytoplankton analysis.

Appendix 7

PAEDS operating checklist

1. Pump Unit with one, 2 in. x 3 in., brass nipple, and two, 2 in., PVC caps.
2. Surge-tank base.
3. Surge-tank with three PVC caps: two, 2 in., one, 1½ in.
4. Filter-stack Unit with two, 1 in., PVC caps.
5. Filter Column in carrying case.
6. 100 ft. hose section, 1½ in. I.D., with one 1½ in. PVC cap.
7. Two 40 ft. hose sections, 2 in. I.D., each with one 2 in. PVC cap.
8. 12 ft. hose section, 2 in., I.D.
9. Overflow discharge hose section, 2 in. I.D.
10. 20 ft. hose section, 1½ in. I.D.
11. Fittings:
    (a) Two modified brass foot valves: 1½ in. and 2 in.
    (b) Two 1½ in. x 2 in. reducer units.
    (c) Filter-stack intake reducer unit, 1½ in. x 1 in.
12. Air-spray Unit:
    (a) Full compressed air cylinder or cylinders.
    (b) Oxy-acetylene hose assembly.
    (c) Air-line hose.
    (d) Compressed air regulator.
    (e) Spray gun.
    (f) Full water reservoir.
    (g) Filter holder.
    (h) Filter cleaning stand.

Appendix 7 (Continued)

13. Salinometer:
    (a) Probe and cable.
    (b) Terminal box.
    (c) Calibrating resistor.
    (d) Spare batteries.
14. Y.S.I. dissolved oxygen meter:
    (a) Terminal box.
    (b) Cable and probe in preparation chamber.
    (c) Calibration chamber.
    (d) O-rings.
    (e) KCl solution.
    (f) Membranes.
    (g) Ring rubber and stoppers.
    (h) Operating instructions and calibration tables.
15. Alternate environmental parameter devices:
    (a) Immersion thermometer, 1/10°C.
    (b) Numbered B.O.D. bottles.
    (c) Manganous sulphate solution and 1 ml. dropper.
    (d) Alkaline iodide solution and 1 ml. dropper.
    (e) Numbered salinity bottles.
16. Instrument Probe Rack.
17. Tools:
    (a) Funnel with strainer.
    (b) Screw drivers (three).
    (c) Set of Allen wrenches.
    (d) Hammer.

Appendix 7 (Continued)

(e) 2 in. Ridgid strap wrench.

(f) Set of spanner wrenches.

(g) Crescent wrenches (three).

(h) Vice-grip wrench.

(i) Large Stelson wrench.

(j) Pliers.

(k) 2 in. lug wrench.

(l) Equipment securing lines.

(m) Hose typing lines.

(n) Electrode cleaning brush.

(o) Wash bottle.

(p) Flat file.

18. Three sets of filters.

19. Six air vent hoses.

20. Hose gaskets: 1 x 1 in.; 3 x 1¼ in.; 5 x 2 in.

21. Metered sounding line.

22. Field compass.

23. Supplies:

(a) Gas container with Regular Gasoline.

(b) Lubricating oil, "For Service M.S": Summer, SAE 30; Winter, SAE 5-20W.

(c) Spare pump diaphragms and valves.

(d) Distilled water.

(e) Teflon Tape.

(f) Filtered sea water.

Appendix 7 (Continued)

(g) Spare pins.

(h) Numbered sample bottles: 8, 32 oz.: 36, 16 oz.

(i) Commercial formaldehyde.

1 liter of TRIS buffered solution.

3 liters of Borax buffered solution.

(j) PAEDS sample data cards.

24. Half-meter net, 233 µ mesh and plankton bucket.

25. Sampling level colour code (meters)

00 Yellow/red

05 Red-yellow/red

15 Brown-yellow/brown

25 White-yellow/white

50 White-blue/white

26. Nitex colour coding

571 µ Red

233 µ Brown

153 µ Yellow

080 µ Green

064 µ Silver.

27. Study Area Maps.

Appendix 8

The Standard PAEDS Sampling Procedure

1. Approach station using land mark co-ordinates.
2. Anchor boat so that the mooring scope places it on station.
3. Assemble PAEDS securing each unit with equipment lines where necessary.
4. Determine the water depth on station using the metered sounding line or the ship's depth sounder.
5. Lower intake hose to required sampling depth and secure.
6. Place filter-stack unit on stand-by.
7. Start motor and pump out the standing column of water in the intake hose.
8. When the surge-tank is full of water from the required sampling level calibrate the salinometer and dissolved oxygen meter.
9. Record the water meter's initial reading and start filtering phase.
10. While the filtering is proceeding take readings of physical parameters: salinity, conductivity, temperature, and dissolved oxygen.
11. Collect water samples as required.
12. When the required volume of sea water has been filtered, first, shut off the filter-stack unit, next, the pump-motor unit and finally, the sensors.
13. Clean plankton filters with air-spray unit taking care to wash down the inside of each acrylic section before removing the relevent filter.

Appendix 8 (Continued)

14. Record all station data with soft lead pencil or water resistant markers on one or more PAEDS sample data cards (Appendix 9).

15. At the end of the field trip dismantle the PAEDS, store the small items in transport boxes and secure equipment for easy transfer to a vehicle.

Appendix 9

PAEDS sample data card

PLACENTIA BAY ZOOPLANKTON STUDY **P.A.E.D.S. MASTER DATA CARD NO.** _____

Study Area: [ ] Station No.: [ ] Sampling level: [00] [05] [15] [25] [50] meters.

Month: [ ][ ] Day: [ ][ ] Year: [ ][ ][ ][ ] Water depth at station: [ ][ ][ ] meters.

Water meter reading: (220 gallons = 1.00012 meters^3) Sampling Time (00.00) hrs.

FINISH: [ ][ ][ ][ ][ ][ ] FINISH: _____

START: [ ][ ][ ][ ][ ][ ] START: _____

VOLUME: [ ][ ][ ][ ][ ][ ] x 4.546 x 10^{-3} = _____ meters^3 TOTAL: _____

PLANKTON SAMPLE

Net No.	Bottle No.
571	_____
233	_____
153	_____
080	_____
064	_____

ENVIRONMENTAL PARAMETERS

Salinity (00.00)	_____	Temperature ($0^oC.$)	_____
pH (0.00)	_____	Dissolved Oxygen (00.0)	_____
Conductivity (00.00)	_____	Turbidity (00.00)	_____
	_____		_____

WIND DIRECTION: _____ (^oTN), WIND VELOCITY: 1 2 3 4 5 6 7 8 9 0

State of the tide: 1 2 3 4 5 6 7 8 9 0

Weather conditions: 1 2 3 4 5 6 7 8 9 0 REMARKS: _____

Appendix 10

The Modified PAEDS Sampling Procedure

1. Approach station using land mark co-ordinates.
2. Anchor boat so that the mooring scope places it on station.
3. Assemble PAEDS securing each unit with equipment lines where necessary.
4. Determine the water depth on station using the metered sounding line or the ship's depth sounder.
5. Attach 0.5 m net to the intake hose foot valve and lower assembly to the 50 m sampling level. Secure hose line.
6. Place filter-stack unit on stand-by.
7. Start motor and pump out the standing column of water in the intake hose.
8. When the surge-tank is full of water from the required sampling level calibrate the salinometer and dissolved oxygen meter.
9. Take readings of physical parameters for 50 m sampling level: salinity, conductivity, temperature and dissolved oxygen.
10. Collect water samples for 50 m level from surge-tank as required.
11. Record the water meter's initial reading.
12. On signal simultaneously start filtering phase and hose reeling.

Appendix 10 (Continued)

13. When the foot-valve breaks surface, shut the pump-motor unit off, and quickly bring the mouth of the net above the surface.
14. Allow filter-atack unit to operate until the water taken at the surface is filtered.
15. Record operating time for hose recovery and filtering phase.
16. Wash down the outside of the 0.5 m net with sea water.
17. Remove zooplankton sample from the cod end and plankton bucket using the air-spray unit.
18. Collect water samples and record values of pbysical parameters for surface sampling level.
19. Switch off sensor instruments.
20. Clean plankton filters with air-spray unit taking care to wash down the inside of each acrylic section before removing the relevent filter.
21. Record all station data with soft lead pencil or water resistant markers, on one or more PAEDS sample data cards (Appendix 9).
22. At the end of the field trip dismantle the PAEDS, store the small items in transport boxes and secure equipment for easy transfer to a vehicle.

Appendix 11

Sedimentation procedure

A. PAEDS Samples

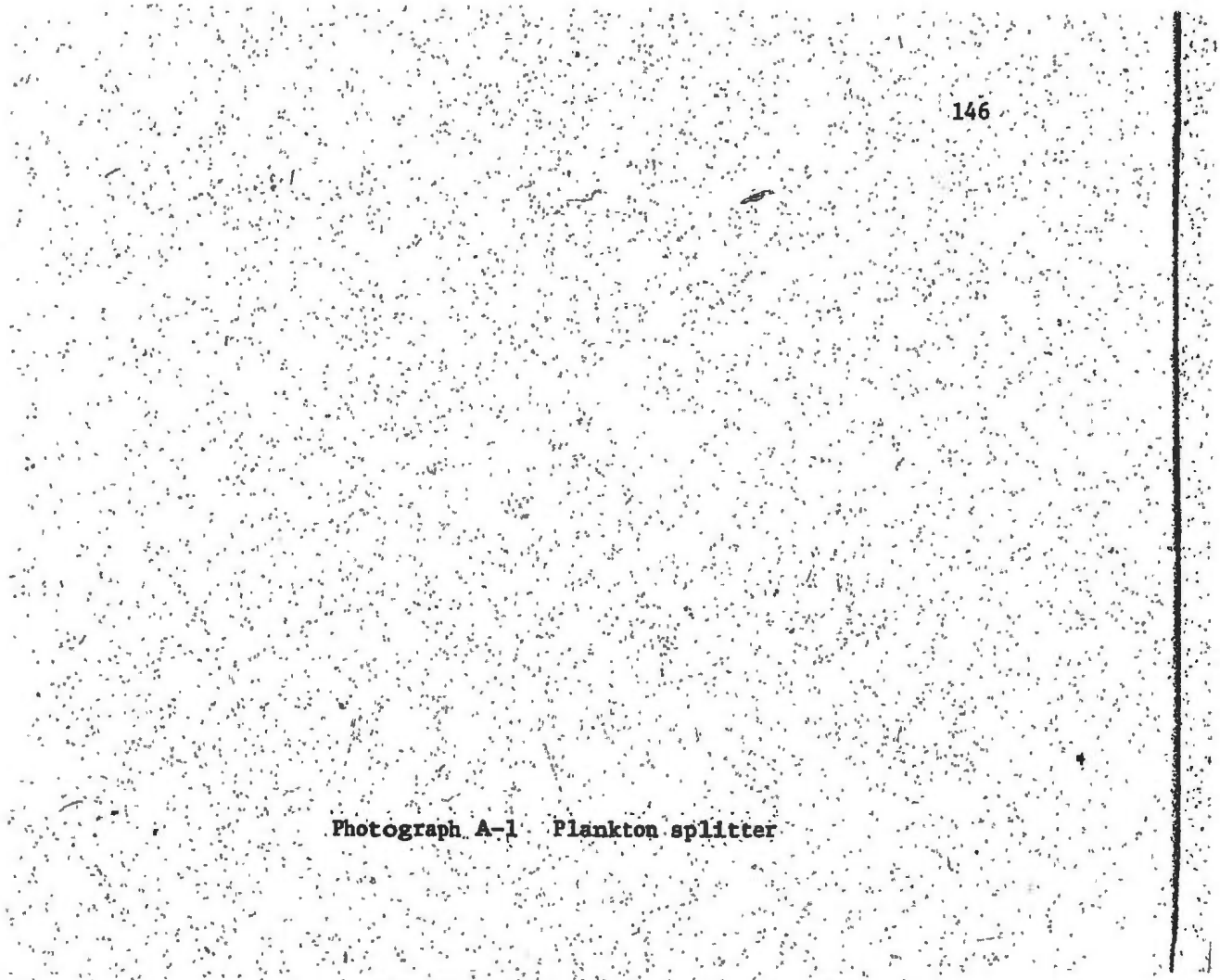
1. Allow field sample bottles to rest on the lab bench for more than 48 hours.
2. Slowly siphon off the supernatant preservative above the settled organisms in each bottle.
3. Pour remaining solution and organisms into a 4 oz. bottle.
4. Rinse field sample bottle with filtered sea water and add washings to the contents of the 4 oz. bottle.
5. Add sufficient formaldehyde to bring preservative strength to 6 ~ 10%. Store samples until required for counting.
6. Remove supernatant solution with controlled siphon.
7. Pour sample and rinsings into appropriate counting dish.
8. Add 20-30 drops of counting stabilization solution, and cover with a Kimwipe lens tissue.
9. Allow most water to evaporate at room temperature.

B. Small 0.5 m. net samples

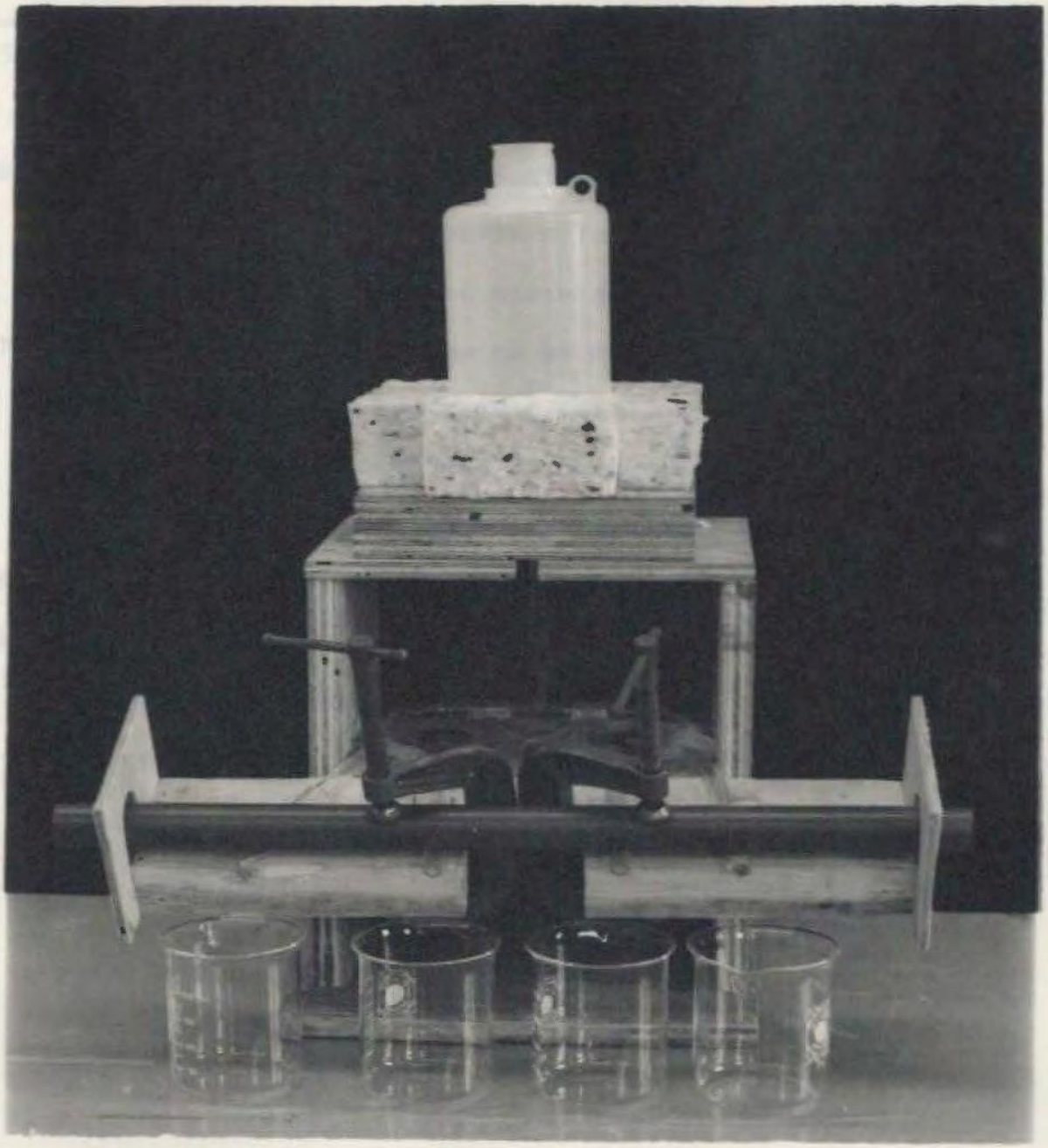
1. Do steps 1, 2 above.
2. Pour sample and filtered sea water rinsings into a 50 ml. graduated cylinder and allow to settle for more than 48 hrs.
3. Remove supernatant solution with control siphon.
4. After thia further period of settling pour sample and rinsings into appropriate counting dish.
5. Add 20-30 drops of counting stabilization solution.

Appendix 11 (Continued)

6. Allow remaining water to evaporate at room temperature after covering dish with lens tissue.
C. 0.5 m. Net large samples.
1. Use plankton splitter (Photograph A-1).
2. Clean glassware and rinse.
3. Bleed air from the splitter by allowing filtered sea water to flush through it. Turn clamps down after air is bled and while some water remains in the reservoir.
4. Place beakers under outlet hoses.
5. Pour sample into reservoir and add filtered sea water rinsings.
6. Shake reservoir.
7. Simultaneously open the two clamps and allow reservoir to drain. Close clamps.
8. Transfer aliquots to correspondingly numbered 500 ml. graduate cylinders. Return beakers to their previous positions.
9. Add another portion of filtered sea water to reservoir, shake reservoir and open clamps allowing remaining specimens to drain.
10. Add washings to respective graduate cylinders.
11. Record the water volumes of each graduate cylinder.
12. Rinse beaker with filtered sea water and add washings to respective cylinders.
13. Add 10-20 drops of Lugol's solution to the surface of each cylinder. Do not mix.
14. Cover cylinders and allow them to stand undisturbed for more than 24 hrs.



Photograph A-1 Plankton splitter



Appendix 11 (Continued)

15. After first settling carefully remove the supernatant from each cylinder.
16. Combine the two portions of the sample not to be counted, allow the solution to settle a further 24 hrs., remove the remaining supernatant and store specimen for reference.
17. Transfer the two portions to be counted to two 100 ml. graduate cylinders and repeat settling and siphoning procedure until the volume of concentrated plankton can be accommodated in the appropriate counting dish.
18. Add 20-30 drops of counting stabilization solution.
19. Cover counting dish with lens tissue and allow remaining water to evaporate at room temperature.

Appendix 12 Zooplankton analysis sheet

Appendix 12

Placentia Bay Zooplankton Study

Zooplankton Analysis

MASTER DATA CARD NUMBER | | | | | | | | | A

Study Area: _____ Station No: _____

Sampling Level: _____ Date: _____

Purpose of trip: _____

_____

Method of sampling: _____

_____

Total filtering time: ____ minutes, Length of water column sampled: ____ m

Volume filtered:

P.A.E.D.S. _____ m^3

0.5 m Net 0.19635 X _____ m = _____ m^3

Filtering rate: _____ Filter No: _____

Bottle No: _____

Method of concentration: _____

_____

_____

Method of counting: _____

Genus	Species	Tally	Total Count	Number/meter^3

Appendix 13

Counting procedure

A. For the PAEDS 233 μ and 153 μ samples and for the smaller o.5 m., 233 μ net samples:

1. Place counting dish on microscope stage.
2. Begin careful systematic search between the parallel lines identifying, counting and removing organisms.
3. Place those to be kept for reference in a Syracuse watch glass containing stabilization solution.
4. After removing all visible organisms take glass tube probe, break all debris masses, identify, count and transfer any trapped specimens to the watch glass and search parallel fields again.
5. Punch counts on the appropriately labelled keys of the counter.
6. After examining reference specimens flush them into a vial, add stabilization solutions and label.
7. Record counts and identification.

B. For the PAEDS 80 μ and 64 μ samples and for the large 0.5 m., 233 μ net samples:

1. Shake and swirl counting dish so that organisms appear to be evenly distributed.
2. After placing dish on the spiral counting block carefully put both on the microscope stage.
3. Enlarge 0.5 cm. diameter field magnification so that it approximately fills the microscope's field.

Appendix 13 (continued)

4. Starting at the center carefully identify, count and remove all organisms inside the outer circumference of all ten circular fields.
5. Record counts for each of the ten fields. Total and average each to obtain estimate count for each taxon.
6. One 0.5 cm. filed is 2.9×10^{-3} of the total inside area of the counting dish. Therefore apply multiplier 334.9 to average counts to obtain an estimate total count for each taxon represented in the sample or sample portion being analysed.
7. Record identifications and counts.

Appendix 14

Specific conductivity in the surge-tank

Experiment: C/S-1L

Observation	Specific Conductivity millemho / cm		D	D^2
	Salinometer X_{11}	Radiometer X_{12}		
1	35.60	28.83	6.77	45.8329
2	36.30	34.51	1.79	3.2041
3	36.10	34.61	1.49	2.2201
4	35.57	34.21	1.37	1.8769

$\Sigma D = 11.42$

$\Sigma D^2 = 53.1340$

$\bar{D} = 2.8550$

$S_D = 2.6160$

$S_{\bar{D}} = 1.3080$

$t_{test} = 2.1827$

C.R. = 3.1825

Accept null hypothesis

Appendix 15

Pooled specific conductivity

Experiment: C/S-2L

Observation	Specific Conductivity millimho/cm		D	D^2
	Salinometer X_{11}	Radiometer X_{12}		
1	31.26	30.45	0.81	0.6561
2	31.20	30.55	0.65	0.4225
3	31.14	30.25	0.89	0.7921
4	31.50	30.35	1.15	1.3225
5	34.86	30.75	4.11	16.8921
6	30.03	30.65	-0.62	0.3844
7	31.26	30.35	0.91	0.8281
8	31.20	30.75	0.45	0.2025
9	31.14	30.25	0.89	0.7921
10	31.50	30.35	1.15	1.3225
11	34.86	30.96	3.90	15.2100
12	30.30	30.75	-0.45	0.2025
13	32.34	30.35	1.99	3.9601
14	31.08	30.55	0.53	0.2809
15	32.16	30.65	1.51	2.2801
16	31.38	30.35	1.03	1.0609
17	38.40	31.57	6.83	46.6489
18	30.48	30.45	0.03	0.0009
19	32.34	30.25	2.09	4.3681
20	31.08	30.65	0.43	0.1849
21	32.16	30.35	1.81	3.2761
22	31.38	30.35	1.03	1.0609
23	38.40	30.75	7.65	58.5225
24	30.48	30.75	-0.27	0.0729

Appendix 15 (continued)

$\Sigma D = 38.5$

$\Sigma D^2 = 160.7446$

$\bar{D} = 1.6042$

$S_D = 2.0745$

$S_{\bar{D}} = 0.4235$

$t_{test} = 3.7880$

C.R. = 2.0687

Reject null hypothesis

Appendix 16

Specific conductivity of isolated pairs

Experiment: C/S-2L

Statistic	Set	Set	Set	Set
	A1 - B1	A1 - B2	A2 - B3	A2 - B4
	1 to 6	7 to 12	13 to 18	19 to 24
ΣD	6.99	6.85	11.92	12.74
ΣD^2	20.4697	18.5577	54.2318	67.4854
$\bar{D}$	1.165	1.1417	1.9867	2.1233
S_D	1.5701	1.4654	2.4719	2.8437
$S_{\bar{D}}$	0.6410	0.5983	1.0091	1.1609
t_{test}	1.8174	1.9084	1.9688	1.8290
C.R.	2.5706	2.5706	2.5706	2.5706
Decision	Accept	Accept	Accept	Accept

Appendix 17

Specific conductivity in the surge-tank

Experiment: C/S-3L

Observation	Specific Conductivity millimho/cm		D	D^2
	Salinometer X_{i1}	Radiometer X_{i2}		
1	27.66	27.41	0.25	0.0625
2	27.66	27.41	0.25	0.0625
3	27.72	27.41	0.31	0.0961
4	27.72	28.12	-0.40	0.1600
5	27.72	27.51	0.21	0.0441
6	27.42	27.00	0.42	0.1764
7	27.42	27.20	0.22	0.0484
8	27.36	27.10	0.26	0.0676
9	27.36	27.41	-0.05	0.0025
10	27.36	27.10	0.26	0.0676

$\Sigma D = 1.73$

$\Sigma D^2 = 0.7877$

$\bar{D} = 0.173$

$S_D = 0.2329$

$S_{\bar{D}} = 0.0737$

$t_{test} = 2.3474$

C.R. = 2.2622

Reject null hypothesis

Appendix 18

Specific conductivity over two gradients

Experiment: C/S-4L

Observation	Specific Conductivity millimho/cm		D	D^2
	Salinometer X_{11}	Radiometer X_{12}		
1	27.66	27.81	-0.15	0.0225
2	25.08	24.97	0.11	0.0121
3	21.30	21.52	-0.22	0.0484
4	15.90	15.23	0.67	0.4489
5	11.10	11.17	-0.07	0.0049
6	7.32	8.73	-1.41	1.9881
7	3.72	3.07	0.65	0.4225
8	7.98	8.63	-0.65	0.4225
9	2.70	3.05	-0.35	0.1225
10	1.02	0.11	0.91	0.8281
11	0.72	0.17	0.55	0.3025

$\Sigma D = 0.04$

$\Sigma D^2 = 4.6230$

$\bar{D} = 0.0036$

$S_D = 0.6799$

$S_{\bar{D}} = 0.2050$

$t_{test} = 0.0176$

C.R. = 2.2281

Accept null hypothesis

Appendix 19

Initial field evaluation of interference

Experiment: C/S-1F

	Surge-tank	Hose intake	Units
Conductivity	37.92	37.86	millimho/cm
Salinity	31.36	31.44	$^{o}/_{oo}$
Temperature	13.76	13.96	^{o}C

Appendix 20

Specific conductivity during the field trials

Experiment: C/S-2

Observation	Specific Conductivity millimho/cm		D	D^2
	Salinometer X_{11}	Radiometer X_{12}		
1	45.4	42.8	2.6	6.76
2	45.1	44.4	0.7	0.49
3	46.6	44.5	2.1	4.41
4	46.9	45.7	1.2	1.44
5	46.5	44.7	1.8	3.24
6	47.2	45.6	1.6	2.56
7	45.5	44.7	0.8	0.64
8	48.2	46.8	1.4	1.96
9	44.4	42.9	1.5	2.25
10	46.3	44.7	1.6	2.56
11	48.6	47.0	1.6	2.56
12	45.2	47.1	-1.9	3.61
13	45.2	47.0	-1.8	3.24
14	45.4	47.0	-1.6	2.56

$\Sigma D = 11.60$

$\Sigma D^2 = 38.28$

$\bar{D} = 0.8286$

$S_D = 1.4850$

$S_{\bar{D}} = 0.3969$

$t_{test} = 2.0876$

C.R. = 2.1604

Accept null hypothesis

Appendix 21

Laboratory evaluation of dissolved oxygen

Experiment: DO-1L

Observation	Dissolved Oxygen ppm		D	D^2
	YSI X_{11}	Winkler X_{12}		
1	8.2	7.27	0.93	0.8649
2	9.6	10.05	-0.45	0.2025
3	8.6	9.15	-0.55	0.3025
4	5.4	8.83	-3.43	11.7649

$\Sigma D = -3.5$

$\Sigma D^2 = 13.1348$

$\bar{D} = -0.875$

$S_D = 1.8323$

$S_{\bar{D}} = 0.9162$

$t_{test} = 0.9551$

C.R. = 3.1825

Accept null hypothesis

Appendix 22

Initial field evaluation of dissolved oxygen

Experiment: DO-1F

	Surge-tank	Hose intake	Units
Dissolved oxygen	9.8	10	ppm
Temperature	13.7	13.7	^{o}C

Appendix 23

Dissolved oxygen - PAEDS field series

Experiment: DO-2F

Observation	Dissolved Oxygen ppm		D	D^2
	YSI X_{i1}	Winkler X_{i2}		
1	8.09	9.09	-1.0	1.0
2	8.3	9.09	-0.79	0.6241
3	8.3	9.32	-1.02	1.0404
4	8.09	9.32	-1.23	1.5129
5	8.09	9.66	-1.57	2.4649
6	8.3	9.66	-1.36	1.8496
7	7.3	8.11	-0.81	0.6561
8	10.0	9.15	0.85	0.7225

$\Sigma D = -6.93$

$\Sigma D^2 = 9.8705$

$\bar{D} = 0.8662$

$S_D = 0.7432$

$S_{\bar{D}} = 0.2627$

$t_{test} = 3.2972$

C.R. = 2.3646

Reject null hypothesis

Appendix 24

Laboratory evaluation of temperature

Experiment: T-1L

Observation	Temperature °C		D	D^2
	Salinometer X_{i1}	Y.S.I. X_{i2}		
1	10.48	10.4	0.08	0.0064
2	10.64	10.7	-0.06	0.0036
3	9.12	9.4	-0.28	0.0784
4	11.72	11.7	0.02	0.0004
5	11.68	11.7	-0.02	0.0004
6	11.00	10.9	0.10	0.0100

$\Sigma D = -0.16$

$\Sigma D^2 = 0.0992$

$\bar{D} = 0.0266$

$S_D = 0.1378$

$S_{\bar{D}} = 0.0563$

$t_{test} = 0.4725$

C.R. = 2.5706

Accept null hypothesis

Appendix 25

Field trial evaluation of temperature

Experiment: T-1F

Observation	Temperature °C		D	D^2
	Salinometer X_{i1}	Y.S.I. X_{i2}		
1	13.92	13.6	0.32	0.1024
2	12.28	12.5	-0.22	0.0484
3	0.72	0.4	0.32	0.1024
4	4.20	4.2	0.00	0.0000
5	18.60	17.3	1.30	1.6900
6	17.68	17.4	0.28	0.0784
7	3.44	3.2	0.24	0.0576
8	2.76	2.7	0.06	0.0036
9	2.96	2.9	0.06	0.0036
10	2.84	2.8	0.04	0.0016

$\Sigma D = 2.40$

$\Sigma D^2 = 2.0880$

$\bar{D} = 0.2400$

$S_D = 0.4098$

$S_{\bar{D}} = 0.1296$

$t_{test} = 1.8516$

C.R. = 2.2622

Accept null hypothesis

Appendix 26

Meter calibration

Experiment: MC-1L

Sample I			
Observation	X_{i1} liters	$X_{i1}-\bar{X}_1 = di_1$	di^2
1	95.000	-0.178	0.0317
2	95.277	0.099	0.0098
3	95.257	0.079	0.0062

$\bar{X}_1 = 95.178$

$\Sigma di_1 = 0.000$

$S_1^2 = 0.0238$

$n_1 = 3$

Appendix 26 (continued)

Sample II

Observation	X_{12} liters	$X_{12} - \bar{X}_2$	di_2^2
1	95.0	-0.71	0.5102
2	95.9	0.19	0.0380
3	95.5	-0.26	0.0674
4	95.9	0.19	0.0380
5	96.4	0.65	0.4219
6	95.9	0.19	0.0380
7	95.5	-0.26	0.0674

$\bar{X}_2 = 95.724$

$\Sigma di_2 = 0.0005$

$S_2^2 = 0.1968$

$n_2 = 7$

Appendix 26 (continued)

Significance of difference between two means

S = 0.3917

t_{test} = -2.0199

C.R. = 2.3060

Accept null hypothesis

Appendix 27

Total plankton count for sources of sets

Experiment: SE-1L

Set 1	Field Sample Bottle	PAEDS Field Trial	PAEDS Filter μ	Total Plankton Count
	a77	9	080	6363
	a61	10	233	665
	a15	11	153	747
	a60	8	153	1445
	a52	11	080	2781
	a14	7	080	----
	a42	7	153	----
	a51	11	233	797
	a76	8	233	699
	a39	8	233	1355
			$\Sigma_{1,1}$ ∓	14852

Appendix 27 (continued)

Set 2	Field Sample Bottle	PAEDS Field Trial	PAEDS filter μ	Total Plankton Count
	U_o	11	233	45378
	X_o		1050	---
	a55	7	064	---
	a40	11	064	2043
	a57	6	571	---
	a45	7	153	---
	a78	10	233	384
	a58	8	080	4221
	a80	9	064	1239
	F_o	6	233	61346
			$1,\Sigma_2$ ÷	114611
Set 3				
	a70	9	233	720
	a38	7	080	---
	a37	7	233	---
	a41		1050	---
	a79	10	153	1203
	B_1	9	233	43749
	F_1	10	233	38976
	a16	7	233	---
	a62	10	064	2177
	a74	9	153	932
			$1,\Sigma_3$ ÷	87757

Appendix 28

Plankton count on supernatant

Experiment: SE-1L

Group	Set 1	Set 2	Set 3
Cnidarians	2	8	16
Gastropod larvae	1	1	0
Bivalve larvae	12	0	13
Polychaete adults	2	1	0
Other annelids	0	0	3
Cladocerans	7	15	19
Calanoids 6 male	1	2	2
Calanoids 6 female	0	2	6
Calanoids 5 male	0	0	2
Calanoids 4	0	1	2
Calanoids 3	3	4	5
Calanoids 2	0	0	1
Calanoids 1	3	0	10
Harpacticoids	3	0	7
Cyclopoids 6 male	0	6	30
Cyclopoids 6 female	2	12	9
Cyclopoids 3 - 5	29	17	69
Cyclopoids 2	34	1	26
Cyclopoids 1	102	0	16
Copepod nauplii	469	100	160
Bryozoan cyphonautes	0	1	0
Chaetognaths	1	2	0
Copelatans	7	0	1
$\sum_{2} n$	678	173	397

Appendix 29

Summary of PAEDS field trials

PAEDS Field Trial	Date	Study Area	Station	Sampling level m.	Conductivity/Salinity	Dissolved oxygen	Temperature	Zooplankton samples	Experiment in progress
1	16-IX-70	2	1	00	✓	✓	✓	4 filters	C/S-1F C/S-2F DO-1F T-1F
	Remarks: Initial field evaluation of equipment Alterations - change position of suction hose - make cover for Surge-tank - improve filter cleaning apparatus								
2	29-I-71	2	1	00	-	-	-	none	no samples
	Remarks: Weather conditions too rough to sample and the surge-tank requires an extension.								

Appendix 29 (continued)

PAFDS Field Trial	Date	Study Area	Station	Sampling level m.	Conductivity/Salinity	Dissolved oxygen	Temperature	Zooplankton samples	Experiment in progress
3	17-II-71	2	5	00	✓	✓	✓	1 filter	C/S-2F

Remarks: Regular stations could not be sampled because ice extended from Bordeaux Island to North Harbour Point. The alterations made to the Surge-tank and the new Air-spray Unit operated satisfactorily.

4	31-III-71	2	1	00	✓	✓	✓	4 filters	C/S-2F Z-1F
				05	✓	✓	✓	4 filters	C/S-2F
5	24-VI-71	2	1	00	✓	✓	✓	4 filters	C/S-2F DO-2F
				05	✓	✓	✓	4 filters	C/S-2F

Appendix 29 (continued)

PMEDS Field Trial	Date	Study Area	Station	Sampling level m.	Conductivity/Salinity	Dissolved oxygen	Temperature	Zooplankton samples	Experiment in progress
5	cont'd.	2	3	00	✓	✓	✓	1 filter	C/S-2F DO-2F
				50	✓	✓	✓		T-1F Z-2F
6	18-VIII-71	2	3	00	✓	✓	✓	1 filter	C/S-2F T-1F
				50	✓	✓	✓		Z-2F
7	18-VIII-71	1	12	00	✓	✓	✓	4 filters	C/S-2F DO-2F T-1F AS-1F
				05	✓	✓	✓	4 filters	C/S-2F T-1F AS-1F
8	18-VIII-71	1	15	00	✓	✓	✓	4 filters	C/S-2F DO-2F
				50	✓	✓	✓		T-1F Z-3F AS-1F

Appendix 29 (continued)

PAEDS Field Trial	Date	Study Area	Station	Sampling level m.	Conductivity/Salinity	Dissolved oxygen	Temperature	Zooplankton samples	Experiment in progress
9	23-VIII-71	2	3	00	✓	✓	✓	4 filters	C/S-2F T-1F
				50	✓	✓	✓		Z-3F AS-1F
10	23-VIII-71	2	3	00	✓	✓	✓	4 filters	C/S-2F T-1F
				50	✓	✓	✓		Z-3F AS-1F
11	23-VIII-71	2	3	00	✓	✓	✓	4 filters	C/S-2F T-1F
				50	✓	✓	✓		Z-3F AS-1F

Appendix 30

Starting dates of laboratory experiments

Experiment	Date initiated
C/S-1L	13-VIII-70
C/S-2L	13-XI-70
C/S-3L	20-IV-72
C/S-4L	21-IV-72
DO-1L	29-V-71
T-1L	13-VIII-70
ML-1L	4-III-72
SE-1L	28-VIII-71

Appendix 31

Details of zooplankton sampling

Experiment	PAEDS Field Trial	Start of filtering (hrs.)	Volume filtered by PAEDS (m^3)	Hose retrieval velocity (m/min.)	Volume filtered by net (m^3)
E - 1F	4	1419	0.9592	---	---
E - 2F	5	1738	0.1000	10.31	10.13
	6	1057	0.1546	6.45	10.13
E - 3F	8	2022	0.1845	7.37	10.13
	9	959	0.1559	6.83	10.12
	10	1158	0.2573	12.88	10.12
	11	1556	0.1709	6.44	10.12

Appendix 32

Approximate water velocities in intake hoses of several plankton pumping devices

Source	Velocity, meters/sec.
Juday 1916	0.5
Gibbons and Fraser 1937	3.2
Wiborg 1948	0.7
*Seymour 1950	0.8
Langford 1953	0.5
Aron 1958	2.8
Cassie 1958	1.5
*Held 1961	3.1
Mathisen 1964	1.5
Beers et al 1967	1.1

*See Aron 1958, 1962.