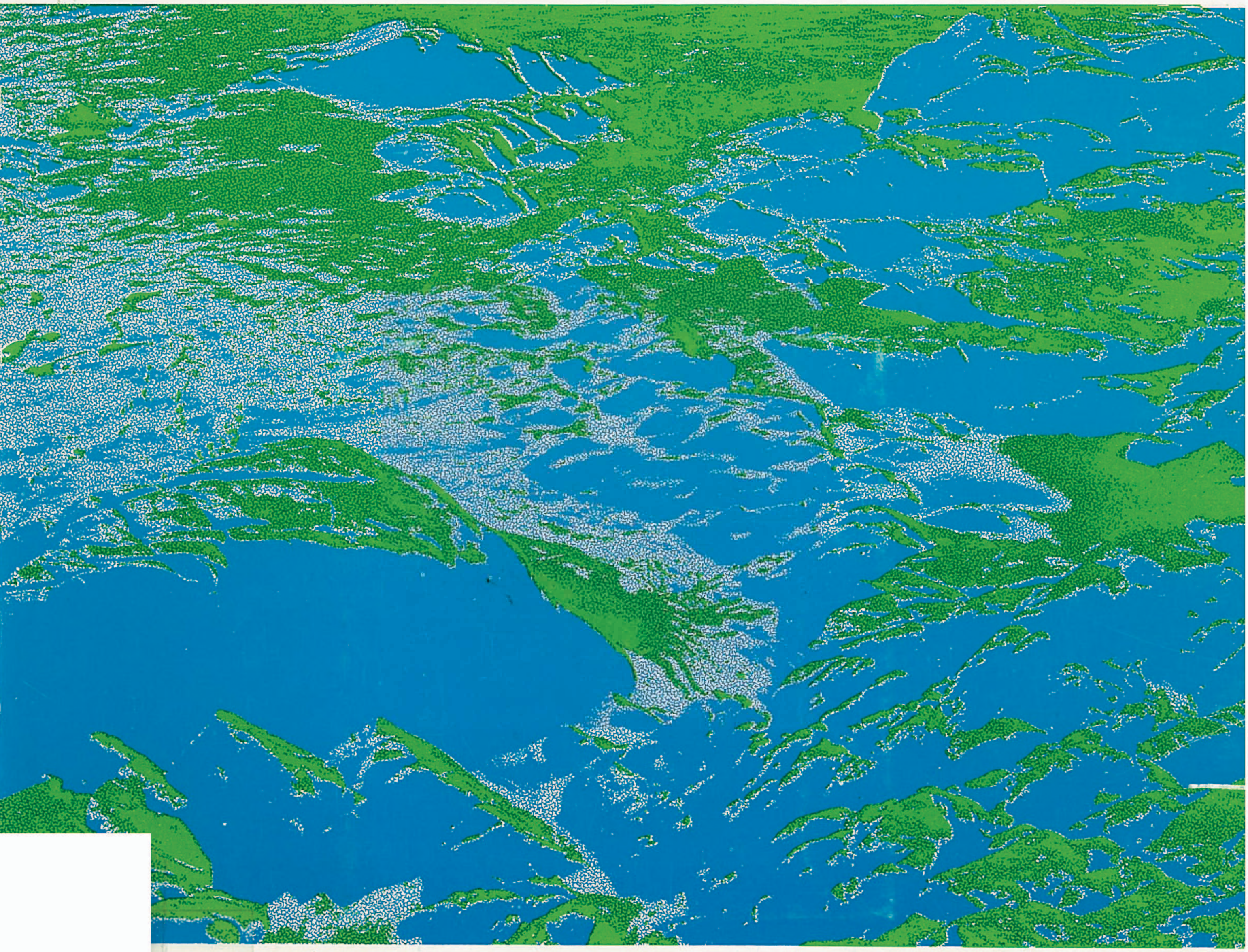
SHIPS OF OPPORTUNITY FEASIBILITY STUDY PART 3: OCEANOGRAPHIC OBSERVATIONS

By: G.A. Borstad
G.C. Louttit
R.D. Gale
J.R. Buckley

SEAKEM OCEANOGRAPHY LTD



EAKEM OCEANOGRAPHY LTD SIDNEY, BRITISH COLUMBIA, CANADA

SHIPS OF OPPORTUNITY
FEASIBILITY STUDY
PART 3:
OCEANOGRAPHIC OBSERVATIONS

by

G.A. Borstad
G.C. Louttit
R.D. Gale
J.R. Buckley

of

Seakem Oceanography Ltd.
9817 West Saanich Road,
Sidney, British Columbia
V8L 3S1

Scientific Authority

Dr. R.O. Brinkhurst
Department of Fisheries and Oceans
P.O. Box 6000
Sidney, British Columbia
V8L 4B2

DSS FILE NO. 08SB.KF833-8-1066
CONTRACT SERIAL NO. 1SB78-00255

MARCH, 1980

FOREWARD

This report constitutes something more than a collation of the data collected during the ships of opportunity feasibility study. Since very few measurements of this kind were available previously, the study was also exploratory. In order to make the report more usable, we have chosen to present most of the data graphically and have spent considerable time in analysis and discussion of the data. The discussions which are included here, while admittedly simplistic, are an effort to facilitate use of the data and provoke thought regarding mechanisms driving the coastal production processes. Even six cruises do not provide sufficient amounts of data to describe much of the temporal and spatial variability off this coast, and it will be necessary to merge several intensive surveys to achieve this with no ambiguity. The discussion of satellite imagery and lighthouse data acquired coincident with ship-of-opportunity cruises was an attempt to do this.

ABSTRACT

This report presents the oceanographic data collected during a study carried out by Seakem Oceanography Ltd. to investigate the feasibility of utilizing commercial ships-of-opportunity off the British Columbia coast. Continuous measurements of temperature, conductivity, *in vivo* fluorescence and zooplankton particles at 3 m depth as well as discrete sampling for chlorophyll, nitrate and phosphate concentrations, salinity, and phytoplankton and zooplankton species determination, also at the same depth was conducted between Howe Sound and Nootka Sound via the Strait of Juan de Fuca.

The data from six monthly cruises between May and October 1979 constitute a large data set describing the temporal and spatial variability of the surface waters of the Strait of Juan de Fuca and coastal area of southwest Vancouver Island. These data demonstrate the importance of the nutrient export from the Juan de Fuca system to the southern continental shelf and show that the high phytoplankton standing crops in this area are generally situated at the outer edge of the cool high nutrient waters exiting the strait along the Canadian shore. Extensive migrations of the boundary of the Juan de Fuca water are also documented.

ACKNOWLEDGEMENTS

Greg Louttit and Derek Gale carried out all of the field work and laboratory analysis. Kris Beadall and Joe Buckley wrote the computer software and together with Bodo de Lange Boom and Marg MacNeill, Joe provided considerable assistance in deciphering the conductivity data. Robin Brown, Pat Rothwell, Randy Forsyth and Irene Stevenson made very real contributions in the preparation of this report. The advice, assistance and criticisms of Dave Mackas, Ken Denman and Dave Blackbourn throughout the project is gratefully acknowledged.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF FIGURES

LIST OF FIGURES
(Continued)

LIST OF FIGURES
(Continued)

LIST OF FIGURES
(Continued)

LIST OF FIGURES
(Continued)

LIST OF FIGURES
(Continued)

LIST OF FIGURES
(Continued)

LIST OF TABLES

LIST OF TABLES
(Continued)

1. DESCRIPTION OF PROJECT

This report summarizes the organization, methodologies and results of the six cruises of a study designed to test the feasibility of using commercial ships of opportunity to gather oceanographic data along Canada's west coast. The project was the result of an unsolicited proposal from Seakem Oceanography Ltd., Sidney, British Columbia, to the Department of Supply and Services, Ottawa. The Scientific Authority is R.O. Brinkhurst, Ocean Ecology, Institute of Ocean Sciences, 9860 West Saanich Road, Sidney, B.C., V8L 4B2.

The basic objectives of the project, which began in October 1978, were:

1. to determine the usefulness of commercial ships of opportunity off the British Columbia coast in the context of a long-term project;

2. to begin collection of simultaneous data describing the temporal and spatial variability of physical, chemical and biological oceanographic conditions off Canada's west coast;

3. to provide nearly-synoptic information describing the near-surface oceanographic and meteorological phenomena off the British Columbia coast.

The report consists of 8 sections, in which the tables and figures are numbered consecutively. The first section which is a description of methods and instrumentation is followed by six cruise reports including tabulated and graphically presented data for each cruise as well as pertinent discussion. These are followed by a general discussion of the entire data set. Pertinent satellite imagery is included where available.

1.1 THE VESSEL - MV RIVTOW VIKING

1.1.1 Description of MV Rivtow Viking

The vessel used during the field season is an all-steel construction oceangoing tug, the MV Rivtow Viking. The Viking is 47 m long, of 578 gross tonnage and is now registered at Vancouver. She carries a crew of 11 and is exclusively employed by Rivtow Straits Ltd. to tow self-loading log barges between Howe Sound and the west coast of Vancouver Island. Figure 1 shows the Viking and her barge in Burgoyne Bay near Saltspring Island prior to her first cruise as a ship of opportunity.

Figure 1. MV Rivtow Viking and self-loading log barge

1.1.2 Route of Rivtow Viking

The Viking is occupied in towing a self-loading log barge between the booming grounds of Nootka and Esperanza Inlets on the west coast of Vancouver Island and the mills of Howe Sound, north of Vancouver. This cruise is made once every week on the average although a number of factors such as mechanical problems with the ship or barge or any disruptions in the flow of logs to or from the mills can alter the schedule. The one way trip between Howe Sound and Nootka Sound takes approximately 36 hours at an average speed of 8-10 knots. The Viking also makes occasional trips elsewhere, to the Queen Charlotte Islands for example. Maps bound with the cruise reports illustrate her routes for each of the six cruises on which oceanographic data were obtained (RV001 through RV006).

Although the Viking's home port is Vancouver, she routinely operates from the Howe Sound area - principally, Gambier Island, only returning to Burrard Inlet for repairs, provisioning and crew change once per month. The loaders (barge crane operators) do not remain on the ship but are transferred from Vancouver to the ship in Howe Sound or Tahsis Inlet and back again by float aircraft each time the barge loads or unloads. The seagoing oceanographic technicians also travelled to and from the vessel in this manner.

1.1.3 Modifications to the Rivtow Viking - the Seawater Loop

Original plans called for use of the ship's own seawater system, either the main intake or one of the auxiliary systems. This did not prove feasible however, since all of the seawater systems contain zinc anti-corrosion electrodes and the main sea chest has an chlorinator. Such devices are common on oceangoing ships and are designed to prevent fouling. It is known that low concentrations of heavy metals affect growth of phytoplankton (Bartlett et al., 1974 and others). In order to avoid the possibility that *in vivo* chlorophyll *a* fluorescence would be affected in water from this seawater system and since an alternative water intake was available on the Viking, the ship's seawater system was not used.

The Viking had an unused pitot tube mounted on the ship's bottom near the keel and 5 m from the bow. With Rivtow Straits permission we had this tube cut off and the through-hull fitting re-opened, thus providing an opening very near the forward hold where space was available for our instrumentation and sample workup and where a nearby overboard discharge also existed. A spare cabin with three bunks was close by for our use. Figure 2 illustrates the relative location of the inlet and instrumentation. The configuration of the new seawater loop installed by Rivtow Straits to meet our requirements is shown schematically in Figure 3. The installation cost was approximately $1,500 (1979).

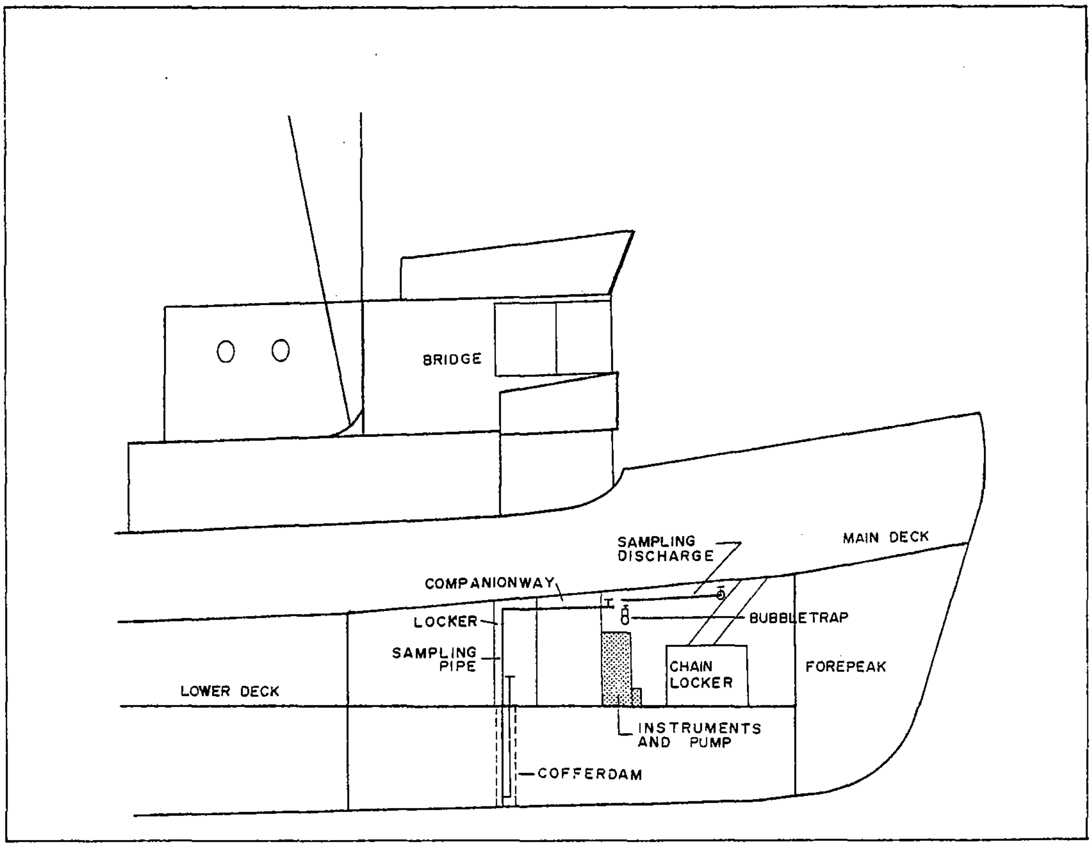


Figure 2 Location of sampling inlet, instrumentation and discharge

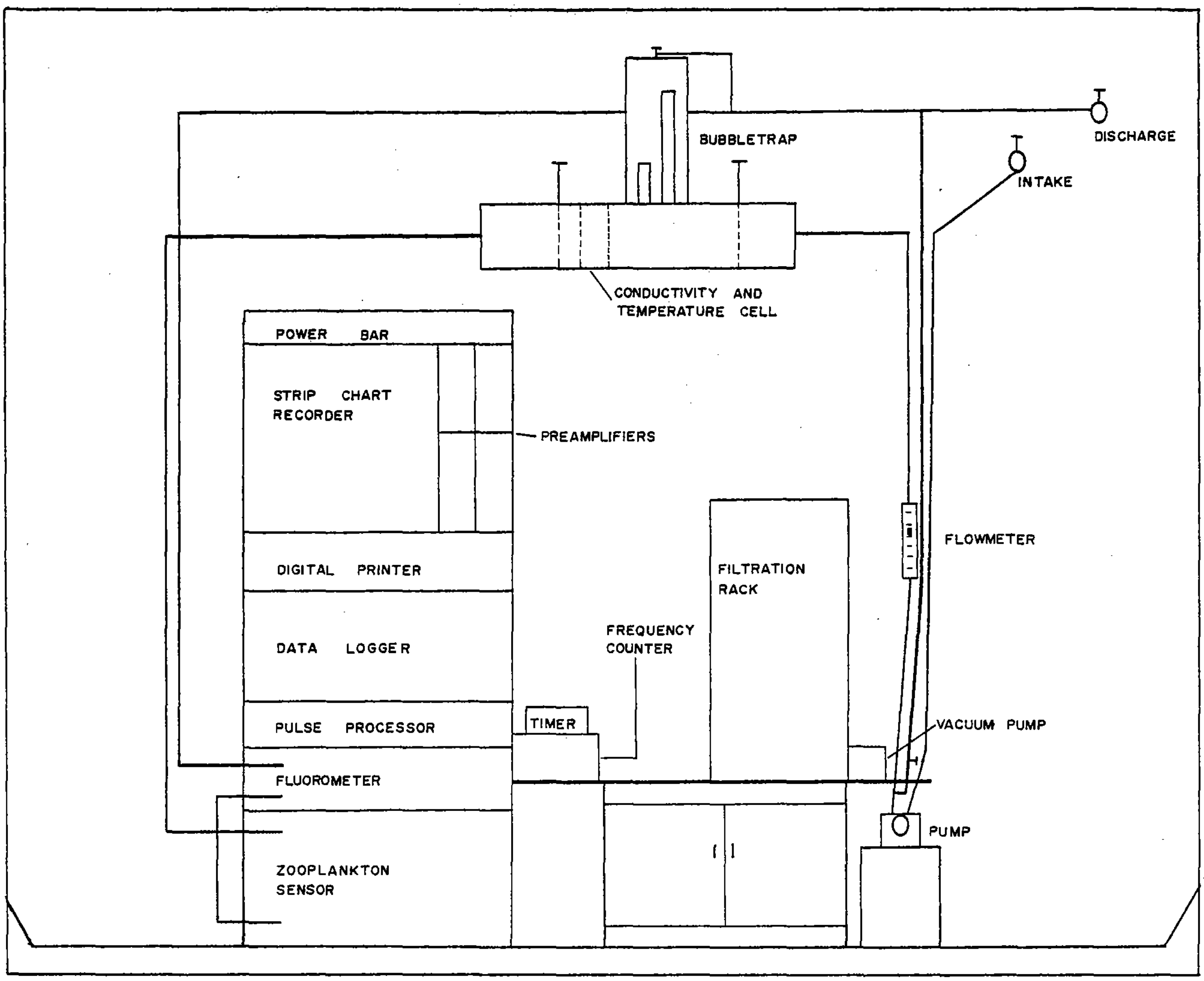


Figure 3 Configuration of seawater loop and instrumentation

1.2 TECHNICAL ASPECTS OF THE PROJECT

1.2.1 Logistics

Since the schedule of the ship was not regular, it was necessary to establish its place and time of departure with the Rivtow Marine dispatcher before each oceanographic cruise. Most of the instrumentation was left aboard the ship and only crated sample bottles, a second bench-type fluorometer, filteration equipment and personal gear were transported back and forth to the laboratory. When the ship was operating from Vancouver the two technicians and their gear were sent to the ship by truck. At other times they were sent to or retrieved directly from the ship in Howe Sound by float-plane. This was efficient since the laboratory was only a few hundred meters from the float-plane jetty and no time was wasted on ferry transport between Sidney and Vancouver, or North Vancouver and Langdale or on waiting for these ferries during the summer tourist season. The average cost of transportation to and from the ship for the first two cruises was $350 in 1979.

On the first cruise, the two technicians worked a three-hour on, three-hour off routine, thus enabling passage from Howe Sound to the Tahsis area. They had cabins on the lower deck, well away from the rest of the ship's company and operation during the night did not disturb the crew. They could also sleep undisturbed while the ship is loading or unloading if they so wished. Accommodation was provided free of charge by Rivtow Straits, and meals cost the project $20 per man per day.

1.2.2 Parameters Measured

The following suite of observations was carried out on most cruises (summarized in Table 1): continuous monitoring of water temperature, salinity,

TABLE 1 Summary of Parameters Measured, with Notes on Sampling Method and Data Analysis

PARAMETER	SAMPLING METHODS	ANALYSIS METHOD	DATA ANALYSIS	NOTES
TEMPERATURE				
Near Surface (approx. 3m)	Continuous from seawater intake	Thermosalinograph on board	Computer translation of magnetic tape records	
Near surface	Manual from seawater intake and/or bucket over side	Crawford bucket	Manual, computer assisted	For calibration and checking of thermo-salinograph
SALINITY				
Near surface	Continuous from seawater intake	Thermosalinograph on board	Computer translation of magnetic tape records	
Near surface	Manual from seawater intake and/or bucket over side	Salinometer ashore	Manual, computer assisted	For calibration and checking of thermo-salinograph
NUTRIENTS				
Nitrite, Nitrate, Phosphate	Manual from seawater intake	Colourometric ashore	Manual, computer assisted	
PHYTOPLANKTON				
Chlorophyll *a*	Continuous from seawater intake	*in vivo* fluorometry on board	Computer translation of magnetic tape records	
	Manual from seawater inatake and/or bucket over side	Spectrophotometry and fluorometry of chlorophyll extracted from filtered phytoplankton - shore based laboratory	Manual, computer assisted	For calculation of *in vivo* fluorescence techniques
DCMU Number	Manual from seawater intake	Ratio of *in vivo* fluorescence before and after addition of the herbicide	Manual, computer archived	Exploratory, recent publication claim number proportional to productivity (Samuelsson and Öquist, 1977)
Phytoplankton	Discrete samples from intake	For species identification	Collection only-no analysis	Deposited with Ocean Ecology, Institute of Ocean Sciences
ZOOPLANKTON/NEKTON				
Near Surface (approx. 3m)	Continuous from seawater intake	Continuous particle counting using low power electric oscillation across seawater intake	Computer translation of magnetic tape records	For description of analytical unit, see Mackas (1977)
Near Surface	Discrete samples from seawater intake	Microscopic examination of zooplankton samples gathered synchronously with several counting cycles of the electronic counting device	Manual	For calibration and checking of the efficiency of electronic counting device
	Discrete samples from seawater intake	For species identification	Collection only-no analysis	Deposited with Ocean Ecology, Institute of Ocean Sciences

in vivo chlorophyll *a* fluorescence and zooplankton concentration* on sea water pumped from a through-hull fitting at 3 m depth; discrete samples from an in-line sampling spigot and/or over-the-side bucket sampling for water temperature, salinity, chlorophyll *a* concentration and dissolved nitrate, nitrite and phosphate concentration. Water samples were also collected for phytoplankton and zooplankton species abundance and composition and are deposited with the Ocean Ecology Division, Institute of Ocean Sciences who will analyse them at a later date. Zooplankton for species identification were collected through the in-line system by diverting the flow through a plankton net built into the zooplankton sensor.

1.3 Instrumentation and Methodology - Continuous and In-Line Discrete Sampling

1.3.1 Seawater Loop

The pumping system installed on board the Viking for this project (ECO model A6-A6TA stainless steel pump with Teflon impeller and bearings) was capable of delivering 45 L/min at 50 psi. In operation it delivered water from a depth of approximately 3 m, through a flush through-hull opening of 2.5 cm (1 inch) diameter) A 2 cm (3/4 inch) inside diameter pipe approximately 7 m long delivered water to the pump, which was mounted before the bubble traps and sampling gear. Immediately downstream from the pump the flow was split with one line going directly to the overboard discharge, and the other through an in-line floating ball type flowmeter to the monitoring equipment. A valve in the line to the discharge permitted adjustment of the flow through the equipment.

The line from the flowmeter went first to the thermosalinograph and its associated bubble-trap, then to the zooplankton sensor and its bubble-trap, through the fluorometer and then into the discharge line. A spigot

* via an electronic particle counter developed by C.M. Boyd, University of Dalhousie, Halifax, N.S. in conjunction with the National Research Council.

between the zooplankton sensor and the fluorometer allowed in-line discrete samples to be drawn easily.

1.3.2 Thermosalinograph

An Applied Microsystems Model #780-9 conductivity and temperature cell (thermosalinograph) was incorporated into the outflow side of a PVC bubble trap located between the pump and the zooplankton sensor. This cell is modelled after the conductivity/temperature sensor designed by the Frozen Sea Research Group at the Institute of Ocean Sciences, Patricia Bay. The ascribed advantages to this design include the ability to have the sensor remote from its electronics and increased stability of the cell constant in spite of biological activity, dimensional changes, or corrosion in the vicinity of the electrodes. A glass bead thermister protruding into a flowthrough well is used in a conventional wheatstone bridge arrangement to determine temperature. The associated electronics are contained within the Applied Microsystems data logger (Model 750).

1.3.3 The Zooplankton Sensor

The zooplankton sensor used here was first developed by NRC and Carl Boyd, Dalhousie University, Halifax (Boyd and Johnson, 1968) and his co-workers (Mackas, 1977). It is now manufactured by Surfline Engineering of Halifax for approximately $6,000. It is basically a particle counter which acts through resistive modulation of a low power electric oscillation passed across a portion of the sea water line. As a particle passes through one of the 4 parallel sensor tubes (each 3 mm in diameter) in the seawater line, the resistance across the tube increases momentarily. Four annular electrodes around each sensing tube provide the means by which a constant 50 kHz carrier signal is applied and by which the oscillating signal is measured. The temporary increase in the amplitude of the signal received from the sensor which results from passage of a particle through the tube is rectified, filtered and amplified to give a raw signal with peak height proportional to particle size. It is possible to discriminate size classes but the electronics utilized here are not configured to provide this discrimination in the final output signal. Instead, all particles above a threshold size are accumulated over an adjustable integration period.

The particular sensor used in this project was not calibrated, and the data collected are all relative. Other instruments of which this is essentially a copy, are accurate to better than 5% when calibrated against discrete samples taken from the seawater line. Because the sensor tubes are of small diameter, large particles are not sampled even though they will usually pass through the system. Large gelatinous plankters will break apart and the resulting fragments will be counted as a spurious burst of counts. The experience of Boyd and Mackas indicates that this is not a problem.

1.3.4 The Fluorometer

A rack mounted Turner Designs model 10-000R fluorometer was utilized in flow-through mode to continuously monitor in vivo chlorophyll fluorescence. A model 10-045 'blue' lamp, in conjunction with a Corning 5-60 filter, provided excitation energy and a R446 infra-red sensitive photomultiplier, in conjunction with a Corning 2-64 filter was used for recording emission energy. The output analogue signal was sent to both the chart recorder and the data logger where it was recorded on magnetic tape. The analogue range indicator was also recorded on magnetic tape.

1.3.5 Chart Recorder

All four continuously monitored parameters were recorded on a four channel strip chart along with 1 minute interval time marks. Ideally this would have allowed the technicians to monitor conditions and adjust the sampling routine for the discrete samples if abrupt changes are observed in the continuously monitored data however, the location of the instrumentation on the ship was very uncomfortable and was generally only visited at ½ hour intervals. The recorder was a Gould model 2007-4424. Each analogue signal is routed through a pre-amplifier prior to reaching the recorder amplifier, which allowed selection of magnitude and polarity of zero suppression capabilities, variable frequency noise filters and full scale deflection voltage.

1.3.6 Data Logger

Data from the fluorometer and the temperature, conductivity and zooplankton sensors were automatically recorded onto ¼" magnetic tapes using an Applied Microsystems Model 750 Data Logger. In operation this logger derived timing intervals from an internal quartz clock and a multiple position switch on the front panel. At chosen integration times between 1.75 seconds and 7.47 minutes, the analogue signals are digitized and, along with the accumulated zooplankton pulse count and a time signal, are serially recorded on two magnetic audio tape tracks in a non-critical binary code. Data tapes are translated using an Applied Microsystems Model 769 Tape Reader. An Applied Microsystems Digi Print 701 was directly linked to the logger to provide real time digital printouts of all the data channels.

1.4 Bucket Sampling

On cruise RV001 and RV002, surface water temperature were determined on water drawn from the sea surface by bucket over the ship's side. The thermometer used was a mercury in glass ASTM 90C type with $0.1^{o}C$ graduations from 0 to $35^{o}C$. It was suspended by foam plugs in a bucket made of PVC 7.5 cm in diameter which was wrapped in 1 cm foam as insulation and as some protection against banging against the ship's side. The bottom of the tube was closed and water was caught in a cavity of about 150 ml capacity around the thermometer bulb. This thermometer bucket was lowered over the port side of the ship, amid-ship and well clear of any discharges. One rinse was made and the temperature of the second sample read after two or three minutes equilibration. Thermometers of this type are accurate to 0.1^{o}C.

Discrete samples for surface salinity, chlorophyll a and/or other parameters were drawn from a second bucket also constructed of rigid PVC tube (dimensions 10 cm diameter x 75 cm long) with an approximate volume of 3 L. In practice this bucket was cast forward from the same position clear of discharges and could easily be retrieved even at speeds of 8-10 knots because of its narrow mouth. A thorough rinse was made and after retrieval of the second cast, the bucket was attached by its line to a nearby bulkhead hook. Samples were drawn through a spigot on the bottom end of the tube. Usually these samples were drawn from two to four minutes after the cast, allowing the single technician on-duty to obtain in-line samples as closely spaced in time as possible. Bucket sampling was discontinued after cruise RV002 because of the lack of a safe sampling platform. The only available locations from which to sample were awash in seas greater than 1 m.

1.5 Analytical Methods

1.5.1 Salinity

Discrete salinity samples drawn from the in-line sampling spigot and/or from surface bucket samples were determined in the laboratory with a Guildline Autosal or a Hytech Model 621 inductive bench salinometer periodically checked against a Guildline Autosal Salinometer. One replicability test (n=10) indicated a standard deviation of 0.03 ppt in sampling and analysis, however see later in section 3 for a discussion of the quality of the salinity data.

1.5.2 Chlorophyll a/Phaeopigment

Discrete samples of sea water (100 ml minimum volume) were filtered on board the ship through 25 mm GFC glass fibre filters at less than 150 mm HG vacuum. A few drops of $MgCO_3$ suspension was added as the last 20 ml are filtered. The filters were folded face inwards, blotted dry on paper towels and wrapped in wax paper and tin foil, labelled and stored in the ship's freezer at - 17°C. At the end of the cruise they were returned to the laboratory in a cooler if the trip was to be by truck, otherwise they were stored in the same boxes as the frozen nutrient solutions. They were kept in the laboratory freezer for approximately a week before analysis using a Turner Model 111 fluorometer with R446 red sensitive photomultiplier and 'blue' lamp.

Analysis techniques were basically the same as Strickland and Parsons (1972) except that a Corning C/S 2-A filter is used in conjunction with the primary filter (Corning C/S 2-64) to more specifically excite chlorophyll a (Saijo and Nishizawa, 1969). The resulting increase in acid ratio allows greater precision in chlorophyll determination.

1.5.3 DCMU Ratio

In an effort to eliminate some of the physiological variability of chlorophyll fluorescence the herbicide 3- [3,4 dichlorophenyl]-1,1-dimethyl urea (DCMU) was employed in conjunction with in vivo fluorescence measurements using a Turner model 111 bench fluorometer. At most stations the in vivo fluorescence of a 5 ml sample was recorded before and after addition of 2 drops of 0.4 mM DCMU. DCMU acts by blocking the electron transport system of the phytoplankton, thereby causing a diversion of energy from excited chlorophyll to in vivo fluorescence enhancing it by up to 4 times or more (Govindjee et al., 1973). The DCMU ratio (in vivo fluorescence divided by DCMU enhanced fluorescence) has been reported to be roughly proportional to carbon uptake (Samuelsson and Oquist, 1977).

1.5.4 Dissolved Nitrate/Nitrite

Dissolved nitrate and nitrite were measured on unfiltered 65 ml samples drawn from the in-line sampling spigot and frozen to -17°C in glass culture tubes. Analysis of nitrite was by the technique outlined by Grasshoff (1967). Nitrate analysis was by the same technique after the nitrate had been reduced

gelatinous
spurious
bang
rinse
equilibration

of nitrate was similar to that described by Grass-
mium wire column replaced the column of cadmium
l of sample were required for reduction (Gardner,
Standardizations were performed using standard
ints exhibiting r^2 value of .98 or more. Where
:y for a sample was less than the reagent blank
reported. All nitrate values reported are corrected for nitrite concentration according to Strickland and Parsons (1972). Where nitrate values are lower than calculated nitrite they were reported as 0.00.

1.5.5 Dissolved Reactive Phosphate

Dissolved orthophosphate concentrations were measured on unfiltered 65 ml samples as per Grasshoff (1974). Standardizations were performed using standard curves with at least 5 points having an r^2 value greater than .98.

1.6 Data Processing

Data processing for this project was done using a Seakem in-house computing system which is a S-100 microcomputer based on a North Star Horizon CPU with 48K of memory.

A sequence of programs was written to create and modify a database file on diskette for each cruise. The raw data (optical densities, fluorometer readings) were entered and the processed data collected for each station and grouped together in a single record along with all of the other computed parameters for each station. Station records were stored sequentially in the data file. This data file was then used to create plots of any variable against any other, regression analyses of any two variables or multiple correlation calculations.

The data on magnetic tape were transferred to the computer via an Applied Microsystems tape translator and interpreted by a program which then wrote them onto diskette. Subsequent programs allowed the operator to remove erroneous points from the data file, plot the data and convert the data logger numbers to calibrated values.

1.7 Data Presentation

The tabulated data which are included in Sections 2.1 through 2.6 are from discrete samples taken from the in-line spigot (drawing from 3 m) or from surface bucket samples with the exception of in vivo fluorescence, sensor in-line temperature and sensor in-line salinity. All three sensor outputs were taken from the digital printer output at the time of the in-line sampling. Sensor temperature and salinity are calculated based on laboratory calibrations and sigma-t calculated from these two parameters. Abbreviations and units of the data listed are given in tables preceeding the data. Following the presentation of the continuous data each of the variables is plotted versus distance along the cruise track to facilitate comparison of conditions during each transit.

Calibrated output from the thermoconductivity sensor and raw digitized voltage outputs from the zooplankton sensor and fluorometer are also illustrated for each cruise. Although the complete continuous data set exists on diskette for all cruises except RV006 at time intervals of approximately 1 minute (56.26 seconds) all examples of continuous data have been plotted using only alternate points in order to facilitate formatting to page size. Time, station numbers and key place names have been added to facilitate comparison with the discrete data and to assist in orientation.

1.8 Coincident Remote Sensing Information

1.8.1 Airborne Chlorophyll and Temperature Surveys

Four airborne remote sensing missions were conducted in association with the ship-of-opportunity cruises RV003, 4, 5 and 6 under the terms of a separate contract (Dept. Supply and Services, Ottawa Contract Serial No. 1SB79-00097 resulting from an unsolicited proposal). The objectives of the project were to demonstrate the usefulness of airborne remote sensing in conjunction with the ship-of-opportunity cruises and to extend the ship data horizontally, thus providing more extensive coverage. Dr. J.F.R. Gower acted as the scientific authority for this project.

Sea surface temperature and chlorophyll a concentration were measured along survey grids over Juan de Fuca Strait and along the west coast of Vancouver Island using an infra-red radiation thermometer and the Institute of Ocean Sciences colour spectrometer. The instruments and techniques provide measurements that are accurate to $\pm .5^{0}C$ and ± 1 mg chlorophyll a/m^3 respectively where sea truth is available. Descriptions of this project including a short discussion of water colour theory and graphical presentation of the data have been reported separately (Borstad and Brown, 1979; Brown and Borstad, 1980). Figure 4 illustrates the distribution of surface chlorophyll a for August 11, 1979 in conjunction with cruise RV004 as determined by airborne measurements.

1.8.2 Available Satellite Imagery

As part of other activities at the Institute of Ocean Sciences, Dr. J.F.R. Gower and Dr. S. Tabata were receiving thermal infra-red imagery from the NOAA, NROS and NIMBUS satellites for British Columbia waters, both in the form of photographic prints and digital data on magnetic tapes. Where possible, those available for the period April to October 1979 have been included here, and discussed briefly.

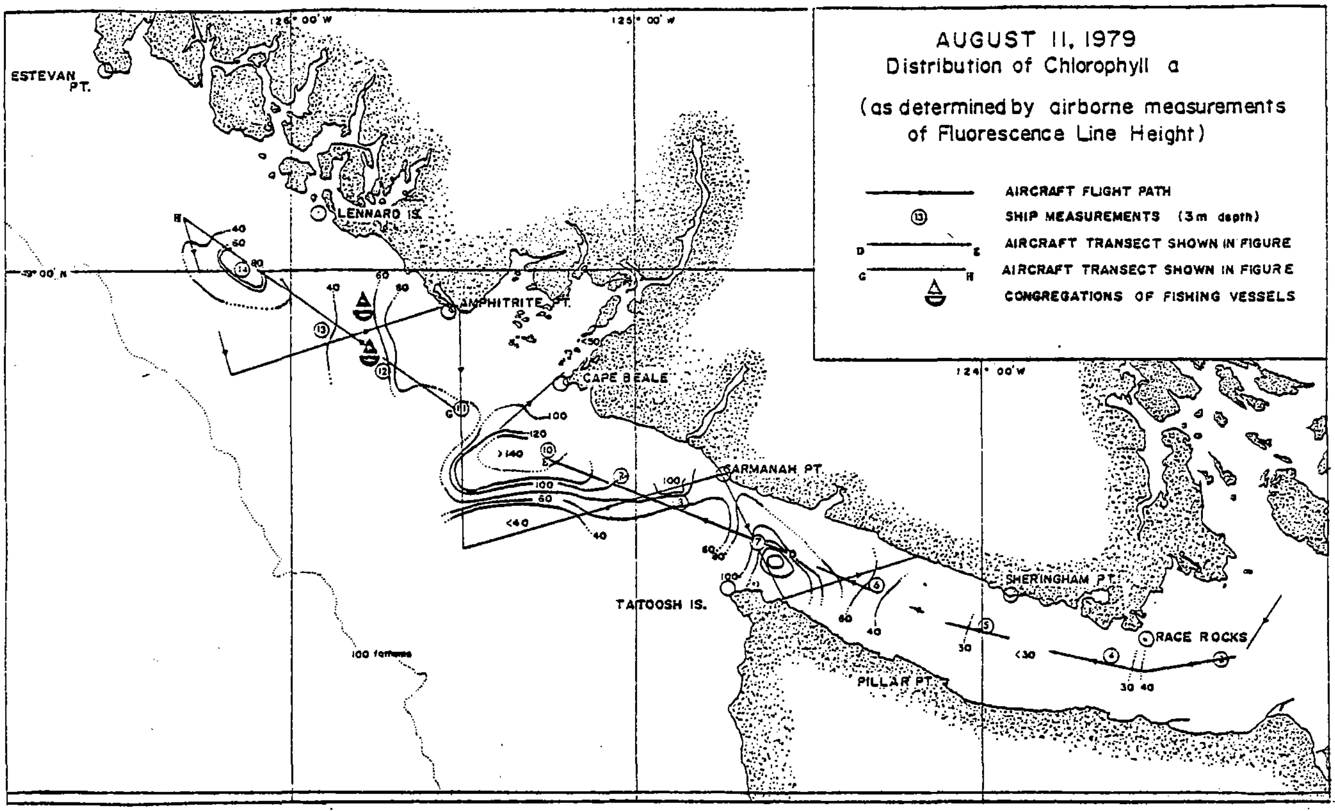


Figure 4: Distribution of chlorophyll a as determined by airborne measurements.

2. CRUISE REPORTS

2.1 Cruise RV001: April 29 - May 3, 1979

2.1.1 Logistical Summary

The first cruise took place at the end of April. A locally chartered boat was used to ferry the two technicians and the instrumentation to the Rivtow Viking which was loading in Burgoyne Bay on Saltspring Island. On April 25th mechanical problems with one of the barge cranes forced the ship to return to Vancouver for repairs, and the two day delay conveniently allowed setup and plumbing of the instrumentation. The ship returned to Burgoyne Bay and left there at midnight April 29th with logs for the Gold River pulpmill. Transit to Gold River took approximately thirty-six hours, with the return trip from Zeballos to Howe Sound being made May 1st and 2nd (see Figure 5). The technicians and their gear returned to Vancouver airport from Howe Sound via the aircraft chartered by Rivtow to ferry the barge crane operators to and from the ship. The journey from Vancouver to Sidney was by car.

Continuous measurements of temperature, conductivity, *in vivo* chlorophyll *a* fluorescence and zooplankton particles were recorded at 57 second intervals on both outward and in-bound trips. While the sea permitted, bucket and/or in-line calibration samples for these parameters plus nitrate, nitrite, phosphate and phytoplankton were collected. On the return trip a three hour watch system was instituted allowing a more regular discrete sampling regime. Chlorophyll analyses were done at sea on this cruise.

2.1.2 Equipment Malfunctions

A low frequency modulation was superimposed on the data recorded on magnetic tape for this cruise because of improper drive belts and a loose capstan on the data logger. As a result individual sweeps were dropped from the record or recorded spuriously. The entire tape has been edited and these points reassigned the value recorded for the immediately preceding sweep. The reconstructed continuous data is presented in Figures 6 and 7.

As discussed fully in part II of this report, the data from the conductivity sensor are of variable quality. During the first half of RV001 (Figure 6) the calibrated continuous salinities are of little use because of a constant drift which appears to have stabilized by the time of the return passage (see Figure 11).

2.1.3 Data Summary and Discussion

Figures 6, 7 and 8 show that the surface waters of Juan de Fuca Strait were cool, near $8^{\circ}C$ and almost $2^{\circ}C$ cooler than waters off the outer coast. There was no distinct thermal boundary between the two areas, but a sharp (1 ppt) salinity front was encountered just south of Carmanah Point (between stations 1.4 and 1.5, and 1.36 and 1.35 (Figures 6,7,9) separating Juan de Fuca water of 32 ppt or more from coastal water of near 31.5 ppt. Salinities increased towards the north from stations 1.5 and 1.33 near Carmanah Point. The much warmer and brackish waters of Nootka Sound and Esperanza Inlet are in evidence at the extreme northern end of the continuous data (last part of Figure 6 northbound cruise data and first part of Figure 7 - the southbound cruise data).

Discrete samples show that both nitrate and phosphate concentrations (Figures 14 and 16) were highest in the saline waters of eastern Juan de Fuca and decreased to low levels in the warmer less saline waters north along the coast. All three nutrients (NO_3, NO_2, PO_4) were highly correlated with each other (see Table 8 and Figure 18) and with temperature (Figures 15 and 17). If the Juan de Fuca stations which show higher N/P ratios are excluded the correlation between nitrate and phosphate concentrations is even higher.

Elevated chlorophyll a concentrations (Figure 20) were encountered over a large portion of the study area from station 1.39 in conjunction with a small salinity depression near the outer edge of the Juan de Fuca water to station 1.19 north of Lennard Island. The highest chlorophyll a concentrations were encountered in patches along the outer coast (stations 1.7, 1.19 and 1.20, 1.26 to 1.28 and 1.36), however the highest in vivo fluorescence* was recorded at station 1.6, just north of Carmanah Point (Figure 19). The continuous data in Figure 6 show a strong discontinuity in both fluorescence and zooplankton counts just north of station 1.6 that does not correspond to the salinity change between 1.4 and 1.5. To the north of this discontinuity in vivo fluorescence declines slowly. As Figures 21 and 22 illustrate, fluorescence yields (in vivo fluorescence - digital fluorometer output/mg chlorophyll a m^{-3}) were significantly higher at stations 1.6 to 1.10 off Cape Beale and at 1.4 (Experanza Inlet). Stations 1.31, 1.36 to 1.38, 1.40 (mostly Juan de Fuca on the return cruise) exhibited lowest fluorescence yields. Those stations with the highest yields correspond to the region of rapidly changing nutrient concentrations marking the outer edge of the Juan de Fuca water. No data is available concerning the species composition or physiological condition of the phytoplankton, although samples were collected for species identification and are deposited with Ocean Ecology, Institute of Ocean Sciences. Based on the explanation of the biochemistry of in vivo fluorescence offered by Govindjee et al. (1973) and the laboratory studies of fluorescence yields by Slovacek and Hannon (1977), those populations showing lowest fluorescence/unit chlorophyll could be considered to be growing rapidly, while those exhibiting higher fluorescence yields were suffering stress (perhaps nutrient limitation). Since the TS characteristics (Figure 12) of the water did not change much between the north and southbound passage it is possible the data represent different stages in the growth of the same phytoplankton population. There is no way of knowing what the chlorophyll concentrations earlier in the year were and therefore whether this represents a 'spring bloom' or not.

Twelve surface bucket chlorophyll samples collected 2 to 3 minutes after the in-line collections are available from this cruise for comparison to in-line samples. Except where the ship was passing through regions of rapidly changing

---

* in vivo fluorescence data for cruises RV001 and RV002 are about 18x lower than those from cruises RV003 through RV006 because of an adjustment to the fluorometer sensitivity made after cruise RV002.

chlorophyll concentration (Stations 1.6, 1.7 and 1.8), the two methods agree well (Figure 24) indicating little stratification between the surface and 3 m depth. Correlation coefficient was .98 if these three stations are excluded.

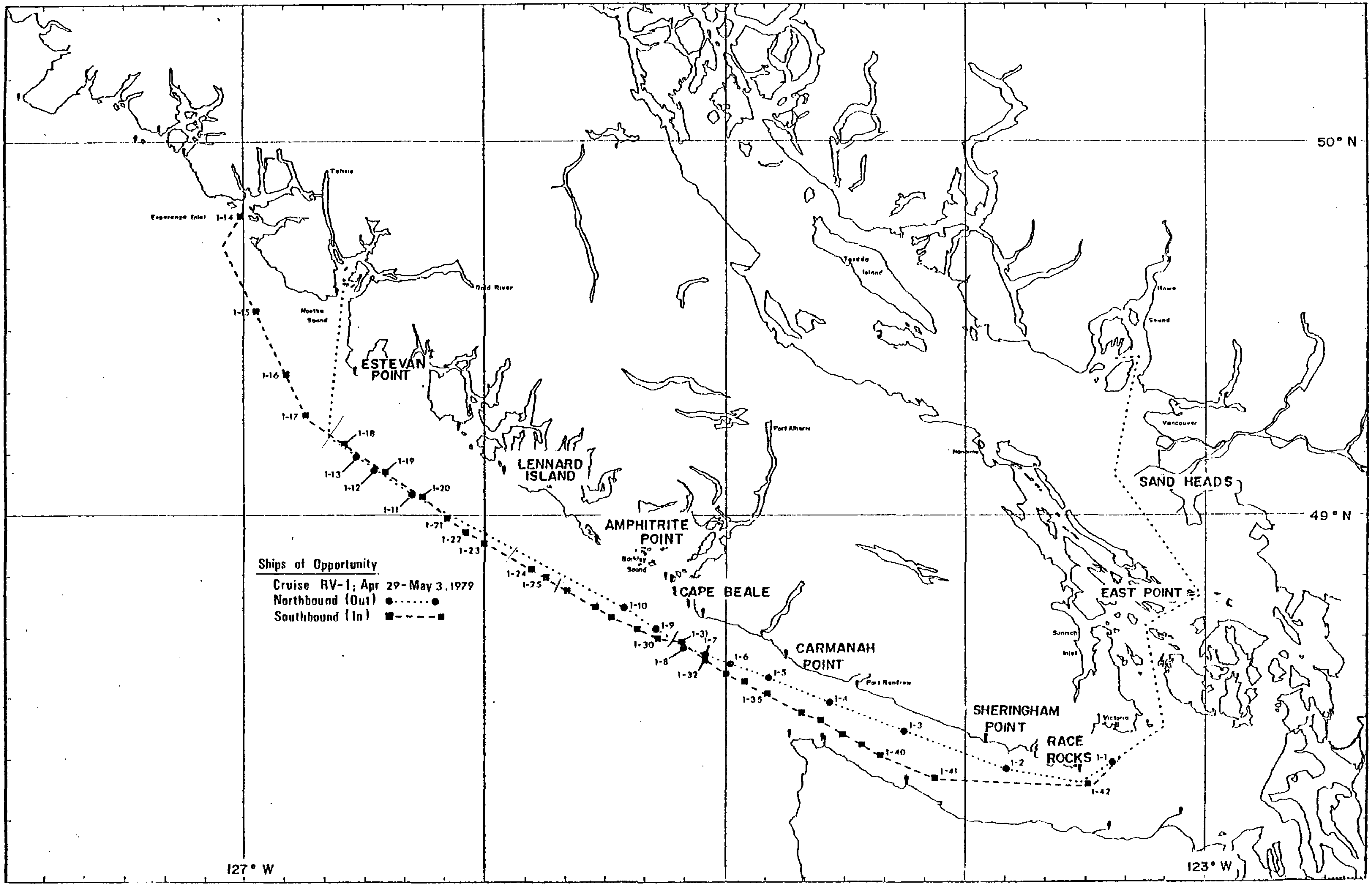


Figure 5. Cruise track and station locations. RV001.

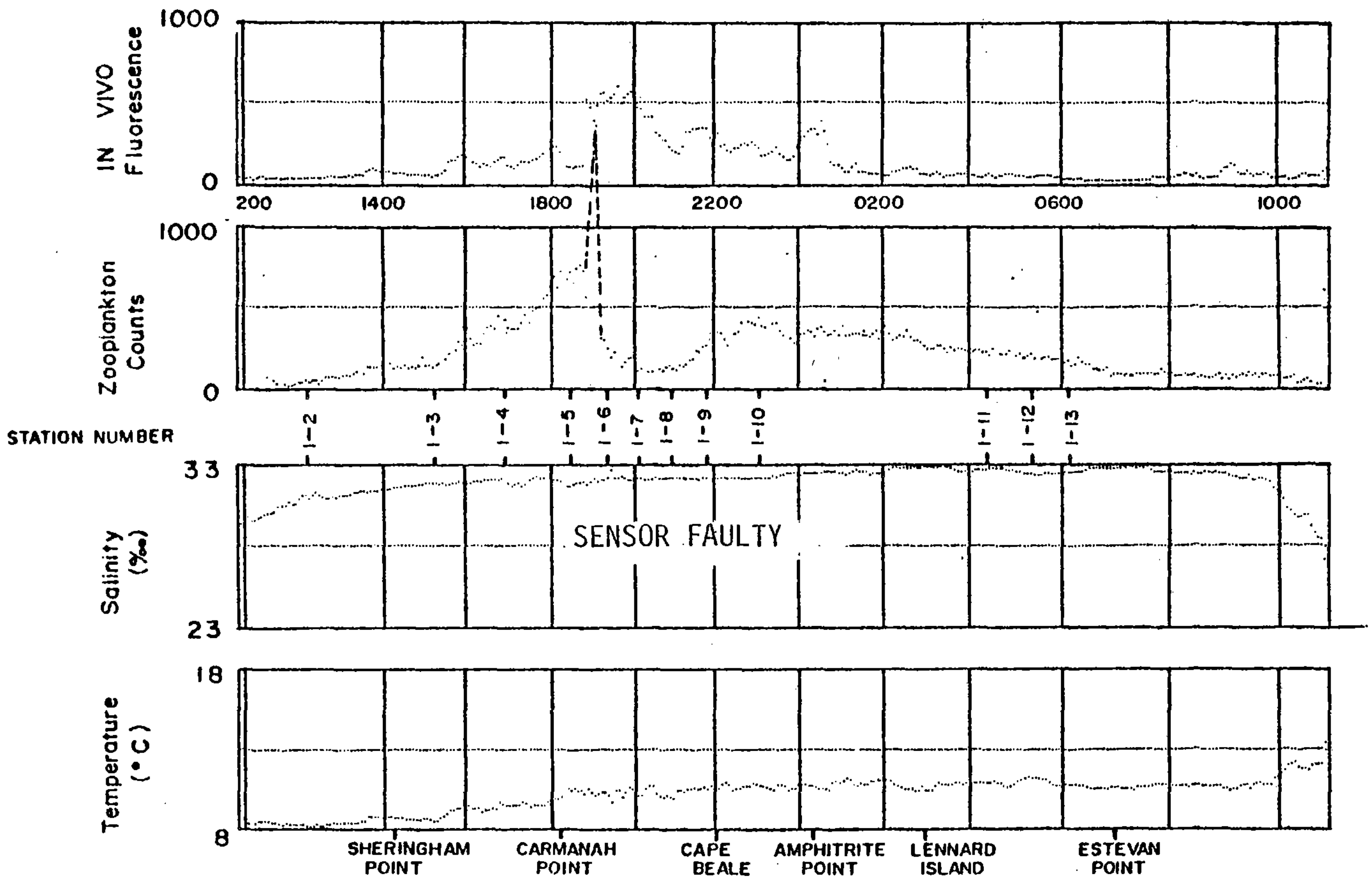


Figure 6. Continuous data record - RV001 (northbound).

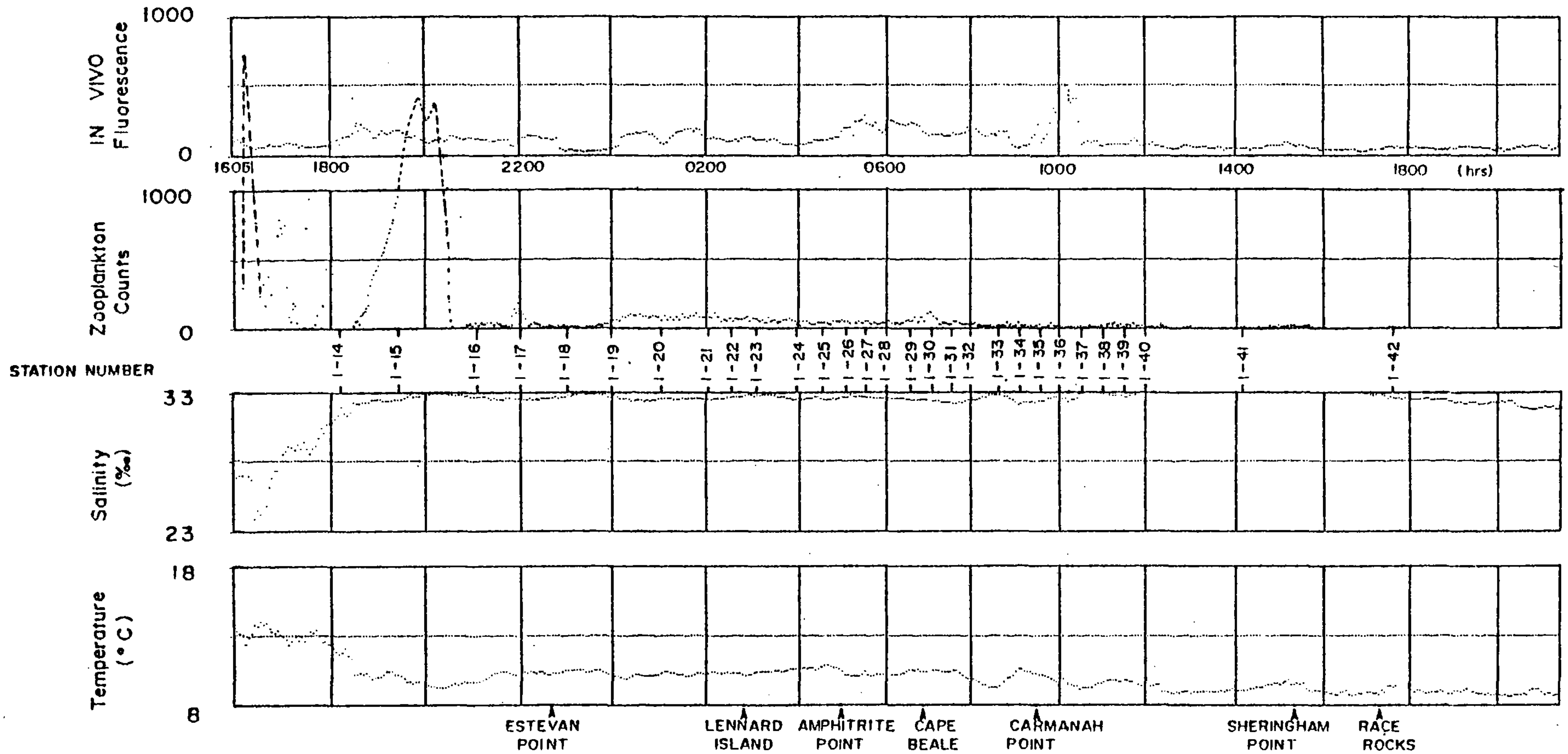


Figure 7. Continuous data record - RV001 (southbound).

Table 2: Abbreviations and Units of Tabulated Data

STN #	- cruise number followed by station number as a two digit decimal
CDATE	- calender date
JDATE	- julian date
TIME	- twenty-four hour time of in-line sample
LATITUDE and LONGITUDE	- approximate latitude and longitude calculated from speed made good between fixes of several lighthouses along the coast. These are made by the first officer using radar and visual sightings of the lights as the ship passes.
DIS	- distance in km from Squamish in Howe Sound (+ indicates outward bound cruise, - indicates inward cruise).
SEN T	- temperature, degrees Centigrade calculated from sensor output at time of sampling
SEN SAL	- salinity calculated from sensor output at time of sampling
DIS SAL	- in-line salinity measured on discrete sampling
SIG	- sigma-t where both temperature and salinity data exist
NO2	- nitrite concentration μg at/ℓ
NO3	- nitrate concentration μg at/ℓ (minus nitrite)
PO4	- dissolved inorganic phosphate μg at/ℓ
CHL	- extracted chlorophyll a concentration mg/m^3
PHAEO	- extracted phaeopigment concentration mg/m^3
%CHL	- (CHL/CHL + PHAEO) x 100
SEN FL	- *in vivo* fluorescence as reported by the digital printer where printer number equals fluorometer output voltage/ 5V x 1024
FL YLD	- *in vivo* fluorescence/mg chlorophyll a/m^3
ZOO#	- zooplankton/m^3 where samples taken. For calibration of sensor only
DCMU#	- digiprint value of *in vivo* fluorescence divided by digiprint value after DCMU addition.

Table 3:

REFERENCE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-1

{ x = Barkley / ✓ = Clayoquot

STN #	CDATE	JDATE	TIME	LATITUDE	LONGITUDE	DIS
1.01	29/ 4/79	119	1040	48-19.4 N	123-23.0 W	173.
1.02	29/ 4/79	119	1250	48-18.1 N	123-50.0 W	206.
1.03	29/ 4/79	119	1513	48-24.5 N	124-14.7 W	238.
1.04	29/ 4/79	119	1655	48-29.1 N	124-34.6 W	264.
1.05	29/ 4/79	119	1820	48-33.0 N	124-48.5 W	282.
1.06	29/ 4/79	119	1918	48-35.6 N	124-58.7 W	296.
1.07	29/ 4/79	119	2008	48-37.0 N	125- 5.0 W	303.
1.08	29/ 4/79	119	2055	48-38.6 N	125-10.6 W	309.
× 1.09	29/ 4/79	119	2155	48-41.2 N	125-17.4 W	319.
× 1.10	29/ 4/79	119	2302	48-45.0 N	125-25.6 W	331.
✓ 1.11	30/ 4/79	120	425	49- 3.0 N	126-18.0 W	403.
✓ 1.12	30/ 4/79	120	526	49- 7.0 N	126-27.0 W	416.
✓ 1.13	30/ 4/79	120	603	49- 9.4 N	126-31.5 W	422.
1.14	1/ 5/79	121	1808	49-49.2 N	127- 0.0 W	503.
1.15	1/ 5/79	121	1932	49-32.5 N	126-57.0 W	473.
1.16	1/ 5/79	121	2105	49-22.6 N	126-50.0 W	453.
1.17	1/ 5/79	121	2200	49-15.6 N	126-45.0 W	439.
✓ 1.18	1/ 5/79	121	2300	49-11.3 N	126-35.0 W	425.
✓ 1.19	1/ 5/79	121	2400	49- 6.8 N	126-24.6 W	410.
✓ 1.20	2/ 5/79	122	100	49- 2.3 N	126-15.1 W	395.
✓ 1.21	2/ 5/79	122	202	48-59.3 N	126- 9.0 W	387.
✓ 1.22	2/ 5/79	122	230	48-57.0 N	126- 4.7 W	380.
✓ 1.23	2/ 5/79	122	300	48-55.2 N	125-58.9 W	373.
1.24	2/ 5/79	122	358	48-50.8 N	125-48.1 W	358.
1.25	2/ 5/79	122	430	48-49.6 N	125-45.0 W	355.
× 1.26	2/ 5/79	122	500	48-47.2 N	125-39.2 W	347.
× 1.27	2/ 5/79	122	530	48-44.9 N	125-32.2 W	338.
× 1.28	2/ 5/79	122	600	48-43.1 N	125-27.4 W	332.
× 1.29	2/ 5/79	122	634	48-41.2 N	125-21.7 W	324.
× 1.30	2/ 5/79	122	700	48-40.0 N	125-17.1 W	317.
1.31	2/ 5/79	122	730	48-38.6 N	125-10.0 W	308.
1.32	2/ 5/79	122	800	48-36.6 N	125- 5.0 W	302.
1.33	2/ 5/79	122	832	48-34.5 N	125- 0.0 W	296.
1.34	2/ 5/79	122	900	48-32.7 N	124-55.0 W	290.
1.35	2/ 5/79	122	935	48-30.7 N	124-49.9 W	283.
1.36	2/ 5/79	122	1000	48-27.3 N	124-40.5 W	270.
1.37	2/ 5/79	122	1030	48-25.6 N	124-35.5 W	265.
1.38	2/ 5/79	122	1100	48-23.6 N	124-30.7 W	259.
1.39	2/ 5/79	122	1130	48-22.0 N	124-25.7 W	253.
1.40	2/ 5/79	122	1200	48-20.4 N	124-21.0 W	247.
1.41	2/ 5/79	122	1410	48-17.2 N	124- 7.0 W	229.
1.42	2/ 5/79	122	1747	48-16.0 N	123-29.0 W	183.

Table 4:

INLINE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-1

STN #	SEN T (°C)	SEN SAL (ppt)	DIS SAL	SIG	NO2	NO3	PO4
1.01	–	–	31.39	–	.49	25.06	2.08
1.02	–	–	32.05	–	.34	26.68	2.25
1.03	–	–	32.11	–	.26	23.64	2.13
1.04	–	–	32.04	–	.27	18.64	1.95
1.05	10.50	31.78	31.39	24.38	.21	13.89	1.22
1.06	10.30	32.21	31.63	24.75	0.00	6.76	.57
1.07	10.17	32.23	31.61	24.79	.27	2.52	.60
1.08	10.03	32.27	31.60	24.85	.20	8.15	1.02
1.09	10.71	32.19	31.45	24.67	.14	2.65	.64
1.10	10.91	32.27	31.42	24.69	.05	1.27	.43
1.11	10.99	32.79	31.77	25.08	.00	3.99	.28
1.12	11.22	32.45	31.48	24.77	.05	0.00	.26
1.13	10.88	32.64	31.64	24.99	.00	.10	.33
1.14	10.33	32.42	31.50	24.91	.15	1.84	.70
1.15	9.36	32.97	31.83	25.50	.18	2.34	.80
1.16	10.25	32.73	31.62	25.16	.21	0.00	.42
1.17	10.38	32.72	31.61	25.13	.07	.08	.35
1.18	10.50	32.81	31.81	25.18	.06	2.01	.32
1.19	10.15	32.51	31.43	25.01	.06	0.00	.29
1.20	10.33	32.65	31.55	25.09	.16	0.00	.34
1.21	10.21	32.76	31.73	25.20	.08	.19	.30
1.22	10.42	32.85	31.55	25.23	.09	.95	.39
1.23	10.63	32.61	31.53	25.00	.00	.71	.22
1.24	10.87	32.55	31.49	24.91	.08	0.00	.22
1.25	10.13	32.79	31.70	25.23	.14	9.46	.51
1.26	10.18	32.70	31.62	25.15	.16	4.07	.59
1.27	10.29	32.64	31.56	25.09	.11	5.85	.68
1.28	10.59	32.53	31.48	24.95	.04	4.19	.48
1.29	10.46	32.35	–	24.83	.11	2.66	.53
1.30	10.33	32.32	31.25	24.84	.10	4.82	.62
1.31	9.57	32.76	31.62	25.30	.27	11.49	1.09
1.32	9.95	32.70	31.64	25.19	.24	10.08	1.21
1.33	10.41	32.35	31.35	24.84	.12	8.50	.75
1.34	10.06	32.64	–	25.13	.23	7.51	.65
1.35	9.50	32.57	31.51	25.16	.29	5.73	.76
1.36	9.36	33.08	32.18	25.58	.27	16.54	.93
1.37	9.82	32.88	31.84	25.35	.27	18.39	1.15
1.38	9.78	32.90	31.83	25.38	.25	15.81	1.15
1.39	9.57	33.04	31.91	25.52	.24	17.81	1.48
1.40	9.00	33.29	32.19	25.80	.25	29.18	1.45
1.41	9.57	33.14	32.08	25.59	.27	20.59	1.31
1.42	9.08	32.64	31.57	25.28	.34	23.76	2.44

Table 5:

INLINE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-1

STN #	CHL	PHAEO	% CHL	SEN FL	FL YD	ZOO #	DCMU #
1.01	.68	.34	.67	-	-	-	-
1.02	1.78	.71	.71	-	-	-	-
1.03	1.39	.89	.61	-	-	-	-
1.04	3.04	1.08	.74	-	-	-	-
1.05	4.07	1.78	.70	115.	28.24	669.	-
1.06	5.32	4.20	.56	531.	99.81	48.	-
1.07	8.23	1.61	.84	497.	60.41	166.	-
1.08	1.77	.75	.70	230.	129.94	149.	-
1.09	5.36	2.52	.68	308.	57.48	323.	-
1.10	3.17	2.07	.60	257.	81.12	423.	-
1.11	2.03	1.29	.61	61.	30.11	234.	-
1.12	1.02	.44	.70	62.	60.54	192.	-
1.13	.97	.31	.76	46.	47.29	170.	-
1.14	4.06	2.28	.64	182.	44.87	567.	-
1.15	4.27	.88	.83	109.	25.50	678.	-
1.16	3.46	.90	.79	76.	21.95	56.	-
1.17	3.81	1.22	.76	117.	30.74	21.	-
1.18	.91	.44	.67	36.	39.58	19.	-
1.19	6.57	1.78	.79	170.	25.88	79.	-
1.20	6.96	.34	.95	154.	22.13	100.	-
1.21	4.06	1.67	.71	124.	30.57	58.	-
1.22	4.27	1.75	.71	113.	26.44	47.	-
1.23	2.43	.90	.73	78.	32.05	43.	-
1.24	5.23	1.33	.80	124.	23.73	47.	-
1.25	9.08	2.28	.80	228.	25.11	59.	-
1.26	12.22	2.57	.83	238.	19.48	45.	-
1.27	12.00	5.74	.68	231.	19.25	42.	-
1.28	12.77	3.23	.80	238.	18.64	57.	-
1.29	7.10	1.64	.81	156.	21.98	48.	-
1.30	6.43	1.87	.77	155.	24.12	37.	-
1.31	8.92	1.95	.82	151.	16.92	21.	-
1.32	6.96	1.78	.80	178.	25.58	40.	-
1.33	3.26	1.01	.76	82.	25.16	26.	-
1.34	4.02	1.35	.75	201.	49.94	14.	-
1.35	21.31	1.00	.96	369.	17.31	22.	-
1.36	9.56	3.54	.73	105.	10.98	14.	-
1.37	4.20	2.88	.59	85.	20.26	25.	-
1.38	5.73	1.44	.80	101.	17.64	41.	-
1.39	5.91	.99	.86	77.	13.02	14.	-
1.40	3.20	.81	.80	59.	18.46	0.	-
1.41	3.06	.73	.81	68.	22.20	7.	-
1.42	5.30	.94	.85	51.	9.62	3.	-

Table 6:

SURFACE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-1

STN #	DIS T	DIS SAL	SIG	CHL	PHAEO	% CHL
1.01	8.90	–	–	.49	.23	.68
1.02	9.10	32.15	24.90	2.14	.90	.70
1.03	10.70	32.10	24.60	1.39	.89	.61
1.04	10.00	30.68	23.61	3.41	1.46	.70
1.05	10.59	31.42	24.09	3.51	1.40	.71
1.06	–	–	–	11.21	.16	.88
1.07	11.05	–	–	4.75	2.17	.69
1.08	10.60	–	–	.21	.08	.73
1.09	10.45	–	–	5.36	2.52	.68
1.10	10.75	–	–	3.17	2.07	.60
1.11	10.90	–	–	2.03	1.29	.61
1.12	–	–	–	–	–	–
1.13	–	–	–	–	–	–
1.14	–	–	–	–	–	–
1.15	–	–	–	–	–	–
1.16	–	–	–	–	–	–
1.17	–	–	–	–	–	–
1.18	–	–	–	–	–	–
1.19	–	–	–	–	–	–
1.20	10.45	31.59	24.25	–	–	–
1.21	–	–	–	–	–	–
1.22	–	–	–	–	–	–
1.23	–	–	–	–	–	–
1.24	–	–	–	–	–	–
1.25	–	–	–	–	–	–
1.26	10.20	–	–	–	–	–
1.27	–	–	–	–	–	–
1.28	–	–	–	–	–	–
1.29	10.24	–	–	–	–	–
1.30	–	–	–	–	–	–
1.31	–	–	–	–	–	–
1.32	10.48	–	–	–	–	–
1.33	–	–	–	–	–	–
1.34	9.90	–	–	–	–	–
1.35	9.52	–	–	–	–	–
1.36	–	–	–	–	–	–
1.37	9.62	–	–	–	–	–
1.38	–	–	–	–	–	–
1.39	–	–	–	–	–	–
1.40	9.28	–	–	–	–	–
1.41	10.31	–	–	–	–	–
1.42	–	–	–	–	–	–

TABLE 7 Extract from ship's log- RV001

Date	Time	Location (lat., long.)	Seastate	Sky
April 29/79	1040	$48^{o}19.4'N$, $123^{o}23.0'W$	calm	Hi-overcast
	1250	$48^{o}18.1'N$, $123^{o}50'W$	choppy	overcast
	1513	$48^{o}24.5'N$, $124^{o}14.7'W$	light chop	overcast-foggy
	1655	$48^{o}29.1'N$, $124^{o}34.6'W$	light chop, low S.W. swell	overcast
	1820	$48^{o}33.0'N$, $124^{o}48.5'W$	choppy, low S.W. swell	overcast
	1918	$48^{o}35.6'N$, $124^{o}58.7'W$	medium chop	
	2008	$48^{o}37.0'N$, $125^{o}5.0'W$	choppy	grey and cloudy
	2055	$48^{o}28.6'N$, $125^{o}10.6'W$	choppy	darkening
	2155	$48^{o}41.2'N$, $125^{o}17.4'W$	medium S.W. swell	cloudy
	2302	$48^{o}45.0'N$, $125^{o}25.6'W$	medium S.W. swell	cloudy
April 30/79	0425	$49^{o}3.0'N$, $126^{o}18.0'W$	heavy S.W. swell	
	0526	$49^{o}7.0'N$, $126^{o}27.0'W$	heavy S.W. swell	
	0603	$49^{o}9.4'N$, $126^{o}31.5'W$	heavy S.W. swell	overcast
May 1/79	1808	$49^{o}49.2'N$, $127^{o}0.0'W$	medium S.W. swell, choppy	cloudy
	1932	$49^{o}32.5'N$, $126^{o}57.0'W$	low S.W. swell, medium chop	overcast
	2105	$49^{o}22.6'N$, $126^{o}50.0'W$	swell, with following sea	high cloud
	2200	$49^{o}15.6'N$, $126^{o}45.0'W$	following swell	dark
	2300	$49^{o}11.3'N$, $126^{o}35.0'W$	low swell	dark
	2400	$49^{o}6.8'N$, $126^{o}24.6'W$		
May 2/79	0100	$49^{o}2.3'N$, $126^{o}15.1'W$	low S.W. swell	clear
	0202	$48^{o}59.3'N$, $126^{o}9.0'W$	low S.W. swell	clear
	0230	$48^{o}57.0'N$, $126^{o}4.7'W$	low S.W. swell	clear
	0300	$48^{o}55.2'N$, $125^{o}58.7'W$	low S.W. swell	clear
	0358	$48^{o}50.8'N$, $125^{o}48.1'W$	slight swell	clear
	0430	$48^{o}49.6'N$, $125^{o}45.0'W$	slight swell	clear, dark
	0500	$48^{o}47.2'N$, $125^{o}39.2'W$	slight swell	clear, dark
	0530	$48^{o}44.9'N$, $125^{o}32.2'W$	slight swell	clear, dark
	0600	$48^{o}43.1'N$, $125^{o}27.4'W$	rolling swell	clear
	0634	$48^{o}41.2'N$, $125^{o}21.7'W$	low S.W. swell	cloudy
	0700	$48^{o}40.0'N$, $125^{o}17.1'W$	low S.W. swell	cloudy
	0730	$48^{o}38.6'N$, $125^{o}10.0'W$	low S.W. swell	cloudy
	0800	$48^{o}36.6'N$, $125^{o}5.0'W$	low S.W. swell	cloudy
	0832	$48^{o}34.5'N$, $125^{o}00'W$	low S.W. swell	overcast, cloudy
	0900	$48^{o}32.7'N$, $124^{o}55.0'W$	low S.W. swell	overcast

TABLE 7 cont'd

Date	Time	Location (lat., long.)	Seastate	Sky
May 2/79 (continued)	0935	48°30.7'N, 124°49.9'W	low swell	clear
	1000	48°27.3'N, 124°40.5'W	gentle swell	hazy
	1030	48°25.6'N, 124°35.5'W	gentle swell	hazy
	1100	48°23.6'N, 124°30.7'W	gentle swell	hazy
	1130	48°22.0'N, 124°25.7'W	long swell	high cloud
	1200	48°20.4'N, 124°21.0'W	gentle swell	high cloud
	1410	48°17.2'N, 124°7.0'W	light chop	mostly cloudy (80%)
	1747	48°16.0'N, 123°29.0'W	calm	clear

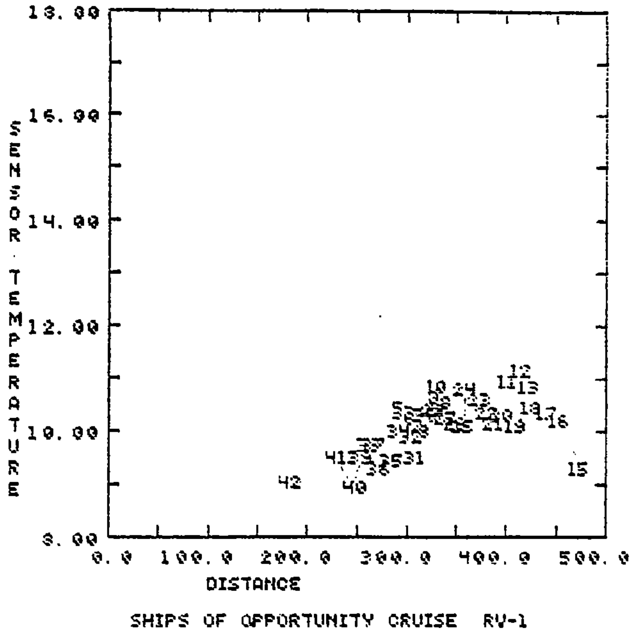


Figure 8. Sensor temperature (^{o}C) vs distance along cruise track - RV001.

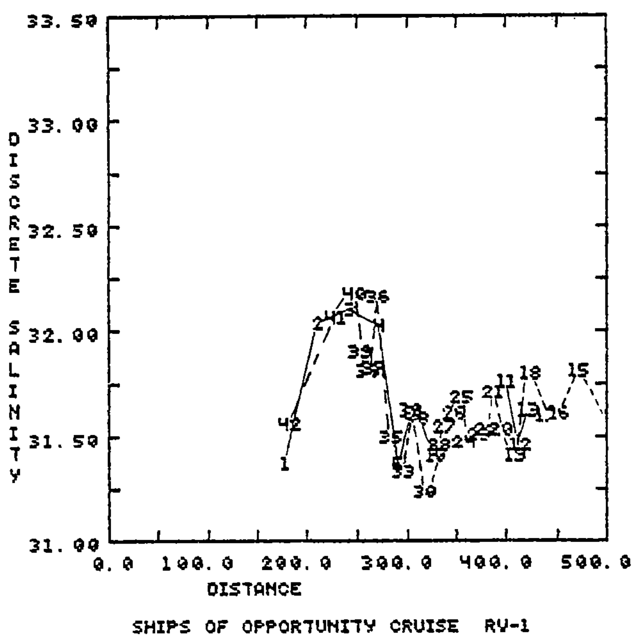


Figure 9. Discrete salinity (ppt) vs distance along cruise track - RV001.

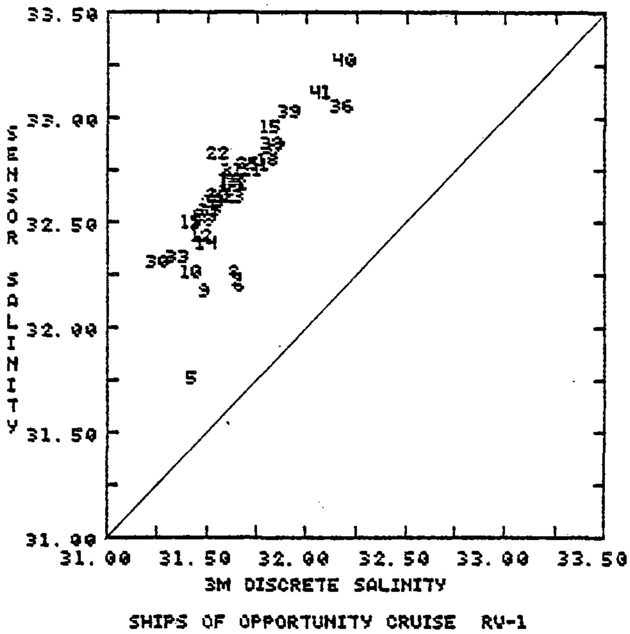


Figure 10. Sensor salinity (ppt) vs discrete salinity (ppt) - RV001.

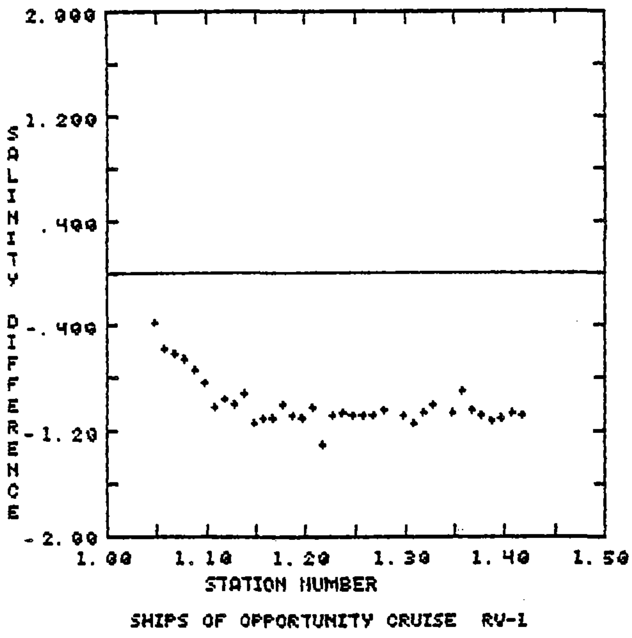


Figure 11. Salinity difference (ppt) - (discrete - sensor) - RV001.

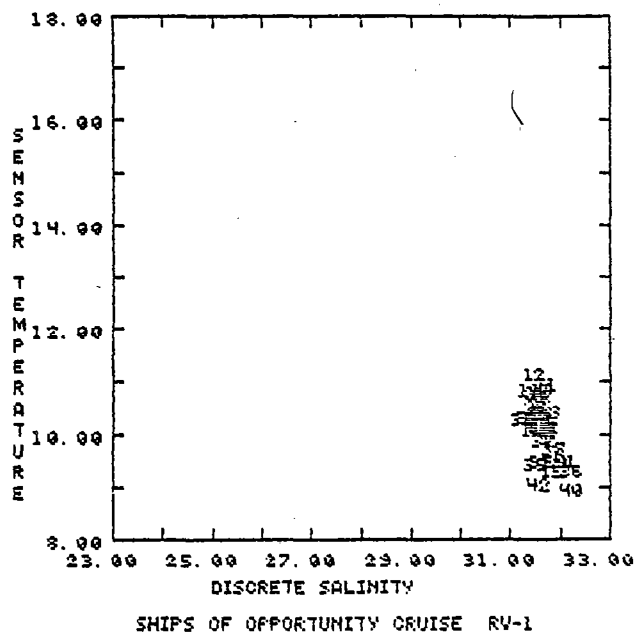


Figure 12. Sensor temperature (^{o}C) vs discrete salinity (ppt) - RV001.

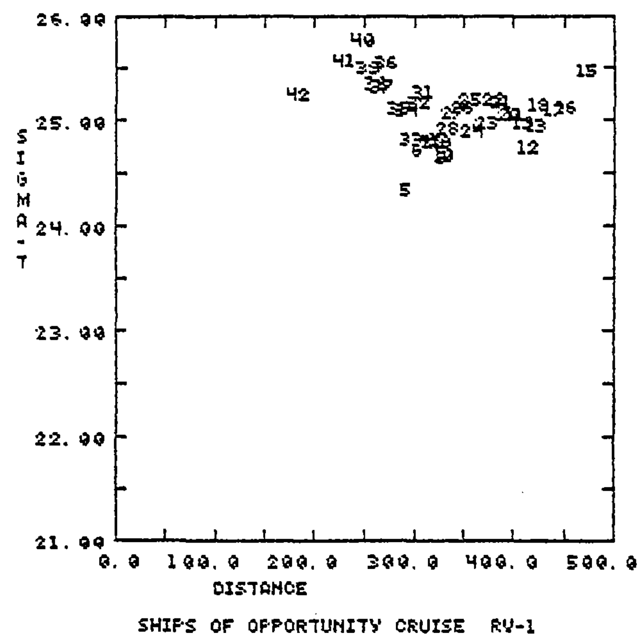


Figure 13. Sigma-t vs distance along cruise track - RV001.

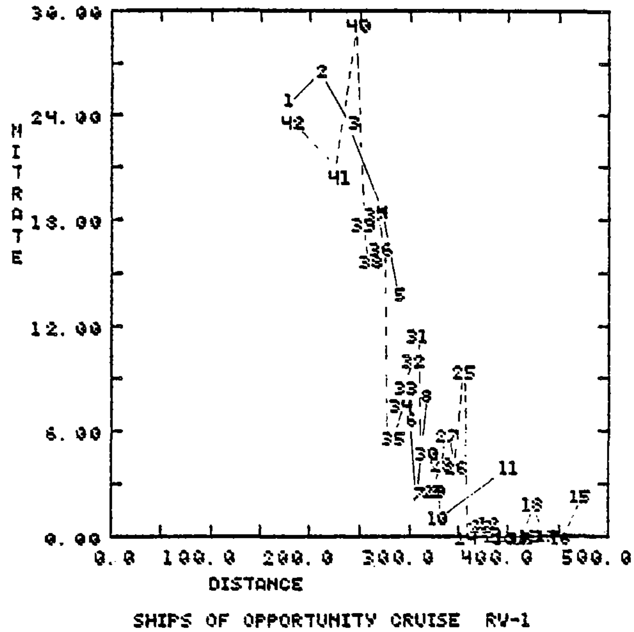


Figure 14. Nitrate concentration (μg at/L) vs distance along cruise track - RV001.

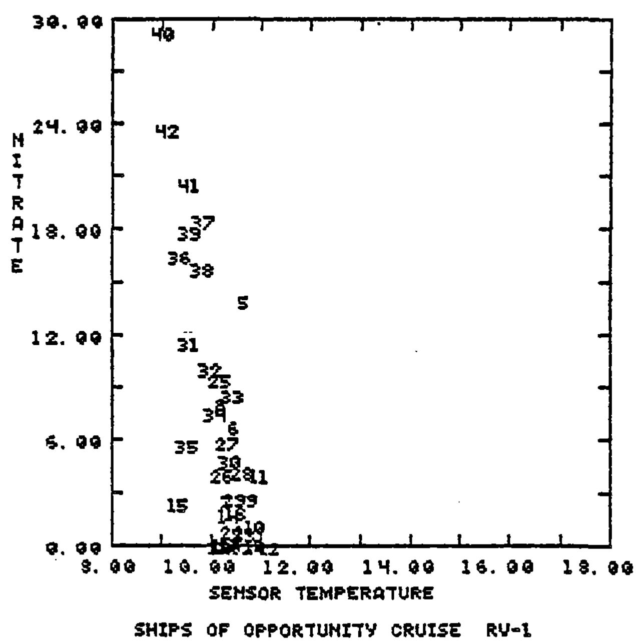


Figure 15. Nitrate concentration (μg at/L) vs sensor temperature (°C) - RV001.

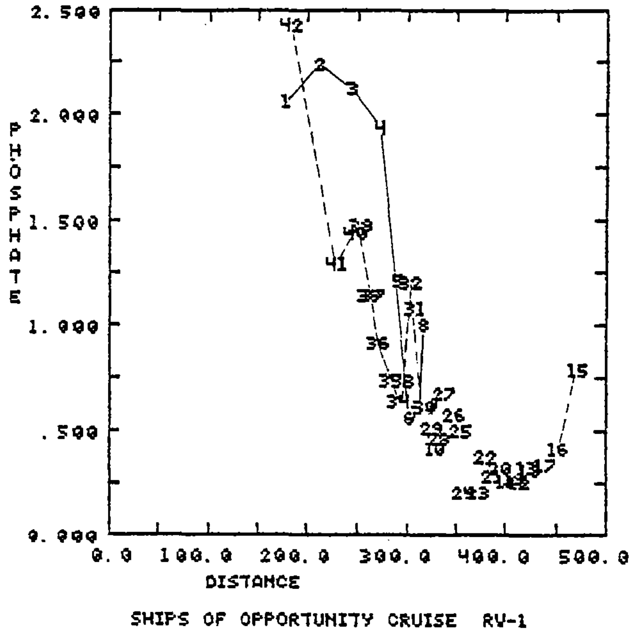


Figure 16. Phosphate concentration (μg at/L) vs distance along cruise track - RV001.

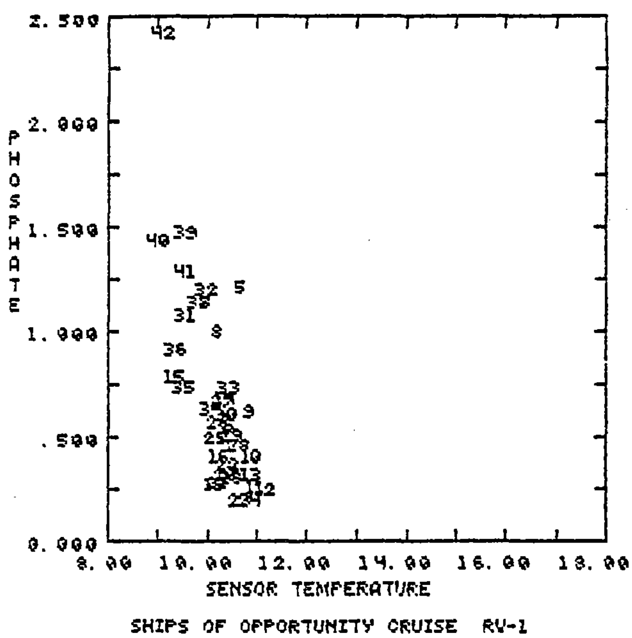


Figure 17. Phosphate concentration (μg at/L) vs sensor temperature (°C) - RV001.

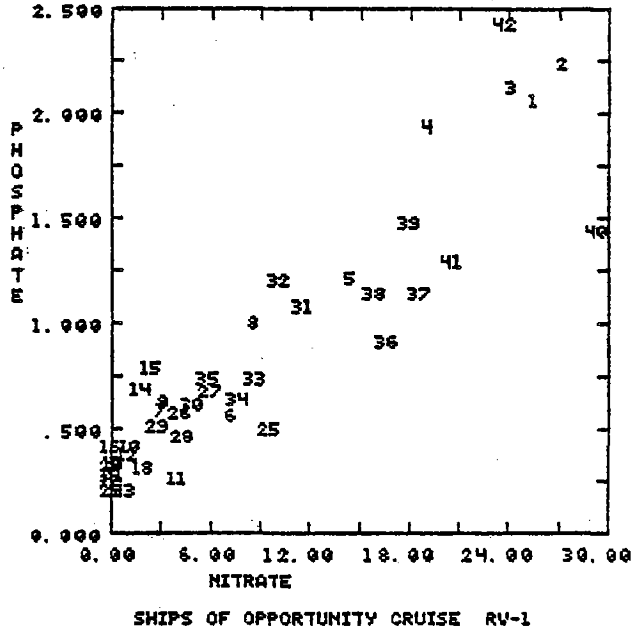


Figure 18. Phosphate concentration (µg at/L) vs nitrate concentration (µg at/L) - RV001.

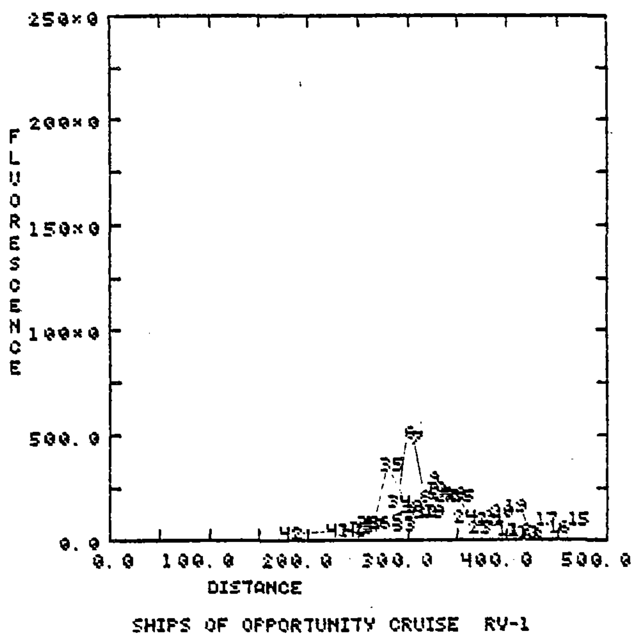


Figure 19. in vivo fluorescence vs distance along cruise track - RV001.

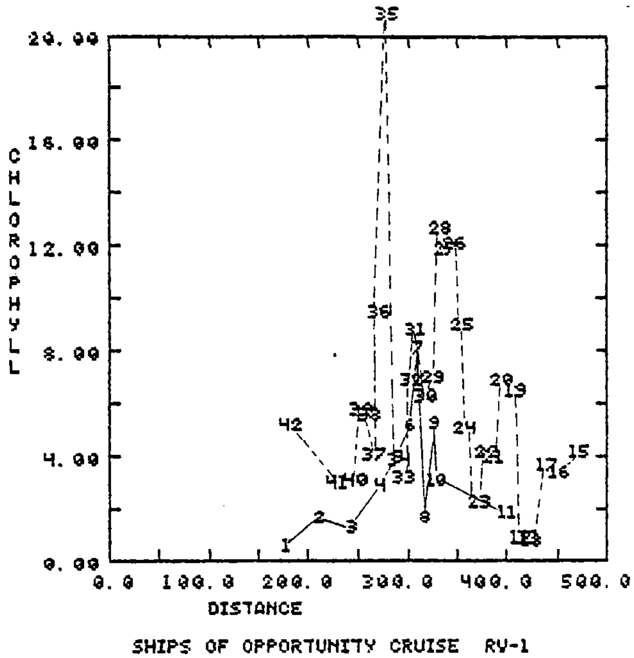


Figure 20. Chlorophyll a (mg/m^3) vs distance along cruise track - RV001.

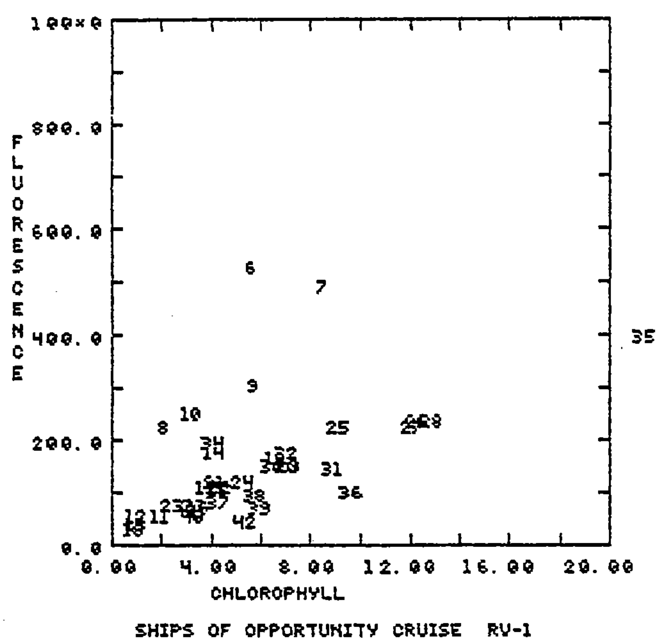


Figure 21. in vivo fluorescence vs chlorophyll a (mg/m^3) - RV001.

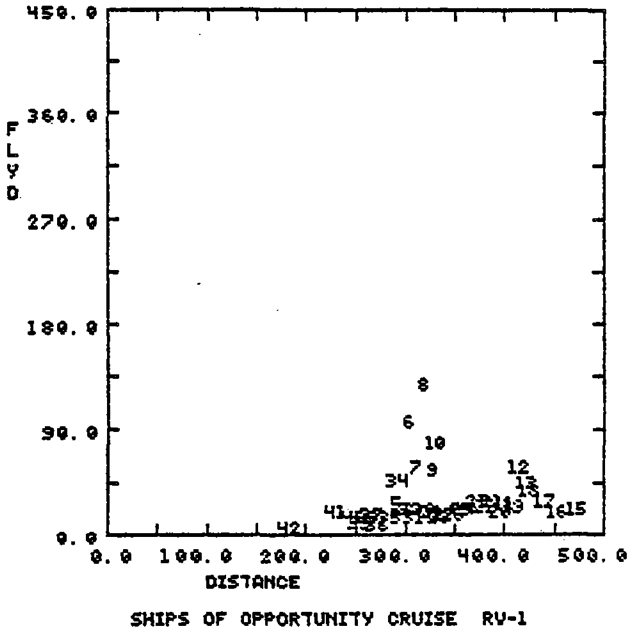


Figure 22. Fluorescence yield vs distance along cruise track - RV001.

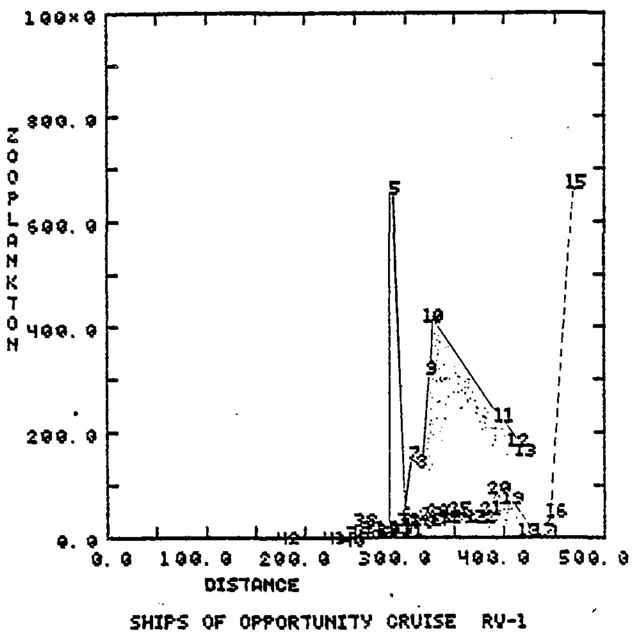


Figure 23. Zooplankton count vs distance along cruise track - RV001.

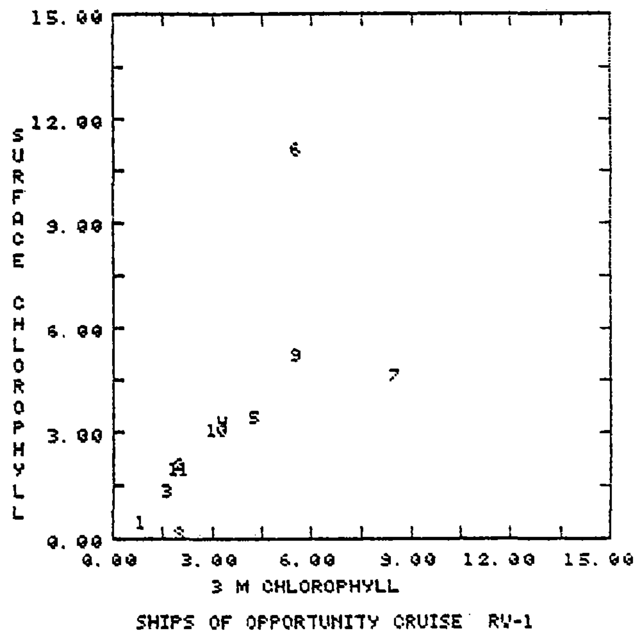


Figure 24. Surface chlorophyll a (mg/m^3) vs 3 m chlorophyll a (mg/m^3) - RV001.

Table 8: Multiple Correlation Table

SHIPS OF OPPORTUNITY CRUISE RV-1

	SEN T	SEN S	3 SAL	3 SIG	3 NO2	3 NO3	3 PO4	3 CHL	3 %CHL	SEN FL	3 FLYD	3 ZOO#
SEN T												
SEN S	-.55											
3 SAL	-.59	.81										
3 SIG	-.74	.97	.83									
3 NO2	-.80	.28	.35	.47								
3 NO3	-.74	.41	.59	.56	.76							
3 PO4	-.76	.22	.45	.40	.81	.91						
3 CHL	-.30	-.01	-.17	.09	.07	-.15	-.16					
3 %CHL	-.44	.25	-.03	.34	.24	-.06	-.02	.53				
SEN FL	.06	-.49	-.29	-.41	-.01	-.22	-.16	.50	-.05			
3 FLYD	.35	-.51	-.23	-.52	-.29	-.28	-.22	-.35	-.50	.48		
3 ZOO#	.50	-.35	-.03	-.38	-.07	-.68	-.61	-.26	-.19	.31	.32	

2.2 Cruise RV002: May 25 - May 29, 1979

2.2.1 Logistical Summary

The second cruise took place from the 25th to the 29th of May coinciding in part with the May Ocean Ecology cruise. Logistics for this cruise were somewhat different than for the first in that the departure time for the ship was unknown until six hours before. The technicians and their gear were sent to Howe Sound by a locally chartered float plane. The ship left almost immediately, proceeding to Tahsis with an empty barge. The turn-around time in Tahsis Inlet was also short and the ship was back in Burrard Inlet for crew change and provisions within four days (see cruise track in Figure 25). The technicians and gear were returned from Vancouver by truck.

Gale force winds and high seas curtailed surface bucket samples on the outward trip on the 25th and 26th. In spite of the weather, 41 sets of in-line samples (salinity, nitrate/nitrite, phosphate, chlorophyll and phytoplankton) were collected as well as continuous data for temperature, salinity and fluorescence. Twenty-one full sets (temperature, salinity and chlorophyll) of surface bucket samples and eleven partial sets (temperature and chlorophyll only) were obtained for comparison with the in-line samples. One set of three replicates for nitrate and phosphate were also taken from the in-line spigot in rapid succession as the ship travelled the southern (inbound) traffin lane in the Strait of Juan de Fuca. At twenty-seven 'stations' the change of *in vivo* chlorophyll *a* fluorescence with DCMU addition was observed. Chlorophyll extractions and analyses were not done on board this cruise because of the disagreeable actone fumes in the enclosed space.

2.2.2 Equipment Malfunctions

Failure of the time base recycler did not allow operation of the zooplankton sensor on this trip. Repairs were attempted at sea but these were unsuccessful. The low frequency modulation of the signal on the magnetic tape continued to be a problem on the tape from RV002, but to a much lesser degree.

The data presented here in Figures 26 and 27 have been edited to remove spurious points resulting from the low frequency modulation. Continuous conductivity data for the first half of this cruise are of no value because of a sensor malfunction unexplained at the time of preparation of this report. Figure 31 illustrates the difference between discrete and sensor salinity at each station. While there appears to have been a drift in the output of the conductivity sensor during the northbound transit, this had stabilized by station 2.16 on the southbound passage. The suggestion that inadequate flushing of the sampling could be responsible for these differences can be discounted by good agreement shown in Figure 29 between the position of gradients on northbound and southbound cruises.

2.2.3 Data Summary and Discussion

Both continuous monitoring and discrete sampling began at 0300 hrs off Race Rocks. At station 2-1 the surface waters were cold (near 9^{O}C) and of low salinity and low density (Figures 26, 27, 28, 29, 33). Dissolved nitrate and phosphate concentrations at the first station (Figures 34 and 36) were high but declined to the west with increasing temperature and salinity. There were strong correlations between nitrate and phosphate concentrations and temperature (Figures 35, 37 and Table 13).

As was the case in early May during cruise RV001, the surface waters of the Strait of Juan de Fuca during the northbound cruise were nearly 2^{O}C colder than those offshore. Figures 26, 27 and 28 illustrate this and also indicate the narrowing of the transition between the two water masses which occurred to the south of Cape Beale between stations 2.6 and 2.8. Both the position and magnitude of this temperature front changed between transits of the area almost certainly because of the presence of warm, less saline and therefore low density water at stations 2.7 and 2.8. This water, which possessed relatively more nitrate than other waters of comparable temperature (Figure 35) and therefore different N/P ratios (Figure 38) contained little phytoplankton.

A strong bloom was encountered just east of the thermal boundary marking the outer extent of the Juan de Fuca water. We interpret the presence of this and other phytoplankton production in this area as being due to the export of dissolved nutrients from the turbulent regions of eastern Juan de Fuca. The high nutrient concentrations present in Juan de Fuca surface waters result from intensive mixing known to occur around the San Juan Islands and in the extreme eastern part of the strait (Herlinveaux and Tully, 1961). As this cold, nutrient laden surface water moves westward the nutrient input from the deep waters will be removed west of the Victoria-Port Angeles sill, and phytoplankton growth will lower the nutrient concentrations present. Note that in the cruise RV002 data the outer edge of the patch of high chlorophyll corresponds precisely with the transition to warmer, impoverished coastal waters (Figures 26, 27, 28, 34, 36 and 40).

While the continuous fluorescence data indicates the exact dimensions of this patch, the fluorescence yield changed rather markedly over the cruise tract (Figures 41, 42), making estimates of phytoplankton abundance from fluorescence alone very poor. The highest fluorescence yields were in the warmer, impoverished waters along the outer coast. These waters also exhibited generally higher DCMU ratios than did those areas in Juan de Fuca, although there is a considerable amount of scatter (Figure 43). The highest correlations for DCMU ratio were with nitrate (-.5), nitrite (-.40) and phosphate (-.46) and with temperature (.40).* No productivity data are available with which to test Samuelsson and Oquist's (1977) report that the DCMU ratio is roughly proportional to carbon uptake, but this is contrary to what might be expected considering the distribution of chlorophyll and nutrient concentrations seen here.

---

* DCMU ratio was not included in the multiple correlation table in each cruise summary primarily because of space and computer memory limitations. All DCMU correlations were low.

2.2.4 Comparison of In-Line Samples with Surface Samples

Over-the-side bucket salinity agreed well with in-line salinity (r = .95, n = 13) except in Juan de Fuca which was an area of rapid change, and off Estevan Point where stations 2.15, 2.16, 2.17 and 2.18 exhibited relatively higher bucket salinity (Figure 44). These stations were sampled by a single technician and may be due to a time delay between surface and in-line sampling.

The in-line and surface chlorophyll samples also agree except where the ship is traversing an area of rapid change such as between stations 2.28 to 2.34 and 2.39 to 2.40 (Figure 45). For 13 pairs of samples r = .90. Since bucket samples were taken from 1 to 2 minutes after the in-line samples this is to be expected.

2.2.5 Replicability Sampling

Replicate sampling (n = 3) for nitrite, nitrate and phosphate showed standard deviations of 0.017, 0.103 and 0.035 μg at/L for the combined operations of sampling and analysis.

% CHL – C CHL / CHL
↑
PHAEO pigment?

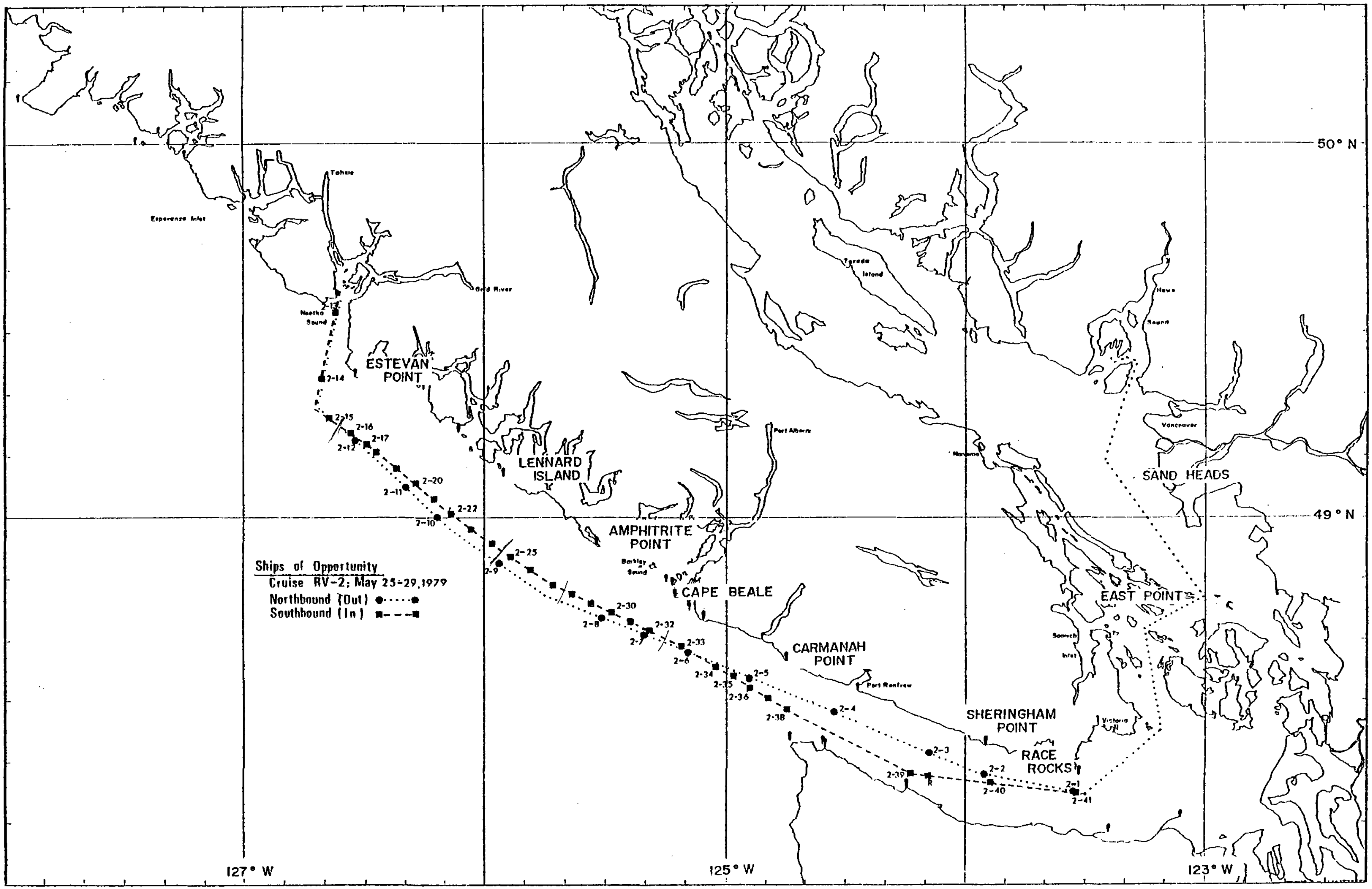


Figure 25. Cruise track and station locations - RV002.

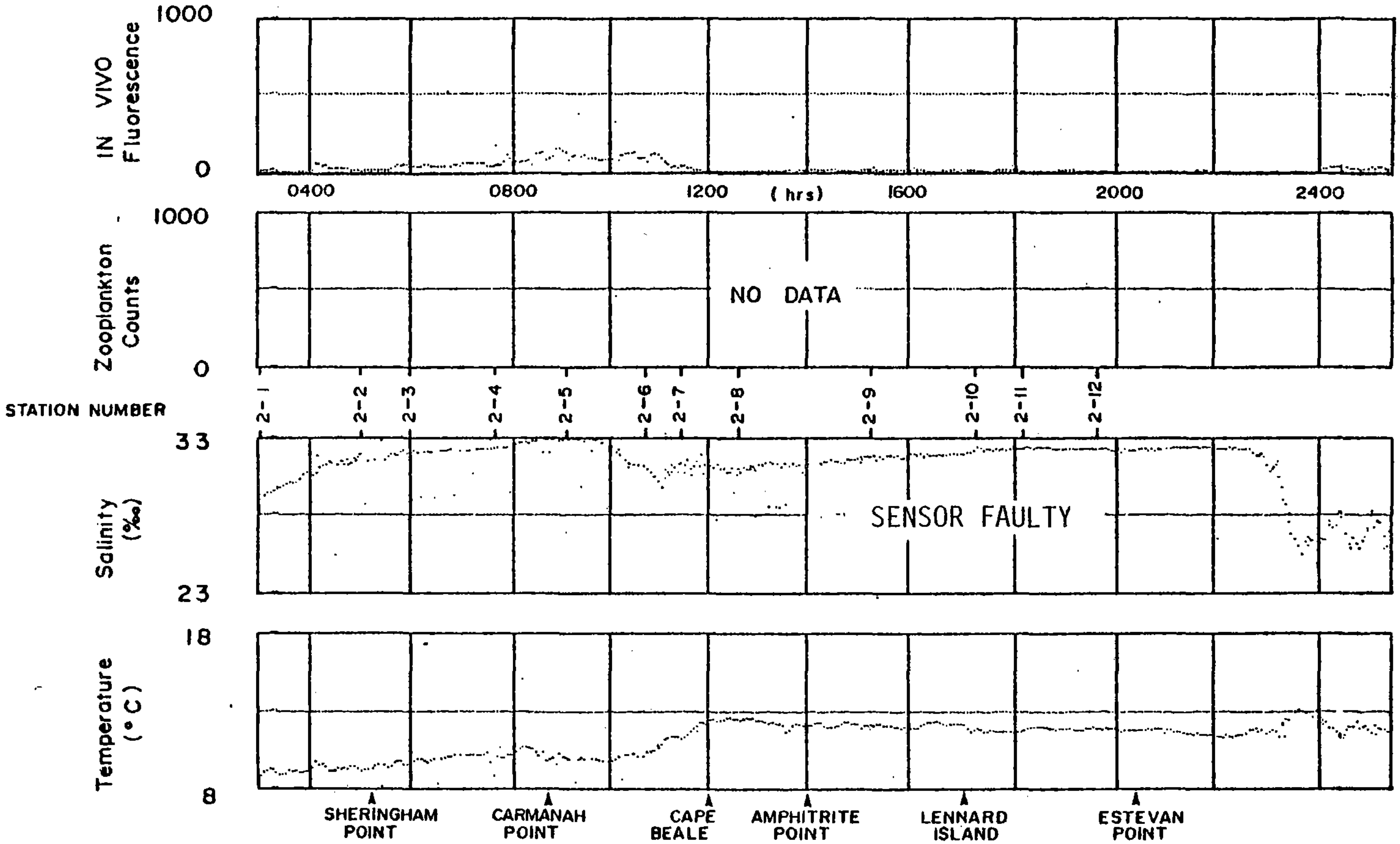


FIGURE 26 Continuous Data Record - RV002 (Northbound)

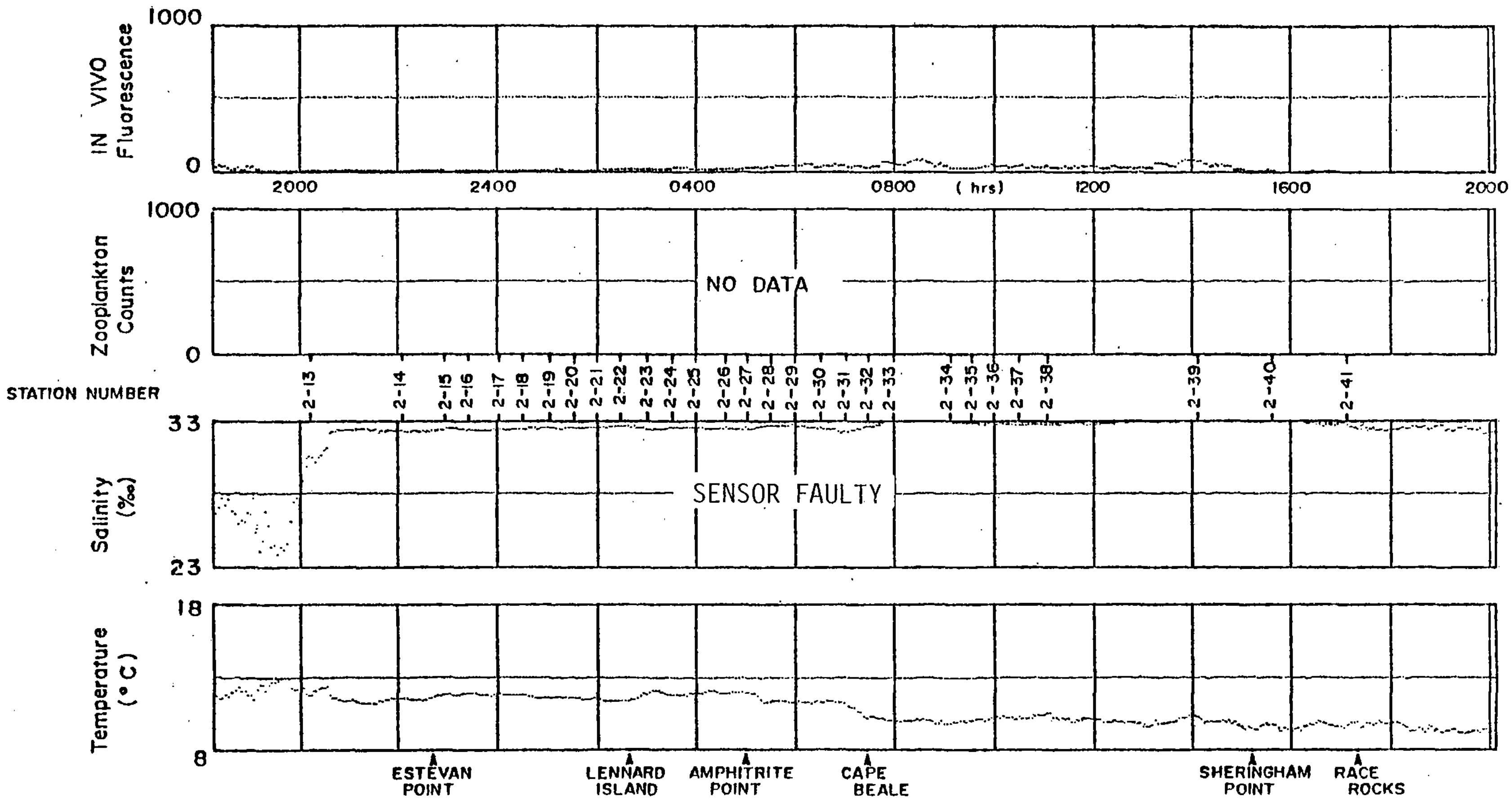


FIGURE 27 Continuous Data Record - RV002 (Southbound)

Table 9:

REFERENCE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-2

STN #	CDATE	JDATE	TIME	LATITUDE	LONGITUDE	DIS
2.01	26/ 5/79	146	304	48-15.0 N	123-33.0 W	188.
2.02	26/ 5/79	146	502	48-18.0 N	123-54.6 W	215.
2.03	26/ 5/79	146	600	48-21.0 N	124-14.4 W	239.
2.04	26/ 5/79	146	740	48-28.0 N	124-32.0 W	265.
2.05	26/ 5/79	146	912	48-33.8 N	124-53.7 W	293.
2.06	26/ 5/79	146	1034	48-37.8 N	125- 9.0 W	313.
2.07	26/ 5/79	146	1134	48-40.0 N	125-20.0 W	327.
2.08	26/ 5/79	146	1234	48-43.4 N	125-31.0 W	341.
2.09	26/ 5/79	146	1525	48-52.0 N	125-56.0 W	376.
2.10	26/ 5/79	146	1721	49- 0.0 N	126-11.1 W	399.
2.11	26/ 5/79	146	1815	49- 4.8 N	126-19.5 W	412.
2.12	26/ 5/79	146	1941	49-12.3 N	126-32.0 W	432.
2.13	27/ 5/79	147	2015	49-33.2 N	126-36.2 W	471.
2.14	27/ 5/79	147	2205	49-22.7 N	126-40.0 W	462.
2.15	27/ 5/79	147	2300	49-16.0 N	126-38.5 W	450.
2.16	27/ 5/79	147	2330	49-13.7 N	126-33.1 W	443.
2.17	28/ 5/79	148	1	49-12.1 N	126-29.5 W	439.
2.18	28/ 5/79	148	31	49-10.5 N	126-26.8 W	436.
2.19	28/ 5/79	148	102	49- 8.0 N	126-22.0 W	429.
2.20	28/ 5/79	148	130	49- 5.3 N	126-17.0 W	421.
2.21	28/ 5/79	148	200	49- 3.0 N	126-12.1 W	414.
2.22	28/ 5/79	148	230	49- .2 N	126- 8.1 W	408.
2.23	28/ 5/79	148	300	48-58.0 N	126- 2.1 W	400.
2.24	28/ 5/79	148	330	48-56.0 N	125-58.0 W	394.
2.25	28/ 5/79	148	400	48-53.6 N	125-53.0 W	387.
2.26	28/ 5/79	148	430	48-51.5 N	125-48.8 W	382.
2.27	28/ 5/79	148	500	48-49.0 N	125-42.9 W	374.
2.28	28/ 5/79	148	530	48-48.0 N	125-38.5 W	369.
2.29	28/ 5/79	148	600	48-46.1 N	125-33.5 W	363.
2.30	28/ 5/79	148	630	48-45.0 N	125-28.9 W	358.
2.31	28/ 5/79	148	700	48-43.5 N	125-23.9 W	352.
2.32	28/ 5/79	148	731	48-42.0 N	125-19.0 W	347.
2.33	28/ 5/79	148	801	48-39.4 N	125-11.0 W	337.
2.34	28/ 5/79	148	901	48-36.0 N	125- 2.5 W	325.
2.35	28/ 5/79	148	928	48-34.6 N	124-58.5 W	321.
2.36	28/ 5/79	148	1000	48-32.6 N	124-54.0 W	315.
2.37	28/ 5/79	148	1030	48-31.0 N	124-50.0 W	310.
2.38	28/ 5/79	148	1100	48-29.5 N	124-45.0 W	304.
2.39	28/ 5/79	148	1410	48- 9.0 N	124-13.9 W	250.
2.40	28/ 5/79	148	1542	48- 7.4 N	123-53.0 W	225.
2.41	28/ 5/79	148	1704	48- 5.9 N	123-32.0 W	199.

Table 10:

INLINE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-2

STN #	SEN T	SEN SAL	DIS SAL	SIG	NO2	NO3	PO4
2.01	9.22	29.11	31.30	22.51	.33	20.13	2.03
2.02	9.52	31.69	31.83	24.47	.36	18.33	1.77
2.03	9.83	32.27	31.91	24.87	.38	18.57	1.71
2.04	10.09	32.48	31.68	25.00	.32	26.37	1.23
2.05	9.90	32.99	31.97	25.42	.22	12.28	.98
2.06	10.16	31.22	32.02	24.00	.21	6.43	.65
2.07	11.89	31.21	31.48	23.70	.12	7.95	.32
2.08	12.49	31.14	31.19	23.53	.20	5.72	.19
2.09	12.22	31.94	—	24.20	.08	8.34	.23
2.10	11.73	32.33	31.60	24.59	.05	1.66	.29
2.11	12.05	32.38	31.66	24.57	.04	.07	.27
2.12	11.89	32.31	31.49	24.55	.06	—	.29
2.13	11.86	30.41	28.51	23.08	.06	1.57	.39
2.14	11.59	32.40	30.63	24.67	.06	.71	.46
2.15	11.89	32.67	31.31	24.82	.05	.35	.38
2.16	11.92	32.43	31.31	24.64	.06	1.11	.36
2.17	11.91	32.49	31.41	24.68	.03	.35	.28
2.18	11.80	32.54	31.47	24.74	.03	.07	.32
2.19	11.62	32.69	31.56	24.89	.08	.30	.34
2.20	11.60	32.69	31.58	24.89	.06	5.04	.34
2.21	11.63	32.65	31.61	24.86	.03	2.38	.14
2.22	11.42	32.78	31.64	24.99	.04	2.03	.34
2.23	11.88	32.59	31.55	24.76	.06	1.14	.30
2.24	11.86	32.61	31.50	24.78	.03	2.00	.24
2.25	12.00	32.60	31.49	24.75	.05	1.72	.21
2.26	12.00	32.57	31.47	24.73	.03	4.29	.21
2.27	12.00	32.61	31.45	24.76	.06	.19	.22
2.28	11.40	32.71	31.59	24.94	.12	.47	.36
2.29	11.31	32.80	31.66	25.03	.06	.44	.23
2.30	11.33	32.59	31.49	24.86	.05	2.88	.42
2.31	11.08	32.37	31.24	24.74	.11	8.64	.52
2.32	10.34	32.79	31.49	25.20	.17	4.05	.77
2.33	10.00	33.13	31.81	25.52	.22	5.33	.75
2.34	9.82	33.16	31.94	25.57	.23	8.99	.88
2.35	9.95	32.96	31.84	25.39	.32	12.76	1.09
2.36	10.16	32.86	31.79	25.28	.32	4.71	.82
2.37	10.38	32.80	31.77	25.19	.28	3.72	.80
2.38	10.43	32.84	31.78	25.22	.29	2.80	.72
2.39	10.17	33.14	31.99	25.50	.34	11.39	.80
2.40	9.72	33.12	31.91	25.55	.37	12.95	—
2.41	9.65	32.86	31.76	25.36	.34	19.54	.86

Table 11:

INLINE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-2

STN #	CHL	PHAEO	% CHL	SEN FL	FL YD	ZOO #	DCMU #
2.01	1.47	1.12	.57	22.	14.92	–	–
2.02	1.96	.97	.67	23.	11.74	–	.33
2.03	10.54	4.79	.69	44.	4.18	–	–
2.04	11.18	7.35	.60	59.	5.28	–	.44
2.05	12.79	4.68	.73	111.	8.68	–	–
2.06	16.76	4.37	.79	102.	6.09	–	–
2.07	4.83	2.88	.63	29.	6.00	–	–
2.08	2.45	1.06	.70	19.	7.74	–	–
2.09	3.44	1.38	.71	19.	5.52	–	.50
2.10	1.78	1.00	.64	12.	6.75	–	.65
2.11	1.17	.99	.54	10.	8.54	–	–
2.12	1.64	1.17	.58	14.	8.54	–	–
2.13	1.31	.72	.65	11.	8.37	–	.55
2.14	1.23	.79	.61	13.	10.56	–	.55
2.15	.99	.56	.64	9.	9.14	–	–
2.16	.88	.48	.65	11.	12.44	–	–
2.17	.84	.50	.63	12.	14.24	–	–
2.18	1.30	.55	.70	15.	11.56	–	–
2.19	1.66	.77	.68	17.	10.24	–	–
2.20	1.82	1.10	.62	14.	7.68	–	.68
2.21	1.52	1.11	.58	15.	9.88	–	.73
2.22	2.65	1.12	.70	25.	9.44	–	.76
2.23	2.31	1.14	.67	27.	11.70	–	.61
2.24	2.42	1.18	.67	28.	11.59	–	.85
2.25	2.46	1.09	.69	23.	9.33	–	.77
2.26	1.99	.96	.67	23.	11.58	–	1.20
2.27	2.67	1.55	.63	30.	11.25	–	.51
2.28	3.40	1.24	.73	37.	10.87	–	–
2.29	4.77	2.02	.70	47.	9.85	–	–
2.30	3.29	.97	.77	39.	11.85	–	–
2.31	6.07	2.12	.74	39.	6.43	–	.63
2.32	6.80	2.47	.73	40.	5.88	–	–
2.33	9.90	2.55	.80	65.	6.57	–	.48
2.34	12.68	5.03	.72	45.	3.55	–	–
2.35	11.92	6.51	.65	36.	3.02	–	.65
2.36	13.55	7.64	.64	59.	4.35	–	.77
2.37	13.10	6.69	.66	48.	3.66	–	.97
2.38	14.00	5.23	.73	39.	2.79	–	.66
2.39	9.04	3.73	.71	78.	8.63	–	.48
2.40	6.38	2.48	.72	12.	1.88	–	.50
2.41	2.66	.92	.74	8.	3.01	–	.44

Table 12:

SURFACE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-2

STN #	DIS T	DIS SAL	SIG	CHL	PHAEO	% CHL
2.01	10.50	31.90	24.48	2.34	1.28	.65
2.02	9.90	31.93	24.60	2.79	1.37	.67
2.03	9.78	31.85	24.55	8.86	3.88	.70
2.04	10.80	31.68	24.25	11.97	3.25	.79
2.05	—	—	—	—	—	—
2.06	—	—	—	—	—	—
2.07	—	—	—	—	—	—
2.08	—	—	—	—	—	—
2.09	—	—	—	—	—	—
2.10	—	—	—	—	—	—
2.11	—	—	—	—	—	—
2.12	—	—	—	—	—	—
2.13	11.80	29.63	22.49	.98	1.71	.36
2.14	11.20	31.42	23.98	1.43	.89	.62
2.15	11.40	31.66	24.13	.80	.38	.68
2.16	11.30	31.49	24.02	.96	.59	.62
2.17	11.40	31.49	24.00	.90	.52	.63
2.18	11.30	31.53	24.05	1.70	.74	.70
2.19	11.10	31.62	24.15	1.98	.92	.68
2.20	11.02	31.60	24.15	1.80	.83	.68
2.21	11.08	31.61	24.15	—	—	—
2.22	11.10	31.65	24.17	2.27	1.08	.68
2.23	11.38	31.54	24.04	2.53	2.56	.50
2.24	11.34	31.51	24.03	3.10	1.10	.74
2.25	11.40	31.49	24.00	2.59	.95	.73
2.26	11.14	31.47	24.03	1.93	1.02	.65
2.27	11.53	31.45	23.94	2.91	1.19	.71
2.28	10.97	31.65	24.20	4.38	1.49	.75
2.29	10.95	31.68	24.22	8.16	2.14	.79
2.30	10.90	—	—	6.12	2.41	.72
2.31	10.72	—	—	9.08	3.57	.72
2.32	10.25	—	—	8.09	2.68	.75
2.33	10.05	—	—	14.74	4.55	.76
2.34	9.23	—	—	11.04	3.82	.74
2.35	9.80	—	—	9.82	5.66	.63
2.36	10.10	—	—	14.03	7.44	.65
2.37	10.25	—	—	13.69	7.08	.66
2.38	10.28	—	—	13.56	4.97	.73
2.39	10.01	—	—	19.04	4.95	.79
2.40	9.80	—	—	4.07	1.91	.68
2.41	10.34	—	—	1.46	.81	.64

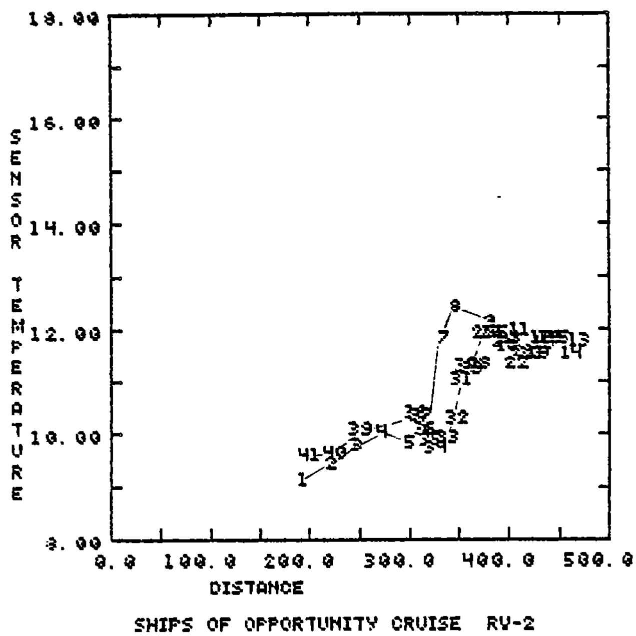


Figure 28. Sensor temperature (^{o}C) vs distance along cruise track - RV002.

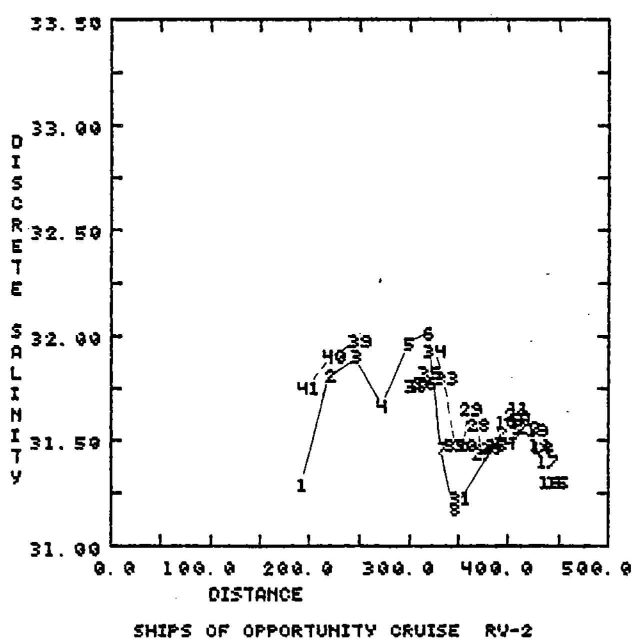


Figure 29. Discrete salinity (ppt) vs distance along cruise track - RV002.

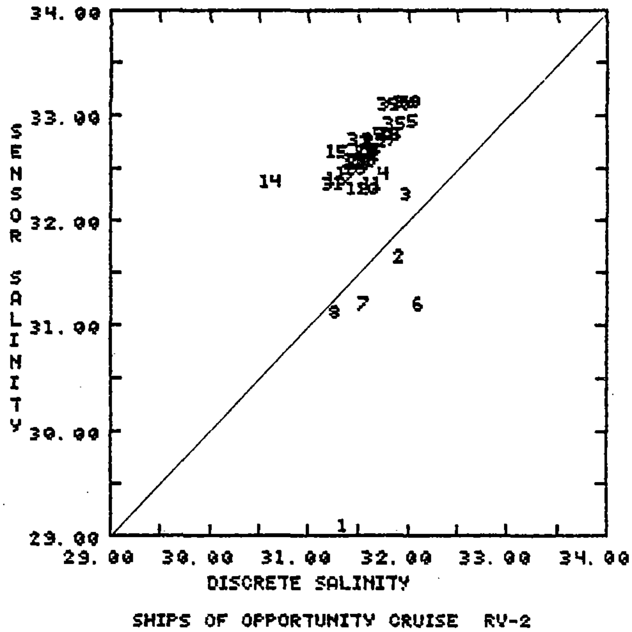


Figure 30. Sensor salinity (ppt) vs discrete salinity (ppt) - RV002.

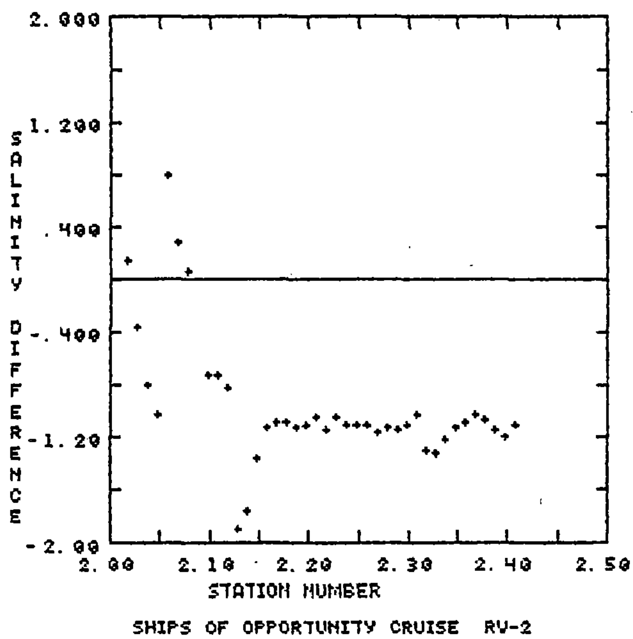


Figure 31. Salinity difference (ppt) - (discrete salinity - sensor salinity) vs station number - RV002.

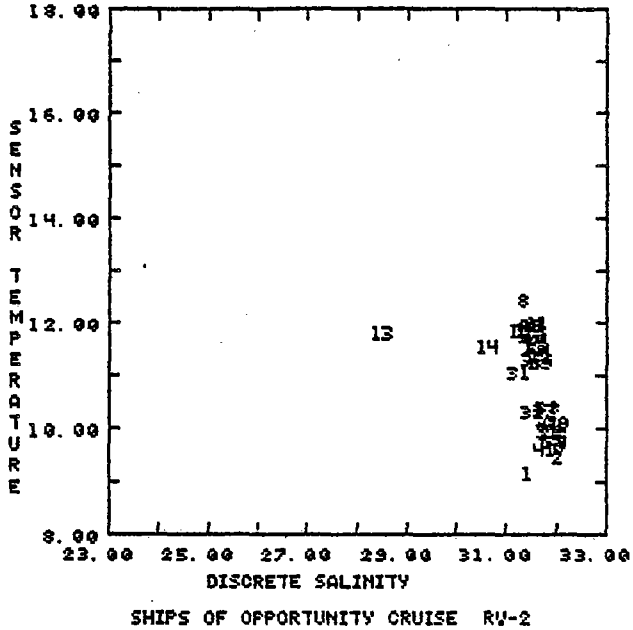


Figure 32. Sensor temperature (^{O}C) vs discrete salinity (ppt) - RV002.

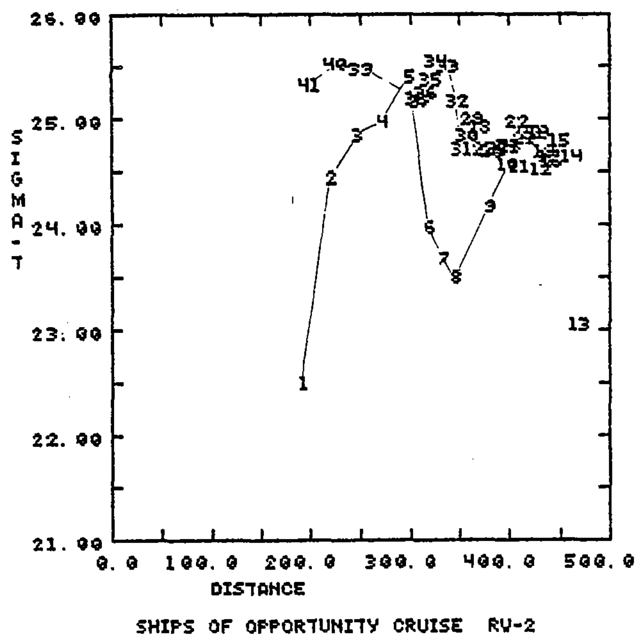


Figure 33. Sigma-t vs distance along cruise track - RV002.

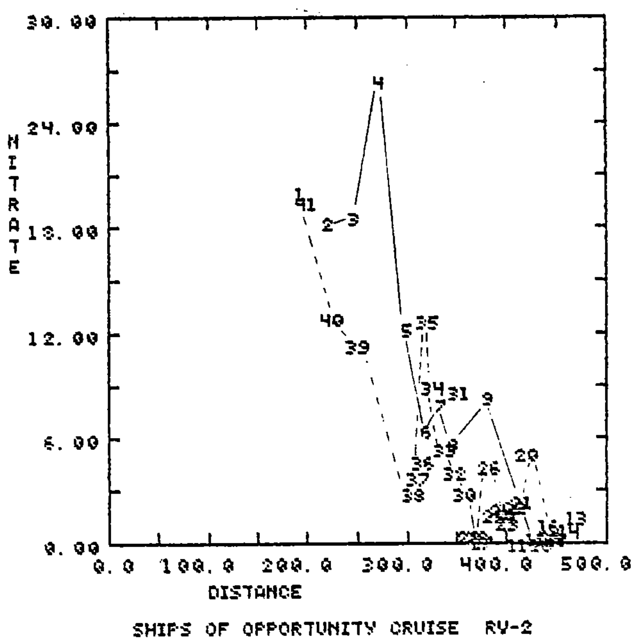


Figure 34. Nitrate concentration (µg at/L) vs distance along cruise track - RV002.

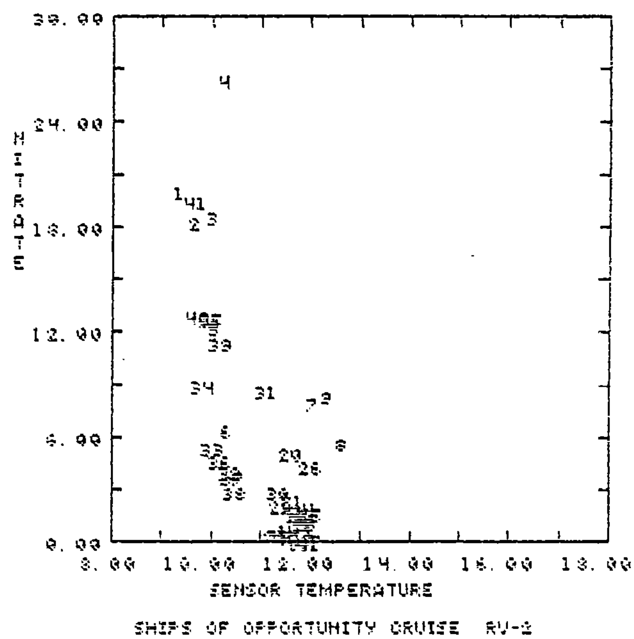


Figure 35. Nitrate concentration (µg at/L) vs sensor temperature (°C) - RV002.

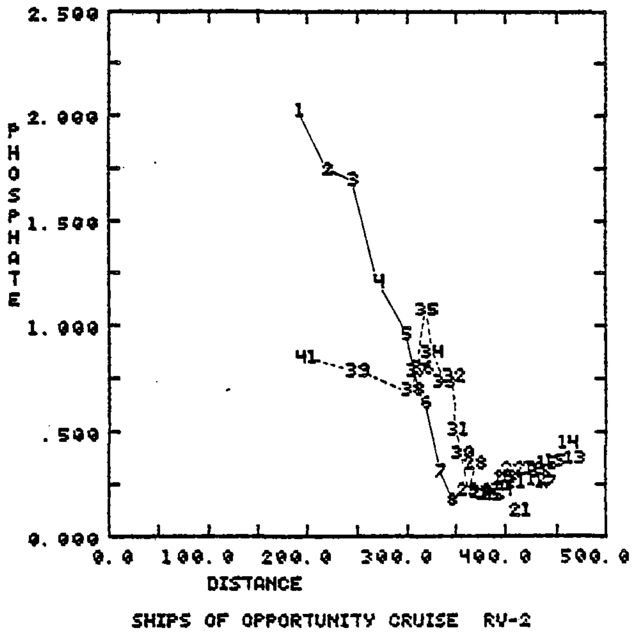


Figure 36. Phosphate concentration (μg at/L) vs distance along cruise track - RV002.

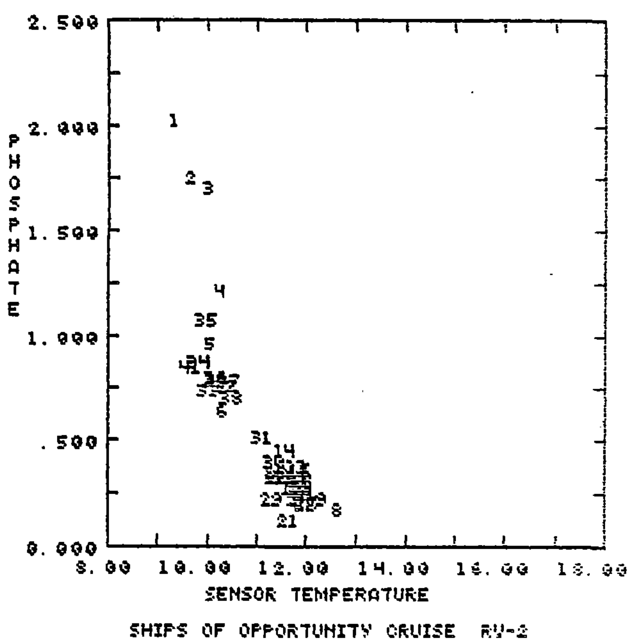


Figure 37. Phosphate concentration (μg at/L) vs sensor temperature (°C) - RV002.

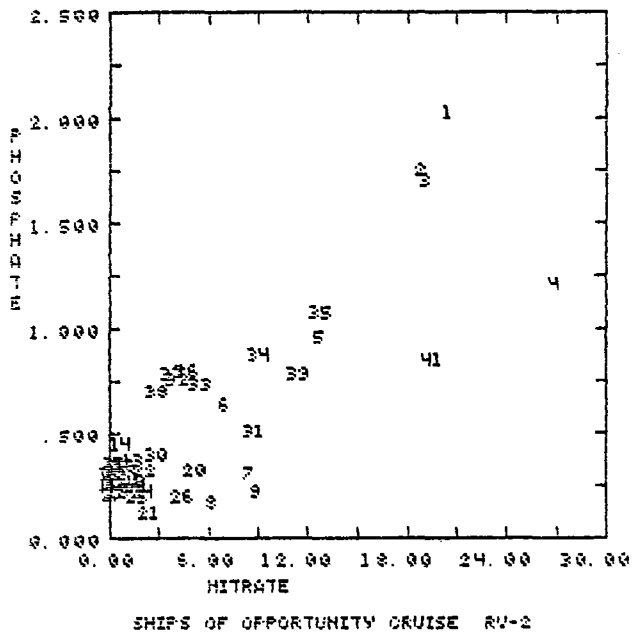


Figure 38. Phosphate concentration (μg at/L) vs nitrate concentration (μg at/L) - RV002.

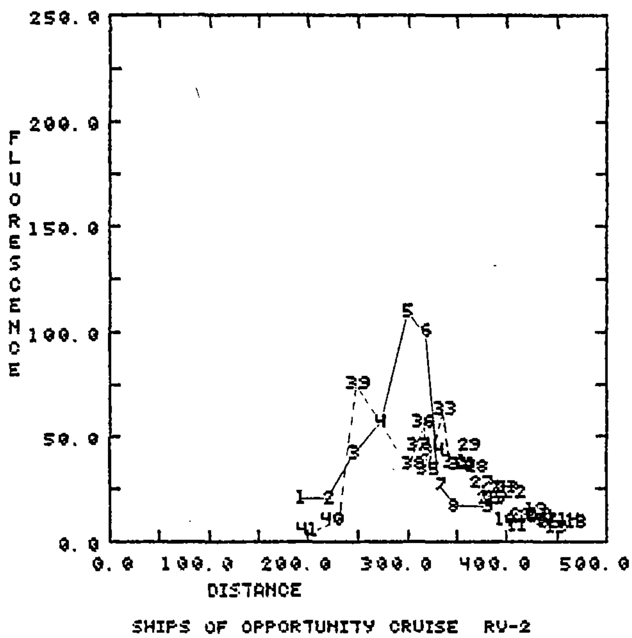


Figure 39. in vivo fluorescence vs distance along cruise track - RV002.

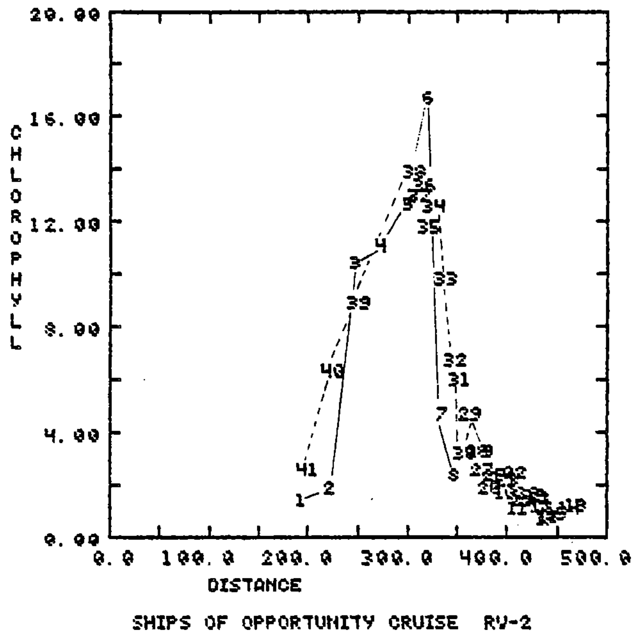


Figure 40. Chlorophyll a (mg/m^3) vs distance along cruise track - RV002.

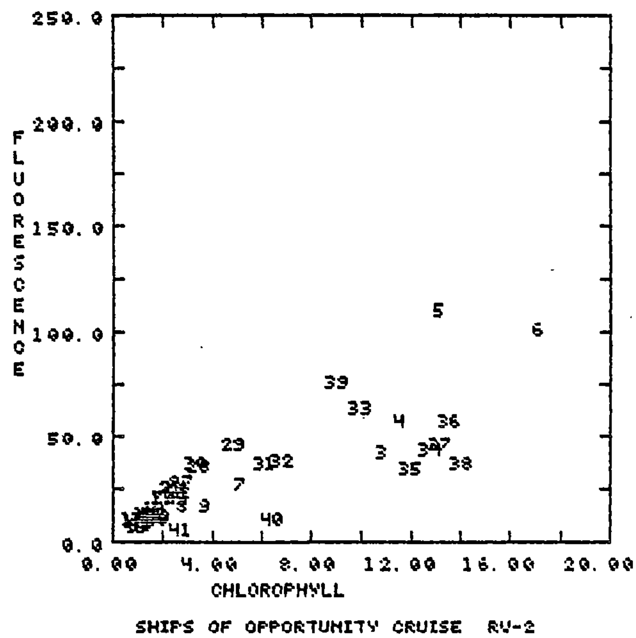


Figure 41. in vivo fluorescence vs chlorophyll a (mg/m^3) - RV002.

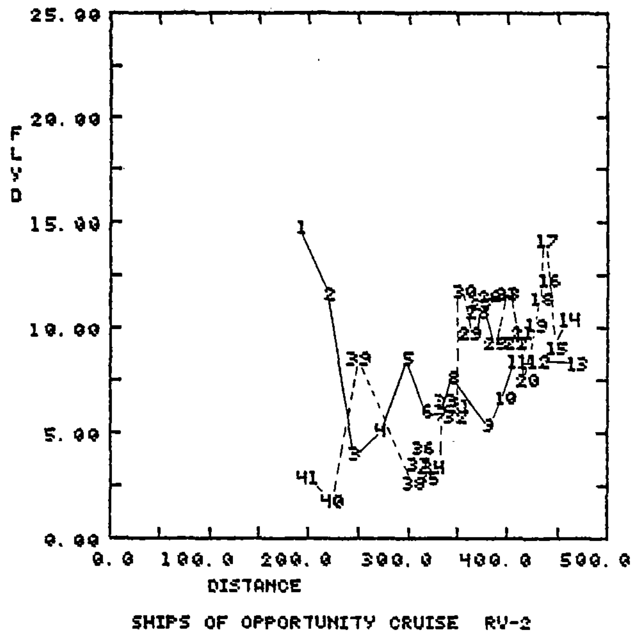


Figure 42. Fluorescence yield vs distance along cruise track - RV002.

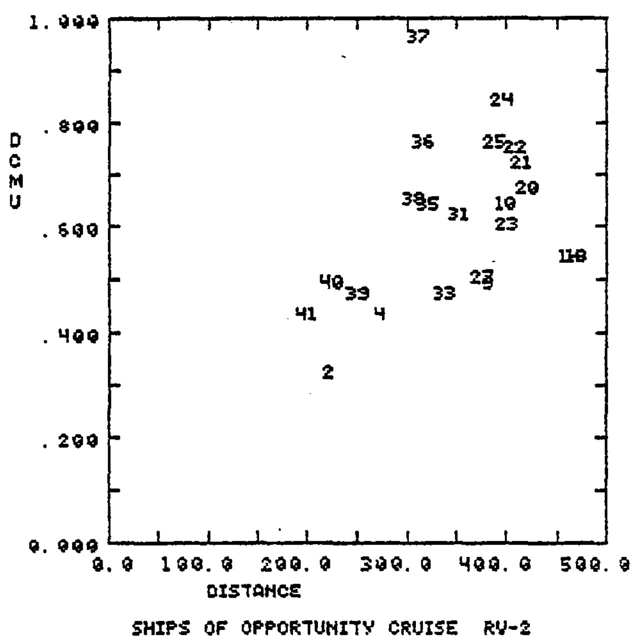


Figure 43. D.C.M.U. ratio vs distance along cruise track - RV002.

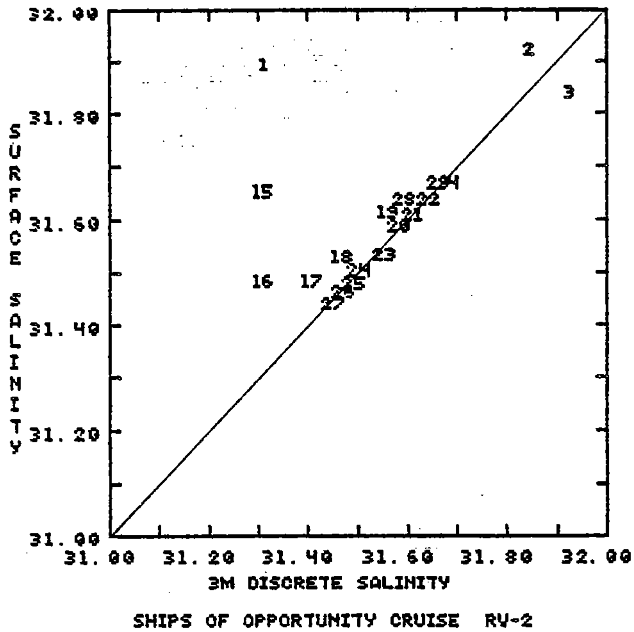


Figure 44. Surface salinity (ppt) vs 3 m discrete salinity (ppt) - RV002.

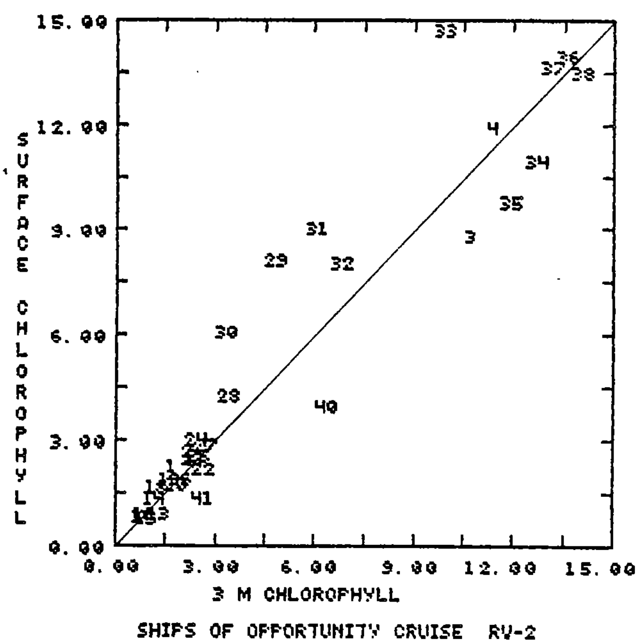


Figure 45. Surface chlorophyll a (mg/m^3) vs 3 m chlorophyll a (mg/m^3) - RV002.

Table 13: Multiple Correlation Table

SHIPS OF OPPORTUNITY CRUISE RV-2

	SEN T	SEN S	3 SAL	3 SIG	3 NO2	3 NO3	3 PO4	3 CHL	3 %CHL	SEN FL	3 FLYB	3 ZOO
SEN T												
SEN S	-.04											
3 SAL	-.41	.49										
3 SIG	-.30	.97	.58									
3 NO2	-.88	-.03	.37	.20								
3 NO3	-.74	-.21	.27	-.02	.79							
3 PO4	-.88	-.28	.24	-.05	.85	.82						
3 CHL	-.66	.24	.43	.40	.65	.35	.43					
3 %CHL	-.29	.29	.24	.35	.20	.02	.01	.41				
SEN FL	-.52	.16	.39	.29	.42	.27	.33	.81	.48			
3 FLYB	.45	-.29	-.25	-.40	-.56	-.35	-.20	-.67	-.28	-.25		
3 ZOO#	-	-	-	-	-	-	-	-	-	-	-	

2.3 Cruise RV003: July 9-12, 1979

2.3.1 Logistical Summary

The third cruise took place from July 9th to 12th, 1979. The technicians and their gear were transported via a locally chartered float-plane from Patricia Bay to the log-loading site near Anvil Island in Howe Sound.

The tug and loaded barge left Anvil Island at 0230 July 9th, bound for Gold River. The return trip (on the 11th and 12th) was from McBride Bay in Esperanza Inlet to Burgoyne Bay on Saltspring Island. The technicians, their gear and samples were offloaded in Vancouver on the 13th and returned to Sidney by truck.

Sampling was spread over a larger portion of the cruise than was the case for RV001 and RV002, extending into Haro strait and the Straits of Georgia (see Figure 46). Rough weather off the west coast of Vancouver Island caused a long gap in sampling on the northbound leg on the 9th and 10th*. Continuous data for temperature, conductivity and chlorophyll fluorescence were collected for the entire cruise. Due to a malfunction in the sensor electronics, continuous zooplankton density data could only be gathered for the first half of the northbound leg cruise. Thirty-seven sets of in-line discrete samples (salinity, nitrite, nitrate, phosphate, chlorophyll and phytoplankton) were collected. At thirty-three stations the change of *in vivo* chlorophyll fluorescence after addition of the herbicide DCMU was also observed. Twenty-six in-line zooplankton samples were also collected. The zooplankton and phytoplankton samples are intended for species identification and are deposited with Ocean Ecology, Institute of Ocean Sciences. The pump flow rate used for cruise RV003 was 30-35 litres/minute, up from 24-28 litres/minute for cruise RV002 and 17-20 litres/minute for

---

* While all of the sampling operations on this cruise and subsequent cruises were conducted from inside the ship, the technicians found our forepeak 'lab' a very uncomfortable and difficult place in which to work in rough weather. Seasickness and difficulty of working caused by the large movements of the bow section often forced curtailment of sampling in rough weather.

Laede Laden
impoverish
plague

cruise RV001. Extracts from the ship [illegible] te and weather are presented in Table 17.

2.3.2 Equipment Malfunctions

Cruise RV003 continued to be pl [illegible] pproximately two-thirds of the way along the [illegible] cruise, the +15VDC voltage regulator ceased functioning and during the attempts to repair this, two capacitors were burned out thus disabling the zooplankton sensor.

A separate problem involving a malfunction in the shift register of the data logger caused successive data bytes near the end of some data sweeps to be overwritten with meaningless numbers. The net result is that while the majority of the time, temperature and conductivity and zooplankton numbers were reliable, the chlorophyll fluorescence was recoverable but of lesser quality. The fluorometer range, the reference number and least significant bits of temperature and conductivity were lost completely.

The continuous data presented here include all of the useful time intervals, the 10 most significant bits of temperature and conductivity and the sigma-t calculated from these parameters, the zooplankton data where they exist and the reconstructed fluorescence data. The flow chart in Figure 66 demonstrates how the fluorescence data have been retrieved. Note that these fluorescence data are of poor quality and should only be used as a relative indicator of events. Dashed lines on the fluorescence record in Figures 33,47,48 indicate the fluorescence recorded by the strip chart (which is assumed correct). These disagreements are the result of real spikes of very short duration which cause the correcting scheme to give erroneous numbers. It has not been considered worthwhile to further manicure these data for this report.

The salinity sensor also continued to misbehave. For cruises RV001 and RV002 the salinities derived from continuous records did not agree with discrete salinity samples. The agreement between discrete salinity and sensor salinity for RV003 was not good (.4 ppt) however the slope of the line is 0.98 (see Figures 51, 52). Only .04 of this scatter can be ascribed to the malfunction of the data logger and the resulting loss of the two least significant bits of conductivity and temperature. It should be noted that the approximate 0.6 ppt offset (sensor salinity high) which appeared in the data from RV001 and RV002 does not appear here. The data logger was returned to its manufacturer after cruise RV003 for repair of the shift register problem, but data from subsequent cruises continued to indicate disagreement between the salinity sensor and discrete salinity samples. Most of this was due to drift and high frequency low amplitude noise on the conductivity sensor output, but close examination of the data and on-board technique suggests inadequate flushing of the sampling reservoir could contribute to the problem occasionally. We put most confidence in the discrete salinity data and include the continuous data here for reference only. It does provide a very rough picture of events along the cruise track when used in conjunction with the plot of salinity difference vs station number.

2.3.3 Data Summary and Discussion

Comparison of surface bucket data and 3 m in-line discrete data from cruise RV001 and RV002 indicated a close relationship over most of the study area except in highly stratified area, or in regions of rapid change where the interval between sampling each depth meant that different water bodies were being sampled. For this reason and because of time and cost considerations surface bucket sampling was discontinued for cruise RV003. Surface temperature data were to be collected but could not be because the bucket thermometer was left on the transfer craft.

The continuous data (Figures 47 and 48) show warm very low salinity* waters containing large amounts of zooplankton and high chlorophyll fluorescence in

---

* Refer to the difference between discrete and sensor salinity (Figure 52) to establish confidence/units for continuous salinity in Figure 3.3, 47, 48.

Georgia Strait. The corresponding discrete data for the first three stations show low nutrient concentrations (Figure 55 and 57) and relatively low chlorophyll concentrations (Figure 61) in this area. A boundary near Patos Island marked the beginning of colder, more saline turbulent waters in Boundary Passage, Haro Strait and Juan de Fuca Strait (Figure 49) having high nutrient concentration. The extreme eastern portion of Juan de Fuca was isothermal with temperature variations beginning west of Race Rocks. On both the outbound and inbound trips there was a warming of the surface waters towards the west with maximum temperatures near station 11 off Carmanah Point in a low salinity water mass located there at this time. This low density water (Figure 54) had very low nutrient levels (Figure 55 and 57) and was separated from the Juan de Fuca water by a sharp thermal front (Figure 49). The TIROS-N image available for July 14, a few days after this cruise (Figure 67) indicates that this warm water (grey in this figure) extended south along the coast. It is reasonable to assume that the Columbia River discharge was responsible for its lowered salinity.

While there was no evidence of large phytoplankton populations anywhere in the study area, the maximum chlorophyll concentrations (4 mg/m^3) were detected at the outer edge of the Juan de Fuca water, at stations 3.9, 3.10 and 3.11. We interpret this as being a result of phytoplankton growth as the water mass moves seaward.

The waters off the west coast of the Island were generally warm and saline with very low nutrient concentrations, with the notable exception of stations 3.22 and 3.23 off the Long Beach area. Sea temperature at station 3.23 was approximately $2^{o}C$ colder than the offshore average on this cruise. While the salinity at this station was only slightly lower than at neighbouring stations (.2 ppt), nutrient concentrations were very high and exhibited a significantly different N/P ratio (Figure 59) indicating the possibility of upwelling. The fact that the chlorophyll concentrations observed at station 3.23 was not significantly greater than the offshore average may be a factor of the stage of the upwelling-bloom sequence observed.

Because of the data logger malfunction the fluorescence values reported here and in Table 16 for each station have been reconstructed from the strip-chart record which is a completely separate system*. The chlorophyll concentrations observed on RV003 were low (between 0.5 and 6 mg/m^3), however, the calculated fluorescence yields (fluorescence/unit chlorophyll) were much higher than observed on cruises RV001 and RV002. This is because of adjustments to the fluorometer blank and sensitivity made prior to cruise RV003 which had the effect of increasing the sensitivity of the instrument by approximately 18x. Comparison of in vivo fluorescence or any of its products between the first two and the last four cruises will be only very rough, even with the 18x factor (which was derived from comparisons between the Turner Designs fluorometer output with that of a Turner 111 bench fluorometer used for the DCMU experiments).

The relationship between extracted chlorophyll and observed fluorescence (Figure 62) illustrates the difficulty with using fluorescence alone as a measure of chlorophyll in such large and diverse areas as studied here. The plot does however allow one to differentiate between areas showing different relationships between the two parameters. Because in vivo fluorescence is thought of as excess energy not utilized in photosynthesis (Govindjee et al. 1973), phytoplankton populations exhibiting low fluorescence yields can mean the population observed is growing actively, while higher fluorescence per unit chlorophyll may indicate nitrate stress (Slovacek and Hannan, 1977). Several other factors including species composition and light conditions may also affect the fluorescence yield so that caution is advised in interpretation of such data. Despite these problems the fluorescence versus chlorophyll plot for cruise RV003 does indicate a rather distinct separation of the phytoplankton sampled into two groups. Stations exhibiting high fluorescence yields were encountered in Juan de Fuca and Georgia Straits (Stations 3.2-3.13) on the outward bound track, and in the offshore area except in the cold water off Long Beach (Stations 3.22 - 3.24). This cold band of high nutrient waters carried phytoplankton which were fluorescing much less "per unit chlorophyll"

---

* Contrary to the reconstruction of the continuous data, tabulated data representing the fluorescence at the time of discrete sampling was calculated from fluorometer output voltage (as recorded on the strip chart) ÷ 5 volts x 1023.

than other coastal plankton and more like the Juan de Fuca populations sampled on the return trip. The increase in chlorophyll concentrations and drop in fluorescence yield observed in Juan de Fuca between trips is consistent with a growing population there. While phytoplankton samples have been taken and are deposited with Ocean Ecology they have not yet been analyzed. It may be possible to resolve whether any of these variations are related to species differences by examining a few samples from each cruise.

Our DCMU data (Figure 64) show relatively low numbers in Juan de Fuca with higher values north of Nootka Sound and in Juan de Fuca on the return trip. The very highest numbers were at stations 3.13 and 3.22, both in the cold water encountered off Long Beach. If Samuelsson's laboratory data (Samuelsson and Oquist 1977) can be extrapolated to these waters, high photosynthetic activity would have been expected in this water, with slightly elevated activity in Juan de Fuca on the return trip. Experimental data being gathered by the Ocean Ecology group should help in the interpretation of these data. DCMU ratios were poorly correlated with all other parameters, the highest correlations were -.37 for NO_3; -.36 for NO_2; -.32 for PO_4.

Figure 65 represents averages of zooplankton counts made over several minutes at the time of discrete sampling and is included here to allow comparison with the other discrete data. Small areas of higher counts can be seen in the vicinity of stations 3.2 and 3.10 which correspond with the east and west boundaries of the turbulent waters of Boundary Passage, Haro Strait and eastern Juan de Fuca. This turbulence manifest itself as cold surface waters in these data.

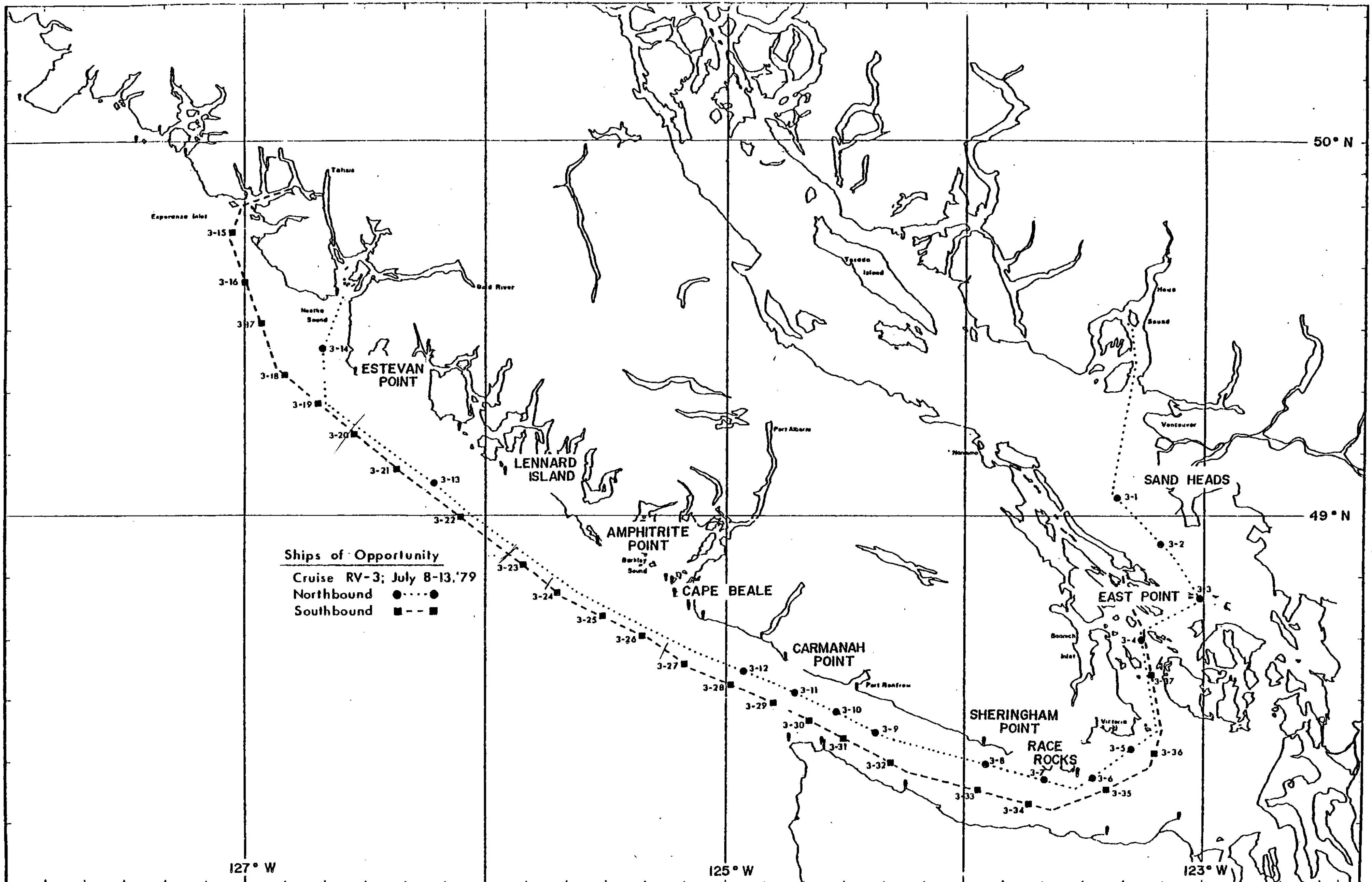


Figure 46. Cruise track and station locations - RV003.

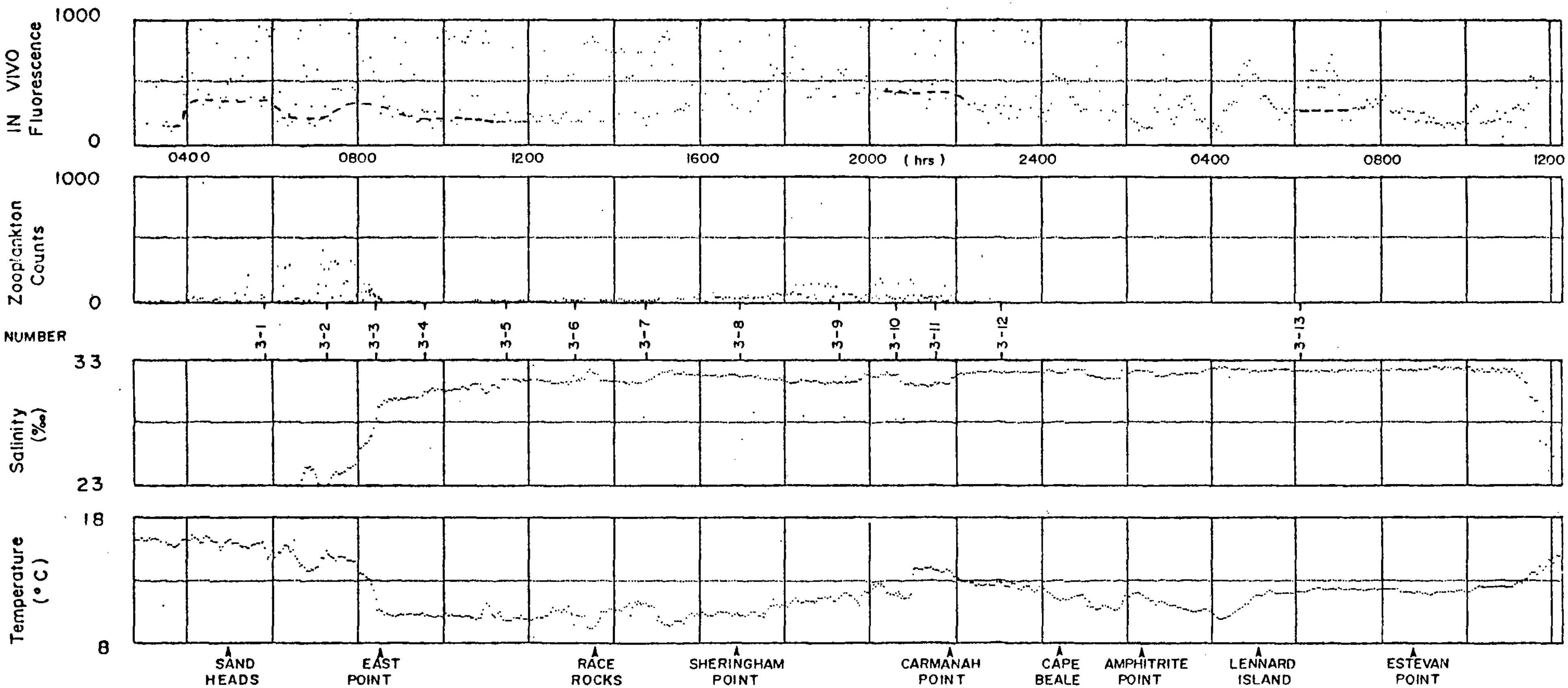


Figure 47. Continuous data record - RV003 (northbound).

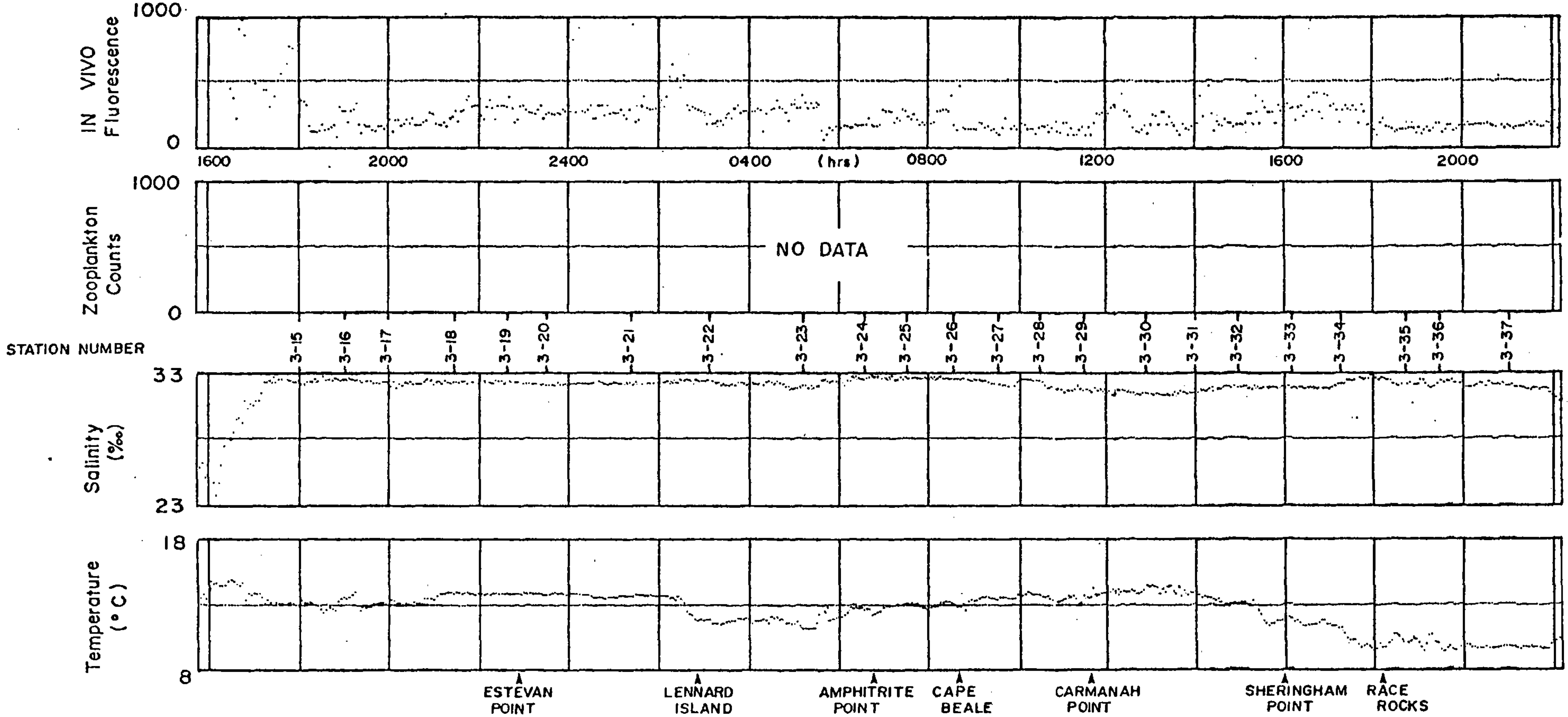


Figure 48. Continuous data record - RV003 (southbound).

Table 14:

REFERENCE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-3

STN #	CDATE	JDATE	TIME	LATITUDE	LONGITUDE	DIS
3.01	9/ 7/79	190	555	49- 2.7 N	123-23.0 W	71.
3.02	9/ 7/79	190	713	48-55.2 N	123-10.9 W	91.
3.03	9/ 7/79	190	830	48-46.0 N	123- 1.2 W	113.
3.04	9/ 7/79	190	949	48-40.0 N	123-15.8 W	135.
3.05	9/ 7/79	190	1130	48-21.7 N	123-17.9 W	174.
3.06	9/ 7/79	190	1320	48-17.0 N	123-28.0 W	188.
3.07	9/ 7/79	190	1430	48-16.8 N	123-40.0 W	206.
3.08	9/ 7/79	190	1635	48-19.0 N	123-55.0 W	221.
3.09	9/ 7/79	190	1920	48-24.2 N	124-22.5 W	255.
3.10	9/ 7/79	190	2030	48-28.3 N	124-32.0 W	267.
3.11	9/ 7/79	190	2130	48-31.0 N	124-43.0 W	284.
3.12	9/ 7/79	190	2230	48-34.0 N	124-55.3 W	300.
✓3.13	10/ 7/79	191	604	49- 5.0 N	126-13.0 W	414.
3.14	10/ 7/79	191	1131	49-26.5 N	126-41.0 W	465.
3.15	11/ 7/79	192	1800	49-45.0 N	127- 5.0 W	507.
3.16	11/ 7/79	192	1900	49-37.0 N	127- 0.0 W	494.
3.17	11/ 7/79	192	2000	49-31.0 N	126-56.0 W	482.
3.18	11/ 7/79	192	2130	49-22.6 N	126-50.0 W	469.
3.19	11/ 7/79	192	2230	49-18.0 N	126-41.9 W	456.
✓3.20	11/ 7/79	192	2335	49-13.1 N	126-33.8 W	442.
✓3.21	12/ 7/79	193	124	49- 7.5 N	126-22.0 W	426.
✓3.22	12/ 7/79	193	301	48-59.9 N	126- 6.9 W	402.
3.23	12/ 7/79	193	521	48-51.8 N	125-51.5 W	379.
× 3.24	12/ 7/79	193	630	48-47.0 N	125-42.8 W	364.
×3.25	12/ 7/79	193	730	48-43.0 N	125-31.0 W	349.
×3.26	12/ 7/79	193	830	48-40.6 N	125-21.2 W	336.
3.27	12/ 7/79	193	932	48-35.6 N	125-10.6 W	318.
3.28	12/ 7/79	193	1032	48-32.5 N	124-59.0 W	303.
3.29	12/ 7/79	193	1141	48-30.0 N	124-48.1 W	290.
3.30	12/ 7/79	193	1252	48-26.2 N	124-39.2 W	277.
3.31	12/ 7/79	193	1359	48-23.8 N	124-30.9 W	264.
3.32	12/ 7/79	193	1500	48-19.3 N	124-18.8 W	250.
3.33	12/ 7/79	193	1606	48-15.4 N	123-57.8 W	222.
3.34	12/ 7/79	193	1711	48-12.8 N	123-44.0 W	208.
3.35	12/ 7/79	193	1835	48-15.0 N	123-24.9 W	187.
3.36	12/ 7/79	193	1933	48-21.2 N	123-12.0 W	170.
3.37	12/ 7/79	193	2100	48-33.5 N	123-13.2 W	149.

Table 15:

INLINE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-3

STN #	SEN T	SEN SAL	DIS SAL	SIG	NO2	NO3	PO4
3.01	14.84	10.49	10.42	7.18	.24	4.28	.71
3.02	15.34	22.20	21.48	16.03	.14	2.14	.09
3.03	11.02	28.74	25.76	21.86	.25	16.05	1.34
3.04	10.17	30.48	29.79	23.36	.28	19.65	1.43
3.05	9.87	31.55	31.05	24.31	.30	21.71	1.82
3.06	9.70	31.89	31.52	24.60	.33	22.46	–
3.07	11.20	31.19	31.21	23.80	.39	25.52	1.85
3.08	10.55	31.89	31.75	24.46	.37	19.82	1.56
3.09	11.92	31.34	31.37	23.79	.38	17.22	1.32
3.10	12.04	31.82	31.44	24.14	.33	11.95	1.13
3.11	13.80	31.34	31.20	23.43	.12	2.17	.51
3.12	12.73	32.15	31.77	24.27	.16	4.62	.56
3.13	12.11	32.28	32.19	24.49	.14	4.74	.59
3.14	13.62	29.79	29.96	22.27	.12	1.56	.62
3.15	13.41	32.09	31.47	24.09	.19	3.91	.67
3.16	13.63	32.47	32.11	24.34	.13	2.54	.50
3.17	13.37	32.17	31.98	24.15	.15	4.01	.59
3.18	14.05	32.28	32.04	24.10	.10	2.26	.48
3.19	14.02	32.26	32.00	24.10	.09	5.85	.51
3.20	13.92	32.14	31.88	24.02	.10	1.85	.40
3.21	13.74	32.29	31.94	24.17	.09	1.80	.40
3.22	11.92	32.38	31.98	24.59	.17	7.98	.69
3.23	11.25	32.01	31.61	24.43	.31	30.97	.85
3.24	12.85	32.61	31.76	24.60	.26	16.22	.96
3.25	13.15	32.71	32.28	24.62	.16	8.53	.66
3.26	13.26	32.62	32.25	24.52	.11	6.01	.66
3.27	13.63	32.34	32.16	24.23	.08	3.99	.44
3.28	13.70	32.07	31.93	24.01	.07	6.18	.49
3.29	13.73	31.78	31.34	23.78	.12	5.33	.60
3.30	14.28	31.54	31.23	23.49	.11	3.00	–
3.31	13.99	31.61	31.13	23.60	.35	4.04	.75
3.32	13.19	31.95	31.60	24.02	.18	6.96	.69
3.33	12.00	31.94	31.52	24.24	.22	12.94	1.08
3.34	11.41	32.10	31.54	24.47	.11	19.23	1.49
3.35	10.59	32.09	31.64	24.61	.33	25.23	1.56
3.36	9.58	32.47	31.80	25.07	.32	25.51	1.80
3.37	9.87	32.08	31.82	24.72	.29	28.40	1.85

Table 16;

INLINE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-3

STN #	CHL	PHAEO	% CHL	SEN FL	FL YD	ZOO #	DCMU #
3.01	1.61	.45	.78	227.	141.08	204.	.38
3.02	1.06	.64	.63	402.	378.49	374.	.42
3.03	2.25	1.06	.68	464.	206.42	37.	.36
3.04	1.10	.91	.55	268.	242.61	13.	.40
3.05	1.15	1.19	.49	248.	216.55	21.	.45
3.06	1.13	.68	.62	258.	228.89	16.	.25
3.07	.78	.40	.66	248.	319.78	64.	.43
3.08	1.71	.62	.73	382.	222.94	34.	.50
3.09	3.66	1.46	.71	557.	152.35	61.	.38
3.10	4.35	1.74	.71	433.	99.53	322.	.42
3.11	3.73	1.93	.66	495.	132.73	44.	.42
3.12	1.93	1.48	.57	341.	176.98	24.	.50
3.13	1.44	1.64	.47	268.	186.55	–	.91
3.14	5.20	3.76	.58	516.	99.26	–	.40
3.15	1.40	1.07	.57	165.	118.16	–	.43
3.16	3.98	2.99	.57	268.	67.31	–	.59
3.17	1.14	1.03	.53	165.	144.87	–	.67
3.18	1.68	1.11	.60	268.	159.91	–	.71
3.19	1.63	1.13	.59	310.	190.42	–	.59
3.20	1.40	1.01	.58	330.	235.01	–	.59
3.21	.72	.45	.62	320.	447.02	–	–
3.22	1.37	.62	.69	258.	188.46	–	.91
3.23	2.20	1.09	.67	227.	103.38	–	–
3.24	1.75	1.11	.61	237.	135.25	–	.56
3.25	1.70	1.00	.63	268.	157.56	–	.50
3.26	1.84	.80	.70	279.	151.75	–	.48
3.27	1.85	1.09	.63	227.	122.63	–	.50
3.28	1.84	.74	.71	217.	118.01	–	.48
3.29	2.83	.76	.79	196.	69.24	–	.42
3.30	2.78	.67	.81	248.	89.09	–	.53
3.31	2.81	.81	.78	206.	73.28	–	.56
3.32	2.43	.69	.78	237.	97.41	–	.50
3.33	2.30	.92	.71	340.	147.92	–	.53
3.34	2.56	.89	.74	361.	141.26	–	.50
3.35	1.73	.60	.74	206.	118.79	–	.40
3.36	1.54	.49	.76	217.	140.90	–	–
3.37	.88	.68	.56	227.	258.62	–	–

TABLE 17 Extract from the ship's log- Cruise RV003
July 9 - 12, 1979

Date	Time	Landmark x Distance Abeam (nautical miles)	Ship's Heading (° True)	Speed Made Good Since Last Entry	Remarks (Technicians observations in brackets)
July 9	0200	completed loading			
	0230	Leave Anvil Isl. with loaded logger			
	0331	Head Pt. X0.35	190		
	0400	Passage Isl. X0.75	190		
	0426	Buoy Q.A	192	9	(Wind NE S-10, waves <1' NW low swell from E, cloud 6/8)
	0719	Pt. Roberts X4.8	135	9	
	0835	E. Pt. X1.0	245	9	(wind W 10,waves <1' west'ly,cloud 6/8)
	0935	Turn Pt. X1.0	170	9	
	1022	Kelp Reef X1.0	177	10.8	
	1105	Discovery Isl. X1.0		10.5	
	1341	Race Rocks X1.6			(wind W10,ripples from W. no swell, cloud 6/8)
	1647	Sheringham Pt.		5.6	(wind W15, chop from W, long swell <1' cloud 6/8)
	1807	San Simon Pt. X4.55	292	6.15	Lt. N.W. choppy
	1907	Sombrio Pt. X5.1	292	6.85	(wind SW15,chop from SW, swell 1' from W) cloud 7/8 Lt. N. choppy
	2016	San Juan Pt. X4.7	292	7.32	Air SW choppy
	2154	Carmanah Pt. X3.8	288	7.65	(wind E5,Lt. chop from E. Cloud 7/8 swell 4' from S) Air NE., mod.SW swell
	2343	Pachena Pt X5.1	288	7.81	winds E 20, Mod-Hvy. SW swell

TABLE 17 - cont'd

Date	Time	Landmark x Distance Abeam (nautical miles)	Ship's Heading (° True)	Speed Made Good Since Last Entry	Remarks (Technicians observations in brackets)
July 10	0220	Amphitrite Pt. X8.8	305	7.8	Wind S.E. Mod-Hvy S.W swell
	0508	Lennard Isl. X8.25	310	7.7	Wind S.E. 25
	0610	Cleland Is. X6.8	310	7.5	Wind S.E. 15-20, Hvy S.W. Swell
	0703	Rafael Pt. X8.65	305	8.9	Wind S.E. 20-25 Hvy S.W. swell
	0843	Estevan Pt. X6.2	310	7.9	Wind S.E. 15-20 Hvy S.W. swell
	1000	Split Cape X8.6	350	8.1	Wind 10-15 mod. S.W. swell
	1235	Anderson Pt.			(Wind S.E.5, ripples from S.E. 3' swell from S, rain, cloud 7/8)
	1530	Dump Gold River			
	1700	Full away			
	2140	Secure McBride Bay for loading			
	2400	Start Loading			
July 11	0600	Loading			
	1500	Complete loading			
	1530	Away from McBride Bay			
	1644	Centre Isl. X0.3			
	1732	Esperanza Buoy			
	1813	Ferrer Pt. X3.1	161	6.1	(Wind SE 10, waves S.E <1'5' swell from S.E., cloud 2/8) Wind S.E. Lt. low S.E. swell
	1931		161	6.4	(Wind S.E. 5, waves S.E. <1'5' swell from S.E. cloud 3/ Wind S.E. Lt., low S.E. swell
July 12	0103	Rafael Pt. X10.9	129	6.9	
	0315	Lennard Isl. X9.6	131	7.	
	0639	Amphitrite Pt. X9.9	109	6.6	Wind Lt. S.E., low S.W. swell(wind E 5-10 S.E. ripple, 3' swell from S. cloud 6/8)

TABLE 17 - cont'd

Date	Time	Landmark x Distance Abeam (nautical miles)	Ship's Heading (° True)	Speed Made Good Since Last Entry	Remarks (Technicians observations in brackets)
July 12	1140	Carmanah Pt. X6.35	128	6.1	(Wind E.S, 4" E. waves 3' swell from S.W., Cloud 1/8)
	1209	Buoy J. X1	117	5.8	
	1328	Waadah Isl. X2.1	115	7.4	(E. breeze, ripples, 1-2' swell at 10 sec. cloud 1/8)
	1444	Kydaka		8.8	
	1514	Slip Pt.		9.8	(Wind 5 Kn,ripples 1' swell at 5 sec, cloud 4/8)
	1738	Buoy J.A. X1	074	9.7	
	1812	Race Rocks X3.5	065	10.4	(Wind W5, waves 1' from W, no swell, cloud 5/8)
	1953	Discovery Isl. X1.8	020	10.1	
	2055	Kelp Reef X1.25	350	7.4	(Wind N.E.5,waves 1' from S.E., no swell, cloud 2/8)
	2148	Turn Pt. X0.5	000	9.3	
	2238	Beddis RK	225		

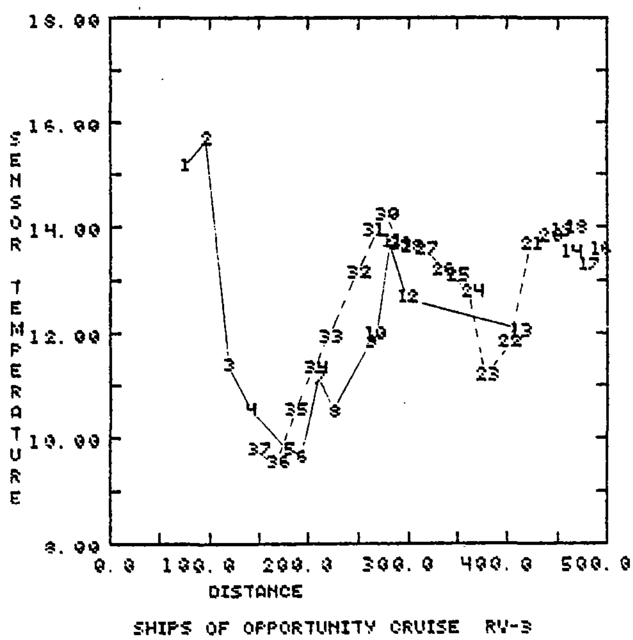


Figure 49. Sensor temperature (^{o}C) vs distance along cruise track - RV003.

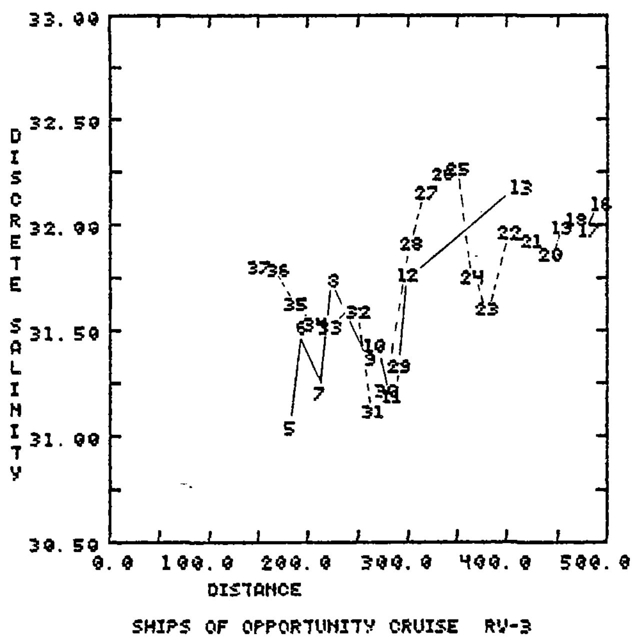


Figure 50. Discrete salinity (ppt) vs distance along cruise track - RV003.

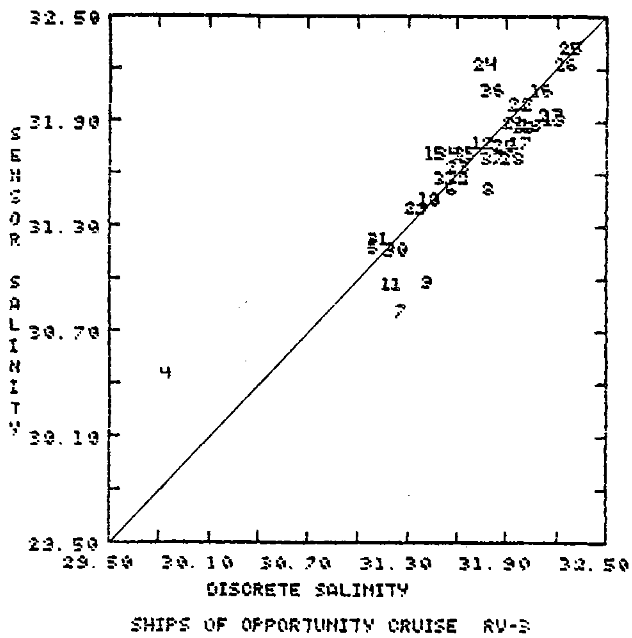


Figure 51. Sensor salinity (ppt) vs discrete salinity (ppt) - RV003.

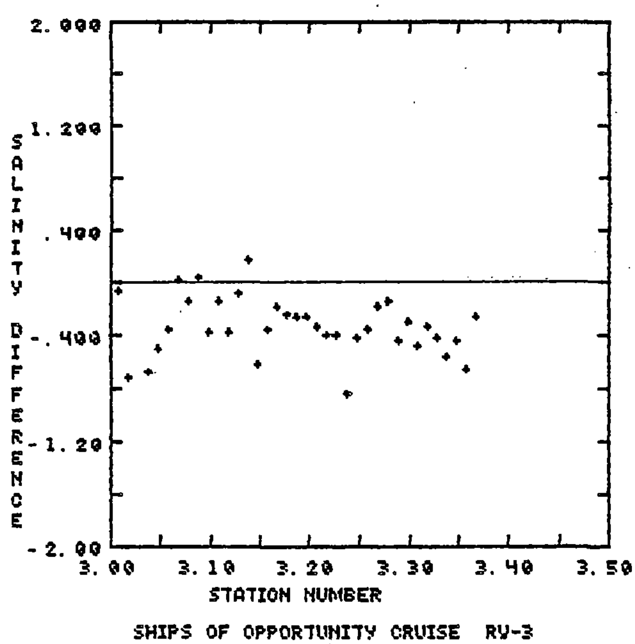


Figure 52. Salinity difference (ppt) - (discrete salinity - sensor salinity) vs station number - RV003.

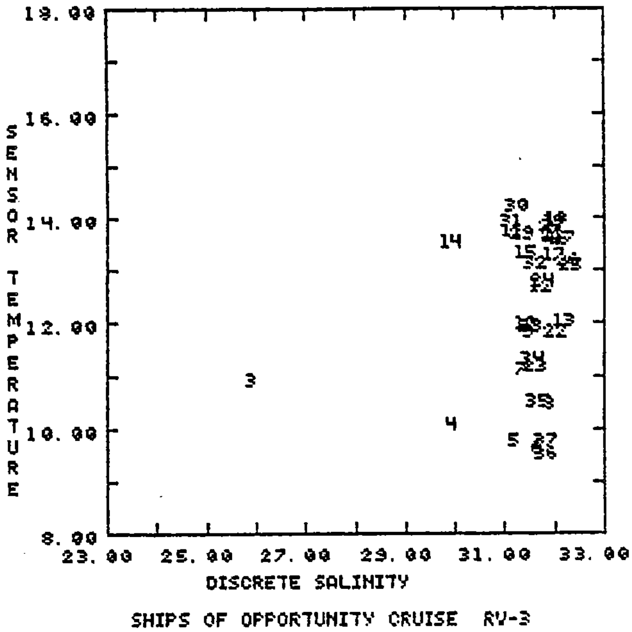


Figure 53. Sensor temperature (^{O}C) vs discrete salinity (ppt) - RV003.

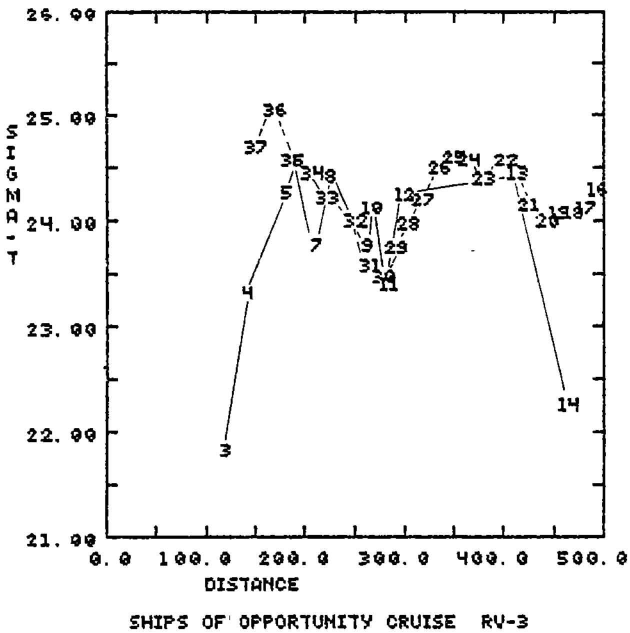


Figure 54. Sigma-t vs distance along cruise track - RV003.

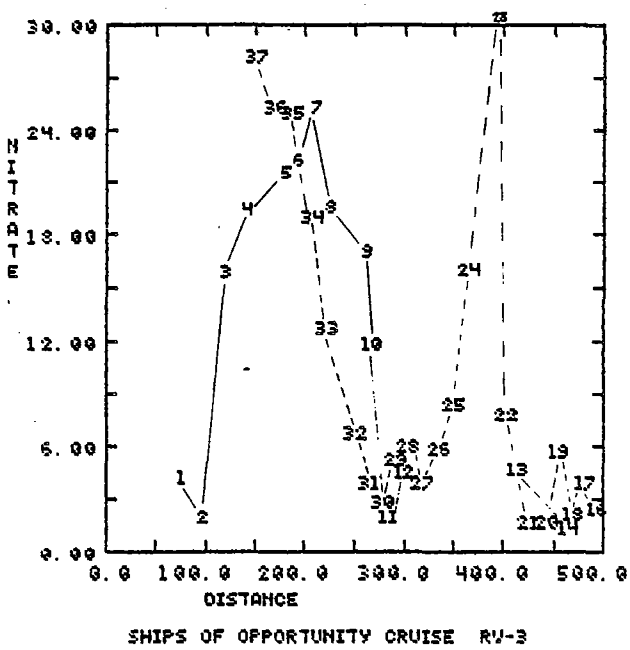


Figure 55. Nitrate concentration (µg at/L) vs distance along cruise track - RV003.

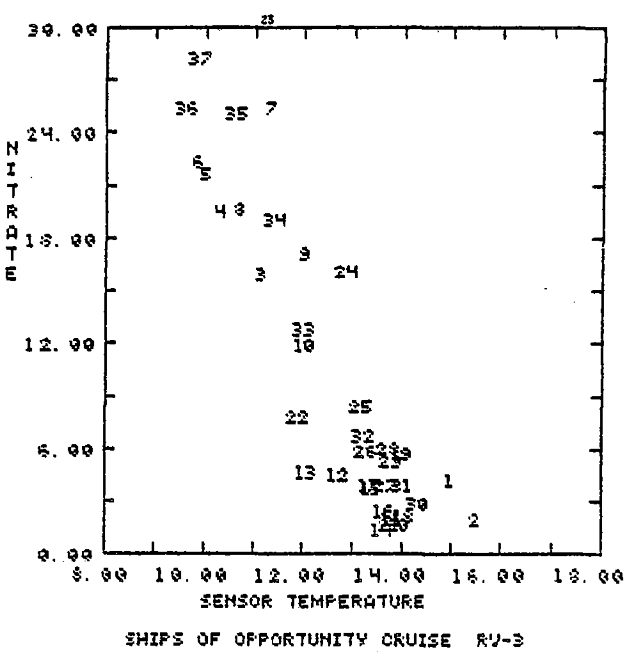


Figure 56. Nitrate concentration (µg at/L) vs sensor temperature (^{o}C) - RV003.

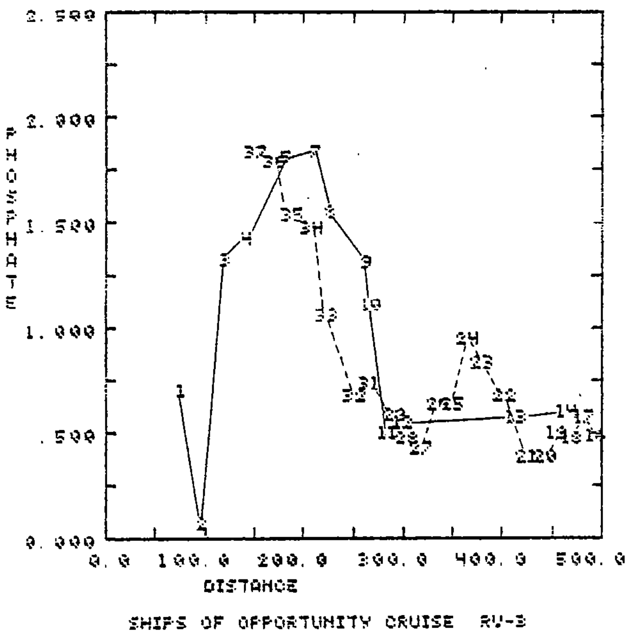


Figure 57. Phosphate concentration (μg at/L) vs distance along cruise track - RV003.

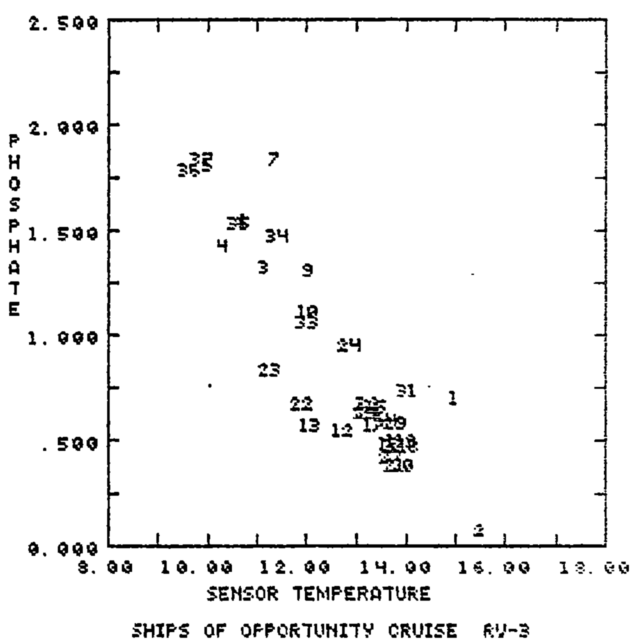


Figure 58. Phosphate concentration (μg at/L) vs sensor temperature (^{o}C) - RV003.

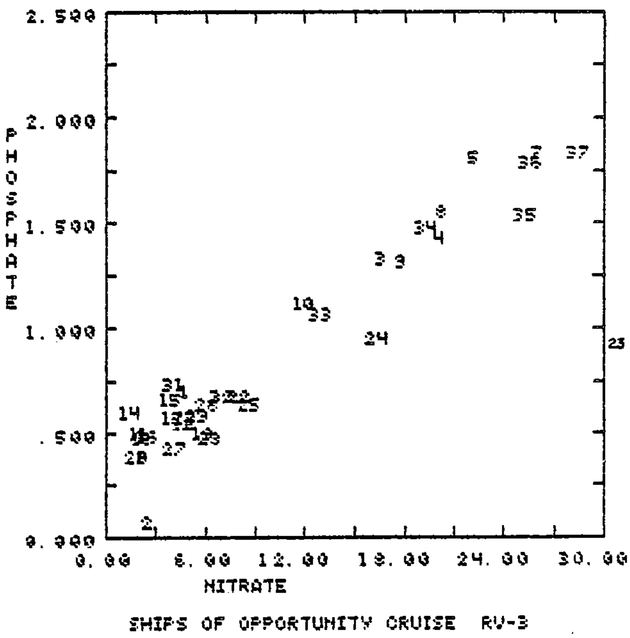


Figure 59. Phosphate concentration (μg at/L) vs nitrate concentration (μg.at/L) - RV003.

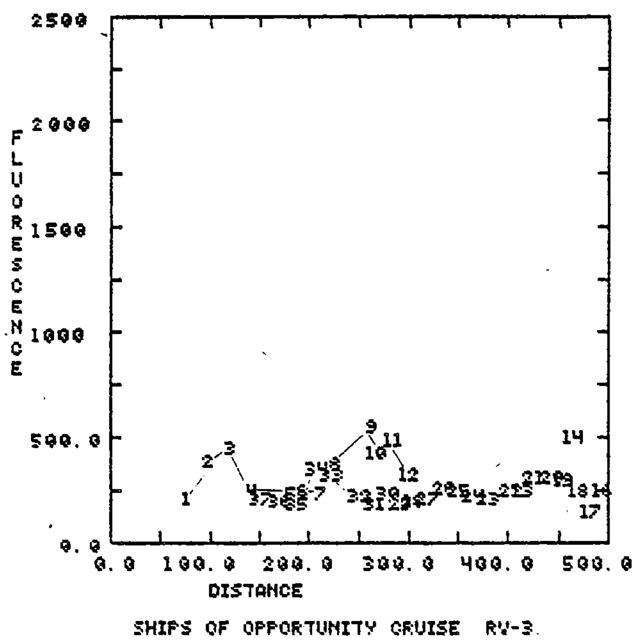


Figure 60. *in vivo* fluorescence vs distance along cruise track - RV003.

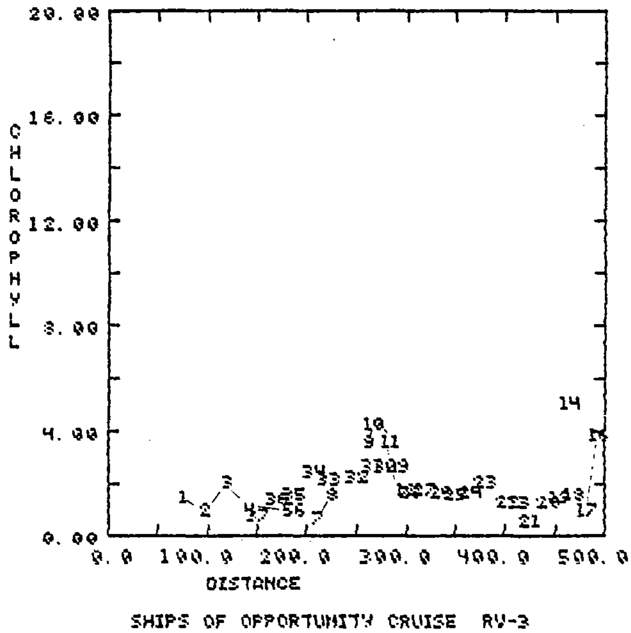


Figure 61. Chlorophyll a (mg/m^3) vs distance along cruise track - RV003.

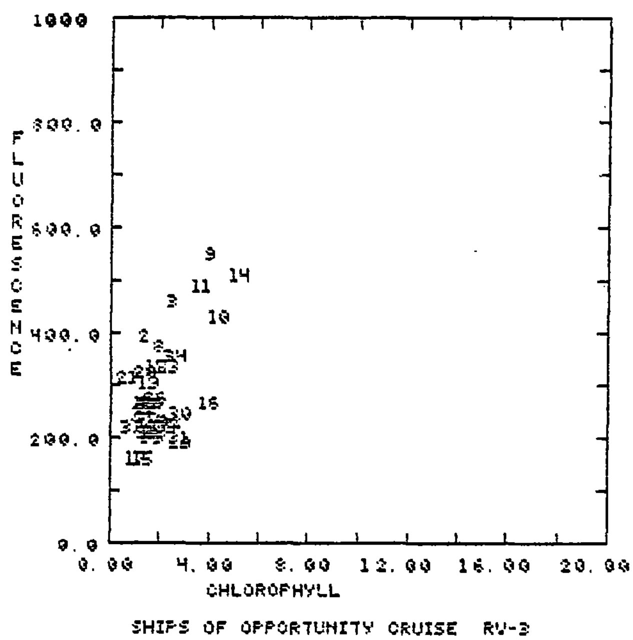


Figure 62. in vivo fluorescence vs chlorophyll a (mg/m^3) - RV003.

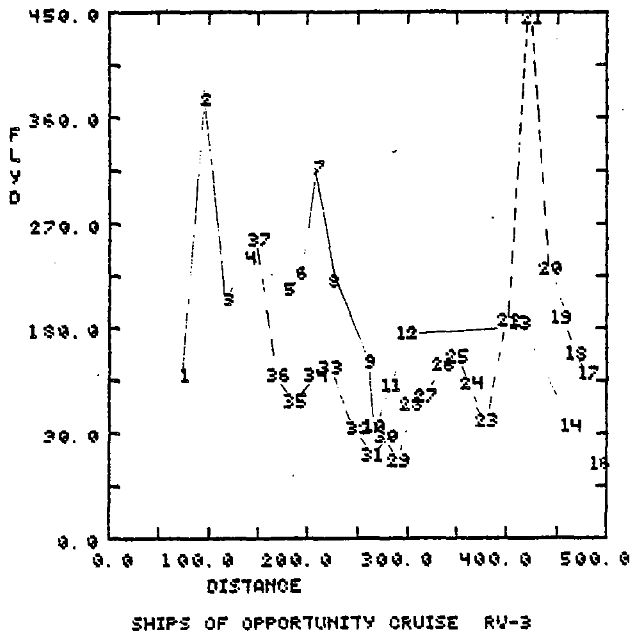


Figure 63. Fluorescence yield vs distance along cruise track - RV003.

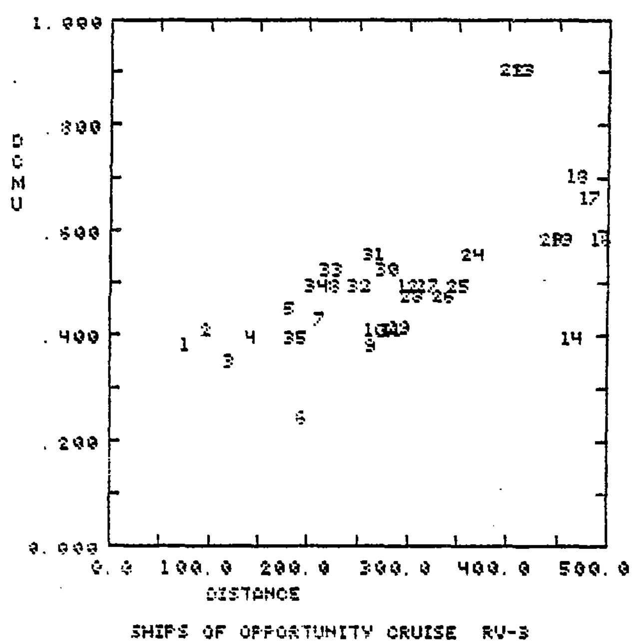


Figure 64. D.C.M.U. ratio vs distance along cruise track - RV003.

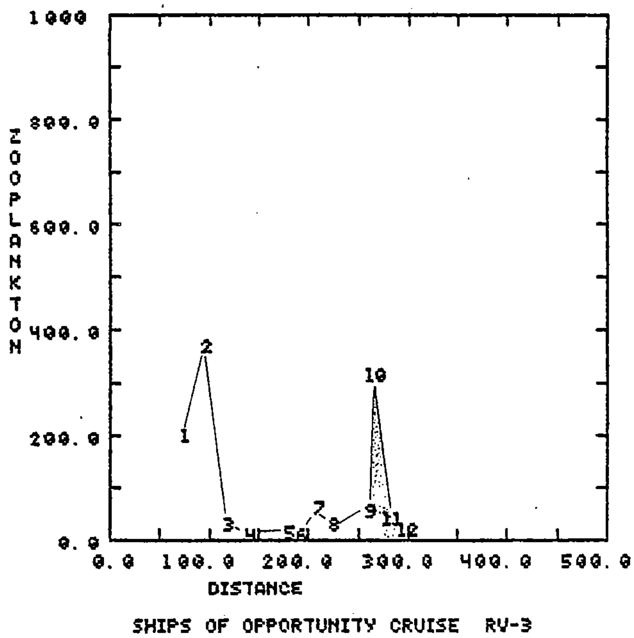


Figure 65. Zooplankton counts vs distance along cruise track - RV003.

Table 18: Multiple Correlation Table

SHIPS OF OPPORTUNITY CRUISE RV-3

SEN T												
SEN S	-.31											
3 SAL	-.28	.99										
3 SIG	-.39	1.00	.99									
3 NO2	-.69	-.04	-.06	.02								
3 NO3	-.89	.16	.14	.24	.76							
3 PO4	-.90	.13	.10	.20	.77	.88						
3 CHL	.23	.06	.08	.04	-.07	-.25	-.13					
3 %CHL	.09	-.20	-.21	-.20	.19	.09	.15	.28				
SEN FL	.03	-.07	-.09	-.07	.02	-.09	-.00	.56	.02			
3 FLYD	-.14	-.13	-.14	-.12	.05	.12	.08	-.62	-.35	.15		
3 ZOO#	.73	-.45	-.43	-.47	-.31	-.61	-.63	.25	.44	.18	.11	
	SEN T	SEN S	3 SAL	3 SIG	3 NO2	3 NO3	3 PO4	3 CHL	3 %CHL	SEN FL	3 FLYD	3 ZOO#

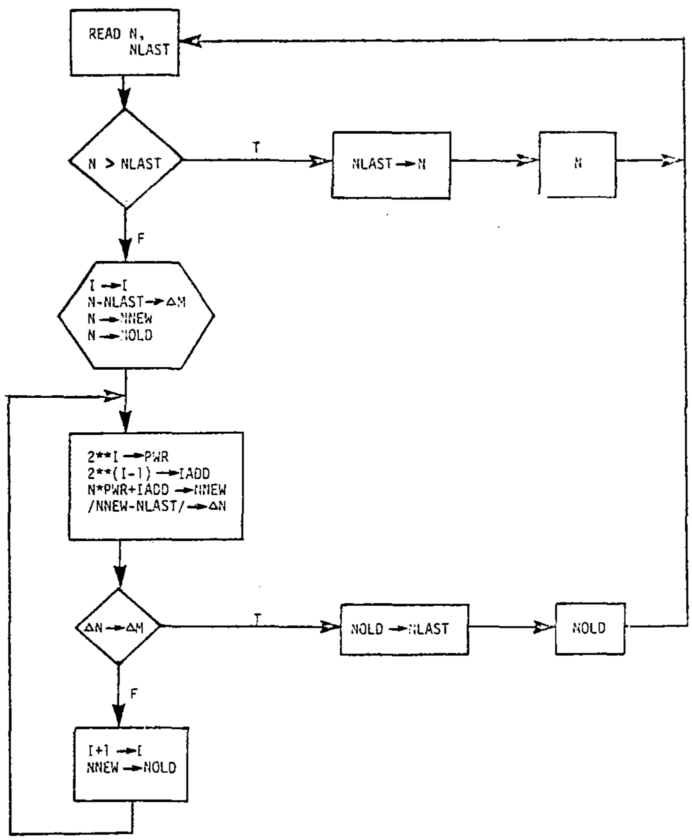


FIGURE 66 Flow Chart showing scheme used for correcting continuoas fluorescence data

FIGURE 67 TIROS-N Satellite Image (Thermal Infrared Band) for July 14,1979

2.4 CRUISE RV004: AUGUST 11-17, 1979

2.4.1 Logistical Summary

On August 10th the technicians were flown via seaplane to Anvil Island in Howe Sound where they met the Rivtow Viking and the self-loading log barge, the Straits Logger. After the barge was loaded it was discovered that the pulp mill at Gold River was on strike and consequently could not accept the load of wood. The Viking therefore anchored the loaded barge and went into Vancouver to pick up another empty log barge. The Viking and empty barge then proceeded to McBride Bay at a speed of between 9 and 11 knots, arriving at 0630 on August 12th. The barge was loaded and the tug heading south by 2330 that night. Speeds of 7.4 to 8.5 knots were made good on this and the two following transits. Instead of completing the trip to Howe Sound, the Rivtow Viking met a second Rivtow tug off Victoria and traded barges; then returned to Gold River as originally planned, arriving at 0630 on August 15th. After dumping in Gold River the barge was loaded at Zeballos and the Viking was headed south once more by 0600 on August 16th. The Viking arrived in West Bay in Howe Sound at 1900 on August 17th where it was met by a seaplane which returned the technicians and their gear to Sidney. Extracts from the ships log and observations of sky and sea conditions by the technicians are presented in Table 22 .

The continuous record of temperature, conductivity, *in vivo* chlorophyll *a* fluorescence, and zooplankton particles will be referred to as two separate cruises. Cruise RV004 is that portion of the trip from Anvil Island to McBride Bay and back down as far as Victoria; cruise RV004a is that portion from Victoria north to Gold River and the return trip to West Bay. Fifty discrete in-line samples were taken during the two cruises, the distribution of which can be seen in Figures 68 and 69. Sampling was concentrated in the area between Cape Flattery and Lennard Island. DCMU numbers were obtained at 49 stations and 28 zooplankton samples were taken for calibration purposes.

2.4.2 Data Summary and Discussion

The pump and continuous monitoring equipment were turned on as the ship left Burrard Inlet August 11th, however discrete sampling did not begin until Boundary Passage and therefore missed the very warm (19^{o}C) brackish (<20 ppt) water in Georgia Strait. Continuous records (Figures 70, 71, 72, 73) show elevated chlorophyll fluorescence and increased zooplankton at the southern edge of the Fraser River plume with a very sharp boundary encountered near Patos Island. The cold (12^{o}C) saline (>30 ppt) turbulent water in Boundary Passage and Haro Strait, by contrast contained very little zooplankton. After station 4.3, south of Victoria, increasing numbers of zooplankton and elevated chlorophyll fluorescence were encountered. Temperature increased steadily between Sheringham and Barkley Sound with a slight decrease in salinity*. This situation generally existed during the entire cruise.

The T-S plot of station data (Figure 78) shows that the very cold (10^{o}C) saline water (>32.3 ppt) in Juan de Fuca and over Swiftsure to station 4.9 on August 11th were separated from warmer, 15^{o}C water of salinity around 31.7 ppt north of station 4.11 by a distance of about 40 km. This situation existed during both the second and third passages through the area but continuous data shows that a warmer water mass (near 16^{o}C) had appeared off Tofino (just north of station 4.32) by the time of the third transit. It was sampled by discrete sampling during the fourth homeward passage on the 16th of August however, having moved onto the cruise track more fully and extending from between stations 4.33 and 4.34 south of Estevan Point almost to station 4.38 off Amphitrite Point (see continuous data in Figures 72, 73 and the temperature vs distance plot in Figure 79). The cold Juan de Fuca water had also moved north with the result being a rather abrupt change in the T-S character of water in the 8 km separating stations 4.40 and 4.41.

---

* Figure 77, which illustrates the difference between discrete and sensor salinity is provided to allow confidence limits to be placed on continuous data.

Nutrient concentrations in the region were closely related to sea temperature, there being correlations of -.89 for phosphate and temperature (Figure 83) and -.84 for nitrate and temperature (Figure 81 and Table 23). Note that most of the points lying well out of the main cloud of points and furthest from this NO_3/T relation, represent stations at which elevated chlorophyll concentrations were recorded. This suggests that strong phytoplankton growth after cessation of mixing is responsible for the 'abnormally' low nitrate concentrations in this water. Figure 84 illustrates that the relationship between dissolved phosphate and nitrate concentrations for cruise 4/4a is close except for stations 4.3 and 4.5 in Juan de Fuca (high phosphate) and stations 4.15 and 4.16 off Lennard Island. It is not clear why these stations should be anomalous since they do not significantly differ from their neighbours when one considers other parameters. The relationship between dissolved NO_3 and PO_4 for RV004 is essentially the same as for previous cruises with N/P ratios around 12 in Juan de Fuca and much lower values (less than 5) in the warm coastal waters north of Amphitrite Point.

Much greater variability in _in vivo_ fluorescence was encountered during RV004 than during previous cruises and the repeated passage gives an indication of the evolution of the chlorophyll field along the cruise track between August 11th and August 17th (Figures 70, 73 and 85). Until August 16th the highest concentrations (10-18 mg/m^3) were in the area north of Tofino-Long Beach and the outward movement of cold Juan de Fuca waters north to the Cape Beale area, resulted in relatively low standing crops along the entire cruise track. By August 16th the highest chlorophyll _a_ concentrations were the 7 mg/m^3 encountered in the Swiftsure area - similar to what was measured in this area on the 11th (Figure 86).

Fluorescence yields were very constant during this cruise except for those six stations exhibiting chlorophyll maxima (Figures 87 and 88). DCMU numbers (Figure 89) on the other hand were very erratic and did not show any recognizable relationship with any other parameters except a trend to higher values towards the north. There was a .35 correlation with temperature and similar but negative correlations with nutrient concentrations.

More zooplankton were encountered on the cruise than on any previous cruise. Figure 70 - 73 illustrates the variability observed and the relationship with other continuously measured parameters. The zooplankton data in Figure 90 are sensor counts at the stations, with stippling indicating those areas sampled at night. As expected much larger numbers were counted during dark hours when the zooplankton are gathered near the surface to feed.

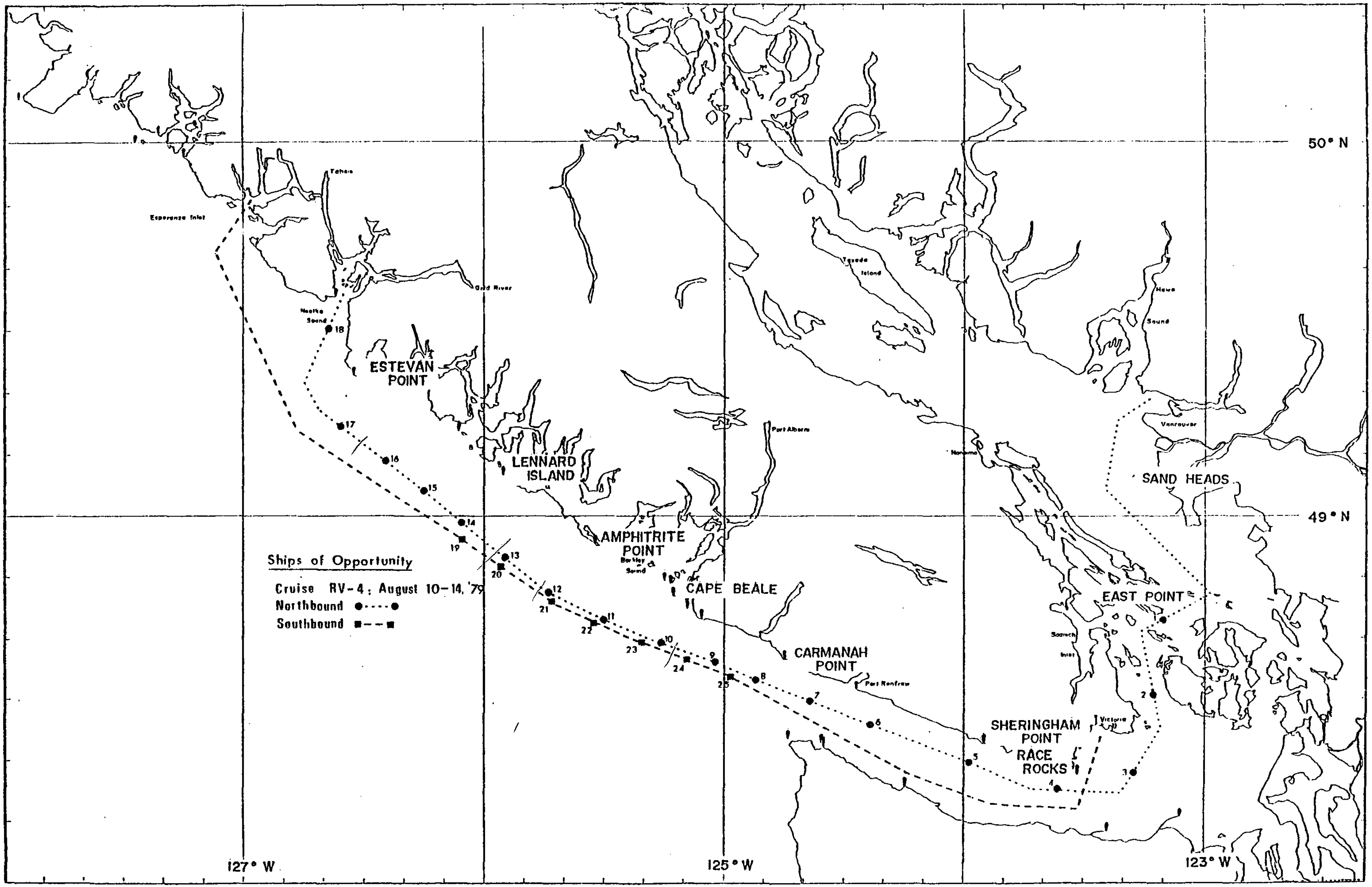


Figure 68. Cruise track and station locations - RV004.

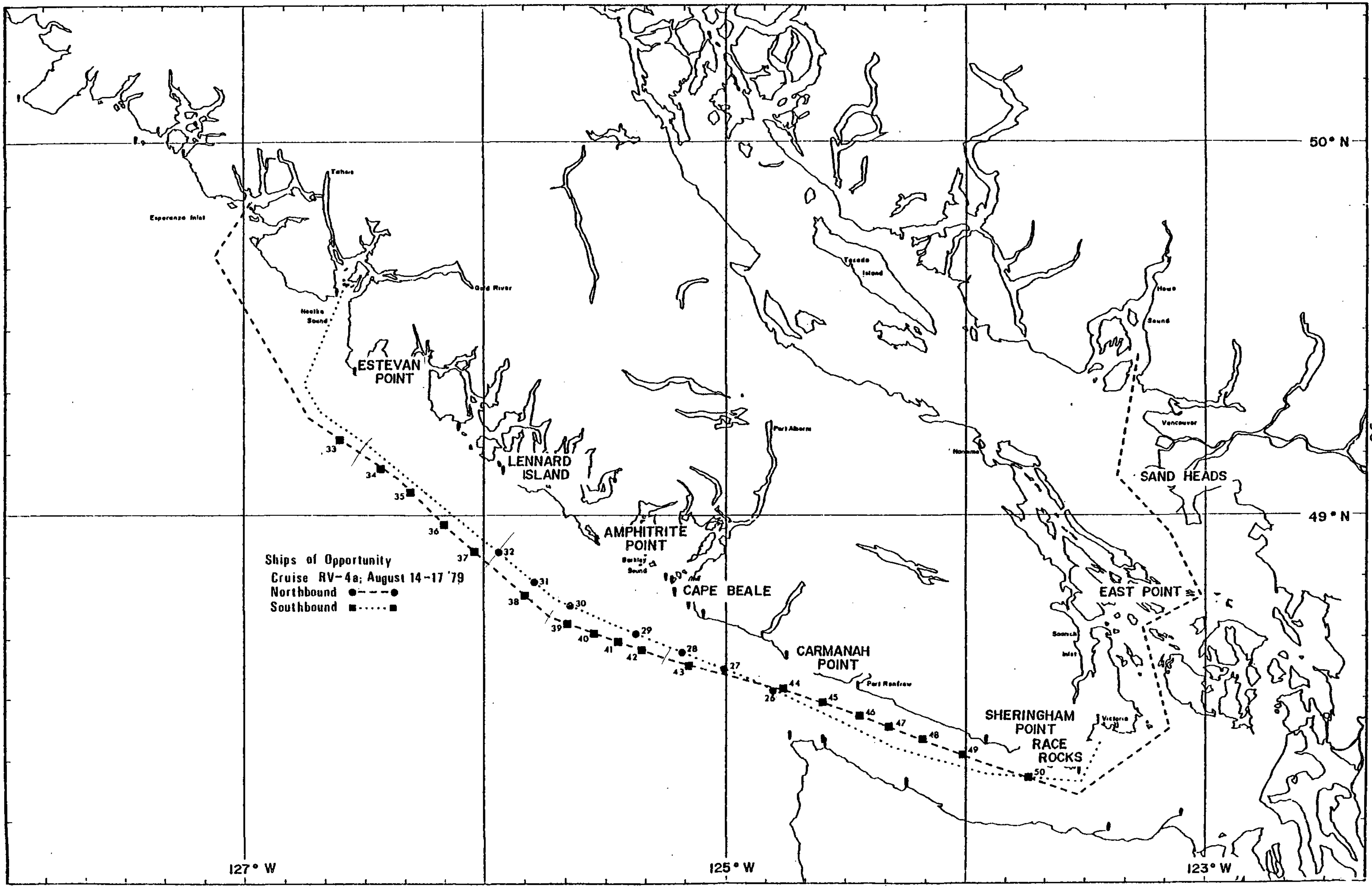


Figure 69. Cruise track and station locations - RV004a.

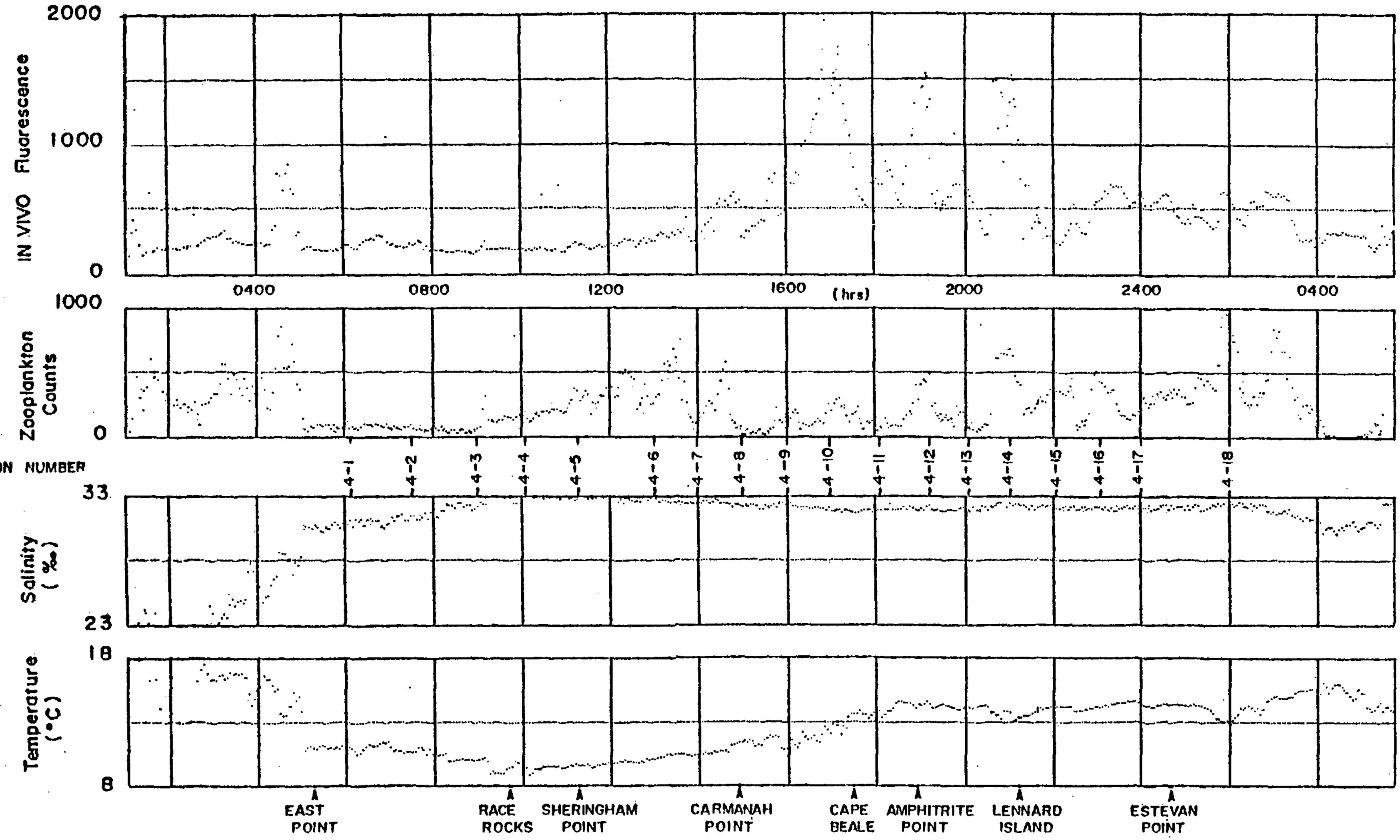


Figure 70. Continuous data record - RV004 (northbound).

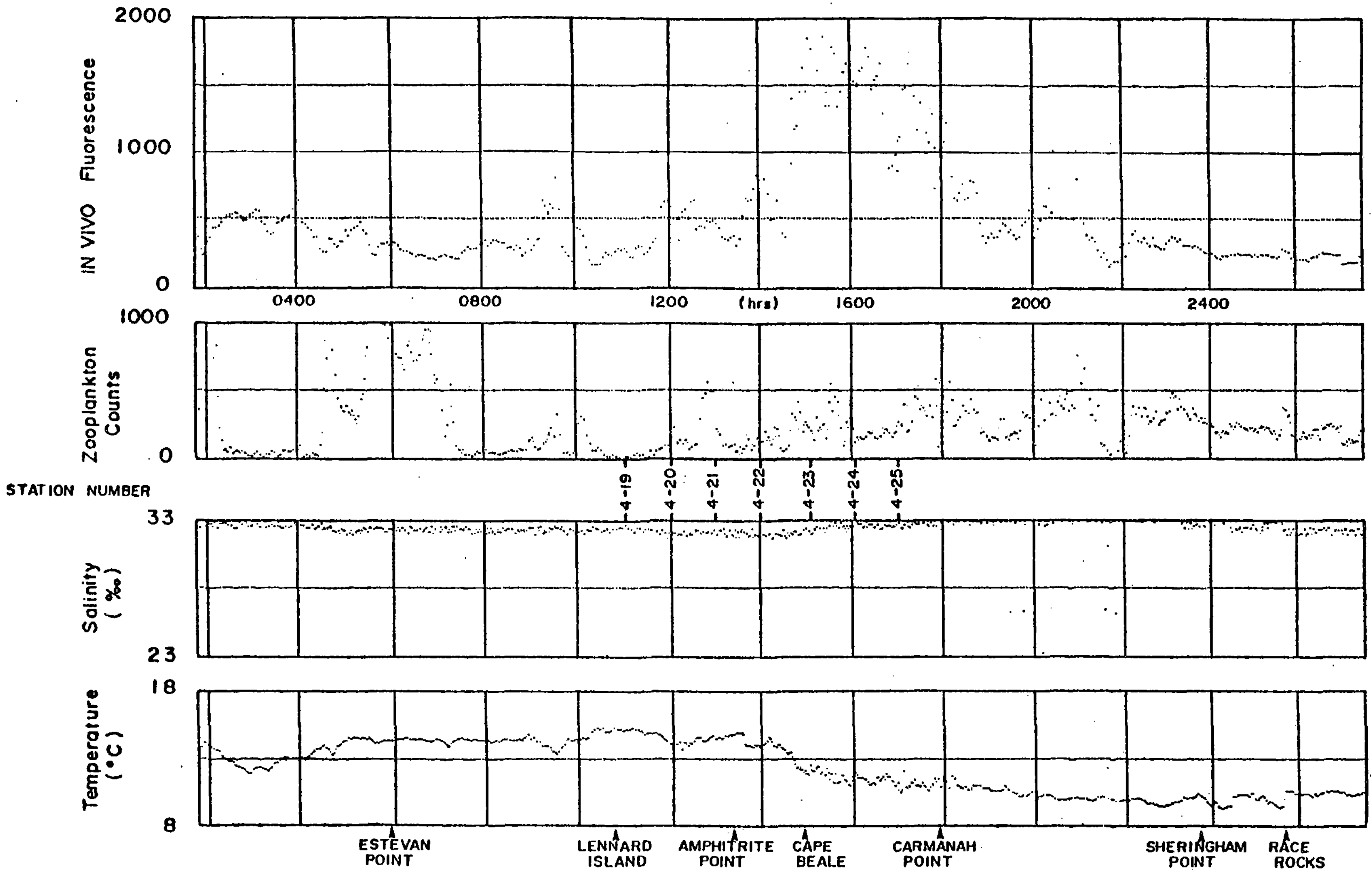


Figure 71. Continuous data record - RV004 (southbound).

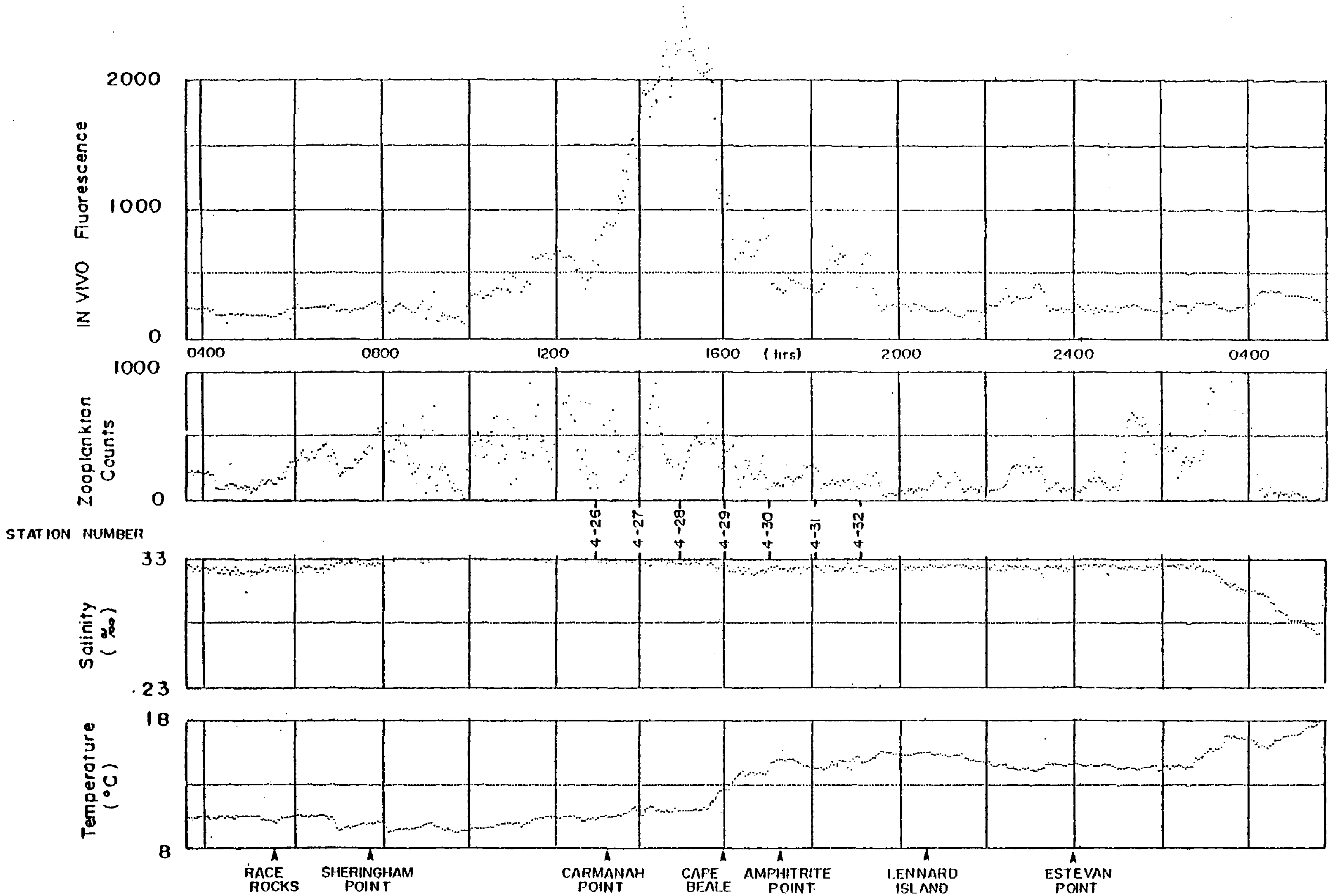


Figure 72. Continuous data record - RV004a (northbound).

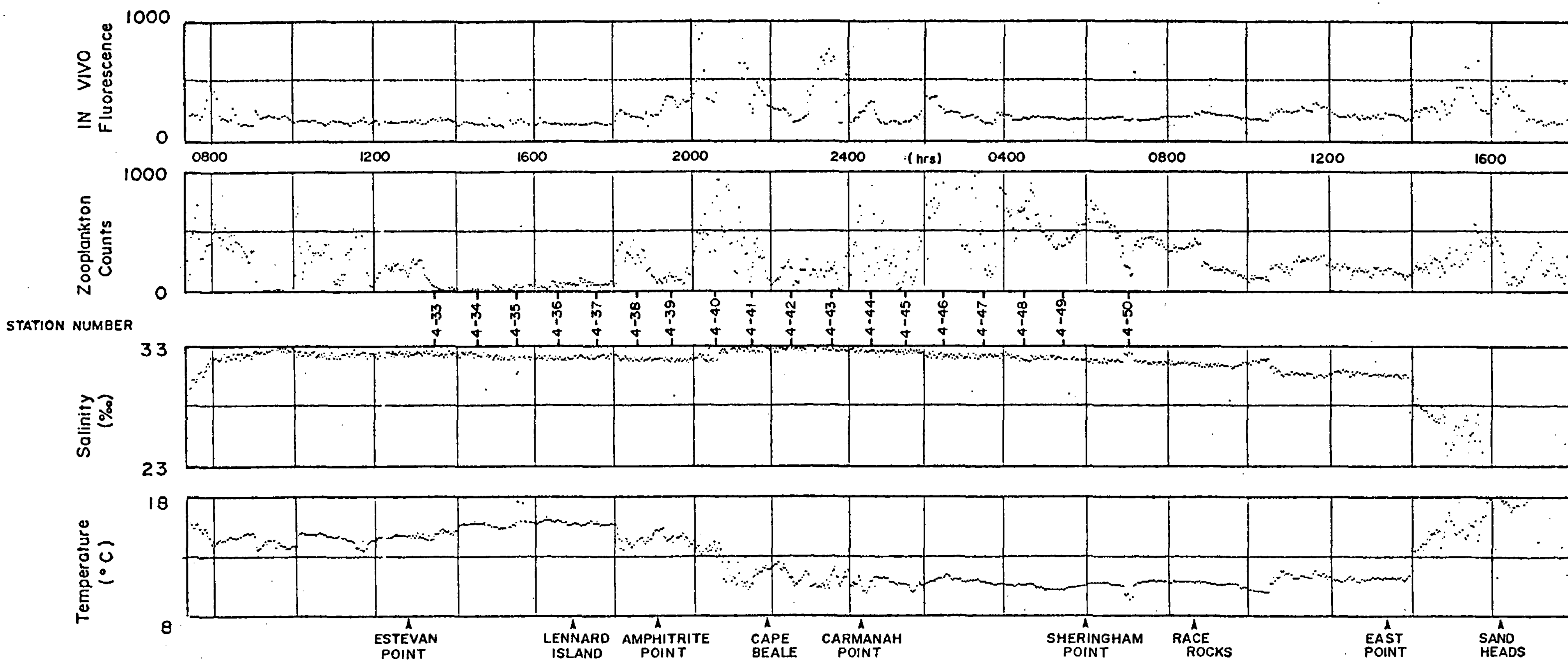


Figure 73. Continuous data record - RV004a (southbound).

REFERENCE DATA FOR SHIPS OF OPPORTUNITY - Table 19:

CRUISE RV-4

STN #	CDATE	JDATE	TIME	LATITUDE	LONGITUDE	DIS
4.01	11/ 8/79	223	602	48-43.5 N	123-11.0 W	127.
4.02	11/ 8/79	223	730	48-31.0 N	123-12.8 W	153.
4.03	11/ 8/79	223	900	48-17.8 N	123-18.0 W	176.
4.04	11/ 8/79	223	1001	48-15.1 N	123-36.6 W	205.
4.05	11/ 8/79	223	1130	48-19.1 N	123-58.6 W	223.
4.06	11/ 8/79	223	1300	48-25.2 N	124-33.5 W	255.
4.07	11/ 8/79	223	1400	48-29.0 N	124-38.6 W	274.
4.08	11/ 8/79	223	1500	48-33.0 N	124-52.1 W	295.
4.09	11/ 8/79	223	1600	48-36.0 N	125- 2.8 W	308.
4.10	11/ 8/79	223	1700	48-38.9 N	125-15.7 W	326.
4.11	11/ 8/79	223	1802	48-42.8 N	125-30.0 W	355.
4.12	11/ 8/79	223	1905	48-47.5 N	125-43.9 W	365.
4.13	11/ 8/79	223	2004	48-53.0 N	125-55.0 W	381.
4.14	11/ 8/79	223	2100	48-58.0 N	126- 5.5 W	398.
4.15	11/ 8/79	223	2201	49- 4.3 N	126-14.8 W	413.
4.16	11/ 8/79	223	2308	49- 8.9 N	126-24.8 W	428.
4.17	11/ 8/79	223	2400	49-14.7 N	126-35.8 W	445.
4.18	12/ 8/79	224	210	49-29.5 N	126-38.8 W	462.
4.19	13/ 8/79	225	1100	49- 4.0 N	126- 5.0 W	398.
4.20	13/ 8/79	225	1200	48-51.9 N	125-56.0 W	381.
4.21	13/ 8/79	225	1300	48-45.4 N	125-43.2 W	365.
4.22	13/ 8/79	225	1401	48-42.0 N	125-32.6 W	352.
4.23	13/ 8/79	225	1504	48-38.9 N	125-20.5 W	336.
4.24	13/ 8/79	225	1604	48-36.7 N	125- 9.1 W	318.
4.25	13/ 8/79	225	1700	48-33.8 N	124-58.0 W	303.
4.26	14/ 8/79	226	1300	48-31.8 N	124-48.1 W	291.
4.27	14/ 8/79	226	1400	48-34.9 N	125- .8 W	317.
4.28	14/ 8/79	226	1500	48-37.5 N	125-11.0 W	321.
4.29	14/ 8/79	226	1600	48-40.0 N	125-22.0 W	338.
4.30	14/ 8/79	226	1701	48-45.2 N	125-38.5 W	360.
4.31	14/ 8/79	226	1804	48-49.0 N	125-48.0 W	372.
4.32	14/ 8/79	226	1907	48-53.8 N	125-56.5 W	386.
4.33	16/ 8/79	228	1330	49-12.9 N	126-35.5 W	446.
4.34	16/ 8/79	228	1429	49- 7.8 N	126-25.8 W	439.
4.35	16/ 8/79	228	1530	49- 4.1 N	126-18.0 W	418.
4.36	16/ 8/79	228	1630	48-58.9 N	126- 9.7 W	405.
4.37	16/ 8/79	228	1730	48-54.9 N	126- 2.8 W	393.
4.38	16/ 8/79	228	1830	48-46.8 N	125-50.0 W	372.
4.39	16/ 8/79	228	1930	48-42.0 N	125-39.4 W	362.
4.40	16/ 8/79	228	2030	48-41.0 N	125-33.0 W	349.
4.41	16/ 8/79	228	2130	48-39.0 N	125-26.8 W	341.
4.42	16/ 8/79	228	2230	48-38.0 N	125-21.0 W	334.
4.43	16/ 8/79	228	2330	48-35.8 N	125- 9.5 W	306.
4.44	17/ 8/79	229	30	48-31.7 N	124-45.8 W	288.
4.45	17/ 8/79	229	130	48-29.0 N	124-35.6 W	274.
4.46	17/ 8/79	229	230	48-27.6 N	124-26.0 W	262.
4.47	17/ 8/79	229	330	48-25.8 N	124-19.2 W	253.
4.48	17/ 8/79	229	430	48-23.4 N	124-11.0 W	242.
4.49	17/ 8/79	229	530	48-21.2 N	124- .5 W	229.
4.50	17/ 8/79	229	700	48-17.5 N	123-44.0 W	209.

INLINE DATA FOR SHIPS OF OPPORTUNITY - Table 20:

CRUISE RV-4

STN #	SEN T	SEN SAL	DIS SAL	SIG	NO2	NO3	PO4
4.01	10.71	30.96	28.02	23.71	.32	22.51	1.52
4.02	10.59	31.51	30.05	24.16	.38	25.58	1.65
4.03	10.01	32.67	31.29	25.15	.46	10.09	1.90
4.04	9.60	32.77	31.90	25.30	.33	25.51	2.00
4.05	9.49	32.98	32.36	25.49	.37	13.41	1.99
4.06	10.15	33.01	32.18	25.40	.55	28.92	1.77
4.07	10.46	32.48	32.09	24.93	–	–	1.49
4.08	11.43	32.49	31.94	24.77	.46	24.81	1.38
4.09	11.17	32.45	31.88	24.78	.48	13.30	1.14
4.10	11.97	32.12	31.72	24.39	.41	8.54	.77
4.11	13.86	31.94	31.60	23.87	.44	7.72	.82
4.12	14.33	32.14	31.74	23.94	.19	1.64	.36
4.13	14.26	32.03	31.68	23.87	.12	2.63	.41
4.14	13.99	32.27	31.81	24.11	.10	4.12	.36
4.15	14.26	32.37	31.86	24.13	.12	7.01	.23
4.16	14.20	32.14	31.78	23.96	.09	5.88	.18
4.17	14.56	32.13	31.78	23.88	.09	1.73	.24
4.18	13.39	32.51	32.01	24.41	.08	3.76	.35
4.19	15.17	32.57	31.64	24.09	.11	4.83	.46
4.20	14.16	32.08	31.76	23.93	.11	2.05	.27
4.21	14.53	31.90	31.67	23.71	.10	–	.23
4.22	14.12	31.74	31.63	23.67	.10	5.41	.37
4.23	12.45	32.28	31.60	24.42	.18	5.90	.40
4.24	11.75	32.92	31.88	25.05	.37	5.15	.59
4.25	10.74	32.60	32.05	24.98	.53	9.99	.91
4.26	10.25	33.23	32.14	25.55	.45	21.39	1.47
4.27	11.36	32.87	32.20	25.07	.50	13.13	1.29
4.28	11.23	33.20	32.13	25.35	.28	2.93	.69
4.29	12.13	32.19	31.85	24.41	.18	3.87	.55
4.30	13.95	32.26	31.63	24.11	.21	2.68	.51
4.31	14.57	32.40	31.65	24.09	.13	4.57	.27
4.32	14.82	32.24	31.70	23.91	.13	-.23	.28
4.33	15.01	32.40	30.99	23.99	.12	2.75	.31
4.34	15.84	32.69	31.89	24.03	.07	.31	.32
4.35	15.93	32.03	31.86	23.51	.08	.30	.23
4.36	16.10	32.06	31.84	23.49	.03	1.80	.18
4.37	16.03	32.34	31.88	23.72	.03	1.52	.23
4.38	13.85	31.93	31.82	23.87	.06	-.16	.22
4.39	14.67	31.79	31.70	23.59	.34	5.04	.34
4.40	13.57	32.09	31.62	24.05	.21	4.70	.44
4.41	10.99	32.88	31.89	25.15	.42	10.94	.91
4.42	11.62	32.87	32.39	25.03	.41	19.70	1.40
4.43	10.38	32.66	32.38	25.09	.46	18.74	1.09
4.44	10.40	32.59	32.35	25.03	.47	25.14	1.42
4.45	10.78	32.78	32.23	25.11	.46	16.93	1.69
4.46	11.23	32.38	31.90	24.72	.46	21.38	1.51
4.47	10.92	32.14	31.80	24.59	.50	26.48	1.95
4.48	10.66	31.87	31.69	24.42	.50	26.13	1.64
4.49	10.30	31.95	31.69	24.55	.47	23.77	2.26
4.50	9.78	32.34	31.83	24.94	.44	24.50	1.83

INLINE DATA FOR SHIPS OF OPPORTUNITY - Table 21:

CRUISE RV-4

STN #	CHL	PHAEO	% CHL	SEN FL	FL YD	ZOO #	DCMU #
4.01	2.08	.87	.70	217.	104.30	90.	.47
4.02	2.00	.80	.71	215.	107.73	80.	.62
4.03	1.66	.73	.70	164.	98.73	45.	.50
4.04	1.85	.85	.68	200.	107.92	162.	.52
4.05	2.65	.95	.74	201.	75.72	212.	.50
4.06	5.16	1.38	.79	259.	50.19	269.	.63
4.07	4.50	1.50	.75	253.	56.20	102.	.56
4.08	6.00	1.88	.76	614.	102.37	86.	.55
4.09	5.82	2.61	.69	457.	78.54	174.	.64
4.10	12.20	5.52	.69	2103.	172.39	269.	.64
4.11	7.89	3.59	.69	666.	84.37	80.	.46
4.12	13.42	2.58	.84	1508.	112.34	419.	.61
4.13	7.30	1.28	.85	781.	107.03	145.	.66
4.14	7.65	1.44	.84	1135.	148.44	648.	.67
4.15	2.97	.84	.78	292.	98.26	361.	–
4.16	4.06	1.29	.76	562.	138.29	445.	.63
4.17	4.82	1.34	.78	608.	126.06	211.	.67
4.18	4.94	1.58	.76	524.	106.16	771.	.79
4.19	2.32	.96	.71	275.	118.45	6.	.66
4.20	4.07	2.18	.65	643.	158.00	157.	.53
4.21	6.60	1.30	.84	485.	73.44	416.	.57
4.22	9.02	2.23	.80	763.	84.55	181.	.48
4.23	9.71	5.20	.65	1736.	178.86	189.	.54
4.24	10.72	5.22	.67	1455.	135.72	146.	.73
4.25	10.66	5.31	.67	1006.	94.41	300.	.58
4.26	12.34	2.38	.84	756.	61.27	191.	.42
4.27	15.07	3.88	.80	1420.	94.21	462.	.40
4.28	17.96	4.01	.82	2185.	121.63	335.	.41
4.29	13.27	4.82	.73	1164.	87.71	398.	.54
4.30	12.02	5.05	.70	983.	81.81	237.	.42
4.31	6.24	1.78	.78	375.	60.05	270.	.47
4.32	5.15	1.60	.76	535.	103.94	170.	.50
4.33	2.36	.95	.71	182.	77.12	33.	.63
4.34	1.79	.50	.78	145.	81.06	27.	.62
4.35	1.63	.50	.76	160.	98.00	45.	.71
4.36	1.37	.33	.81	146.	106.92	44.	.57
4.37	1.19	.30	.80	146.	122.41	55.	.57
4.38	1.50	.58	.72	225.	149.94	335.	.58
4.39	2.98	1.38	.68	361.	121.24	88.	.56
4.40	4.44	1.69	.72	339.	76.44	276.	.60
4.41	–	–	–	595.	–	304.	.63
4.42	2.93	.69	.81	224.	76.57	232.	.53
4.43	7.67	1.85	.81	764.	99.61	165.	.48
4.44	5.26	1.75	.75	303.	57.59	201.	.58
4.45	1.91	.55	.78	153.	80.25	26.	.50
4.46	2.69	.99	.73	247.	91.71	797.	.50
4.47	1.65	.60	.73	152.	92.32	311.	.47
4.48	1.65	.96	.63	186.	112.57	692.	.56
4.49	1.89	.68	.74	181.	95.71	372.	.47
4.50	1.72	.77	.69	178.	103.33	178.	.47

Table 22: Extract from ship's log - Cruise RV004
August 10-17, 1979

TIME	LANDMARK X DISTANCE ABEAM (nm)		SHIP'S HEADING (°TRUE)	SPEED MADE GOOD SINCE LAST ENTRY	REMARKS (Technicians observations in brackets)
Aug 10 0600	Loading Anvil Island				
1630	Loading complete				
1700	Away Anvil with loaded Logger				
1930	Arrive Centre Bay				
2030	Barge anchored and away to Vancouver				
2345	Away with Straits Traveller				
2400	Second Narrows				
Aug 11 0107	Pt. Atkinson	x .6	230		
0413	Pt. Roberts	x 5.2	132	9.5	
0525	East Pt.				
0631	Turn Pt.	x .9	170	9.5	(clear, calm no swell)
0813	Discovery Isl.	x 1.0	212	9.9	
0945	Race Rock	x 2.5	270	10.5	Lt. WSW wind. Chop (wind WSW 15, waves 2' west'ly)
1123	Sheringham	x 3.4	292	11	
1325	San Juan Pt.	x 4.7	292	10.8	
1445	Buoy J	x 1.0	292	9.4	
1630	Pachena Pt.	x 5.8	291		(clear wind W5-10, waves 1-2', 2' swell from W period of 10 sec.)
1846	Amphitrite Pt	x 11.0	307	9.1	
2115	Lennard Isl	x 9.9	308	8.9	
2302	Rafael	x 10.9	308	9	
Aug 12 0032	Estevan Pt.	x 8.2	330		

Table 22:-cont'd

TIME	LANDMARK X DISTANCE A BEAM (nm)		SHIP'S HEADING (°TRUE)	SPEED MADE GOOD SINCE LAST ENTRY	REMARKS (Technicians observations i brackets)
Aug 12 0253	Nootka Lt.				
0403	Canal Isl.			slow	
0515	Tsowan Narrows			"	
0630	Arrive McBride Bay				
0715	Secure for loading				
0900	Start loading				
2300	Loading completed				
2330	Away McBride with loaded Traveller				
Aug 13 0003	Steamer Pt.				Thick Fog
0132	Esperanza Bouy		230		Thick Fog
0230	Ferrer Pt.	x 6.6	154	7.4	
0349	Banjo Pt.	x 8.75	154	7.9	
0559	Estevan Pt.	x12.5	126	7.9	
0834	Rafael Pt.	x13.9	126	7.6	
1040	Lennard Is.	x12.3	122	7.85	Calm, Low S.W. motion
1319	Amphitrite Pt.	x11.1	110	Variable	Fishing vessels
1605	Pachena Pt.	x 5.7	120	7.7	(cloud 8/8, wir E.5, 2' swell from W @ 11 se
1807	Buoy J	x .4	120	8	Lt. S.E.Low S. motion
2105	Slip Pt.	x 2.5	110	8.5	(cloud 7/8,cal 2' swell from at 10 secs.)
Aug 14 0010	Bouy J.A.		080		
0140	Race Rocks				
0230	Shorten up trade barges with Island Commander				

Table 22:-cont'd

TIME	LANDMARK X DISTANCE A BEAM (nm)		SHIP'S HEADING (° TRUE)	SPEED MADE GOOD SINCE LAST ENTRY	REMARKS (technicians observations in brackets)
Aug 14 0415	Away with loaded Logger				
0535	Race Rocks				
0746	Sheringham	x 4.4	273	7.5	
1025	Sombrio Pt.	x 6.2	293	6.8	
1251	Bouy J	x .85	298		
1448	Pachena Pt.	x 5.8	290	8.5	
1720	Amphitrite Pt.	x 11.0	295	8	
1835	Quisitis Pt.	x 13.2	305	7.5	(cloud 7/8, 1-2' W. swell at 10 sec.)
2031	Lennard Isl.	x 10.66	312	7.3	Lt.W.,W motion
2231	Rafael Pt.	x 10.5	315	7.8	
2400	Estevan Pt.				Thick fog
Aug 15 0303	Nootka Lt.				
0412	Atrevida Pt.				
0551	Victor Isl.	x 2.0			
0630	Arrive Gold River				
0825	Sand Pt. Chief Arrives				
0835	Open Valves				
0930	Dump				
1250	Tahsis Narrows				
1350	Arrive Zeballos				
1420	Secure for loading				
1515	Start loading				
Aug 16 0530	Completed loading				
0600	Away from Zeballos with loaded logger				
0738	Centre Isl.	x .3	242		
0821	Esperanza Bouy	x .2	190	8.4	
1016	Bajo Pt.	x 7.6	150	7.8	
1240	Estevan Pt.	x 9.9	128	7.3	S.E. 5 rippled

Table 22:-cont'd

TIME	LANDMARK X DISTANCE A BEAM (nm)		SHIP'S HEADING (° TRUE)	SPEED MADE GOOD SINCE LAST ENTRY	REMARKS (technicians observations in brackets)
Aug 16 1453	Rafael	x 11.8	128	7.8	S.E. 5 rippled
1658	Lennard Isl.	x 12.0	133	7.6	(1-2' W. swell at 10 sec)
1816	Quisitis Pt.	x 13.3	133	8.5	
1907	Amphitrite Pt.	x 13.7	110	8	
2156	Cape Beale	x 9.6	106	7.6	Fog
2333	Pachena Pt.	x 7.4	105	8.3	Fog
0042	Bouy J		108	7.2	Fog
0210	San Juan Pt.	x 3.7	112	7	Fog
0327	Sombrio Pt.	x 3.1	115	6.8	
0440	San Simon Pt.	x 3.5	105	6.3	Clear
0557	Sheringham Pt.	x 2.0	108	5.9	Clear
0830	Race Rocks	x 2.0	058	6.4	Clear
1025	Discovery Isl.	x 2.0		7.5	Clear Lt. West'ly
1137	Kellett Bluff	x .35	340	8.8	
1222	Turn Pt..			9.0	
1325	East Pt.				
1445	Pt. Roberts	x 3.1	315	9.2	
1613	Sand Head				

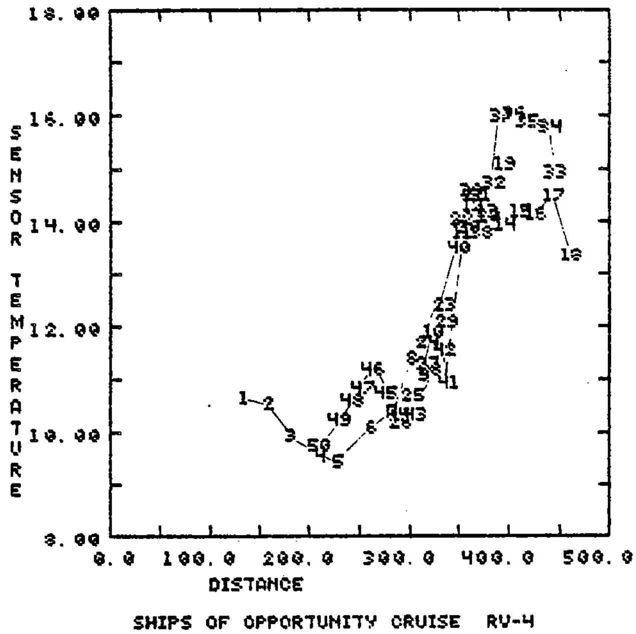


Figure 74. Sensor temperature (^{O}C) vs distance along cruise track - RV004.

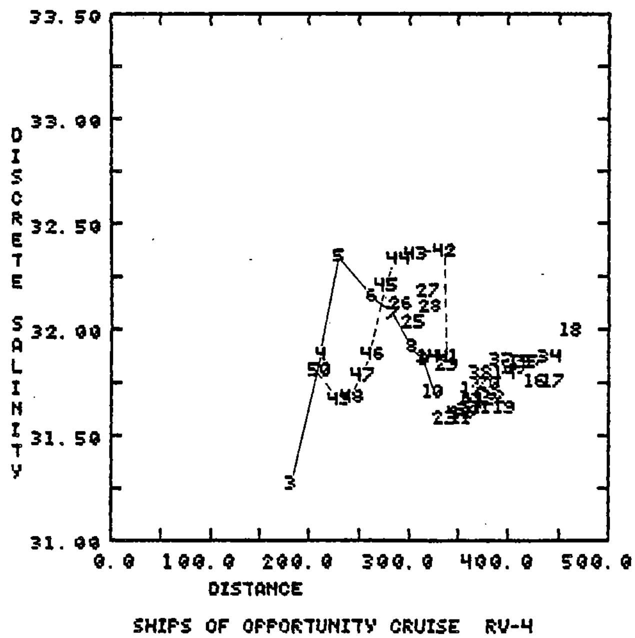


Figure 75. Discrete salinity (ppt) vs distance along cruise track - RV004.

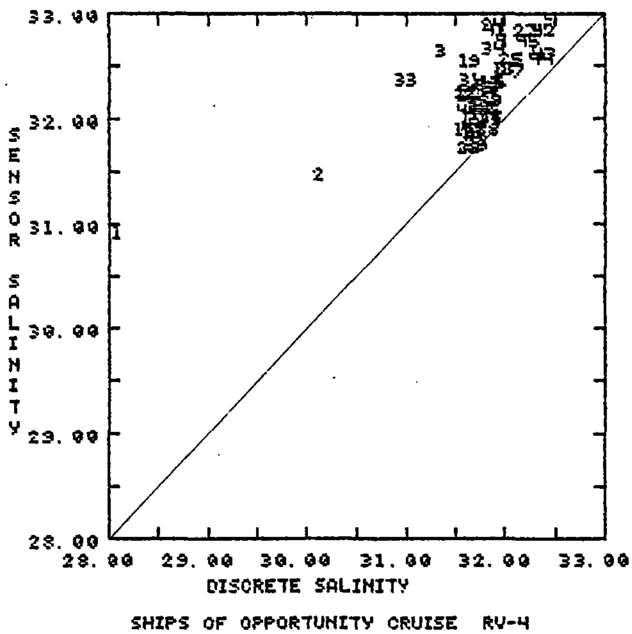


Figure 76. Sensor salinity (ppt) vs discrete salinity (ppt) - RV004.

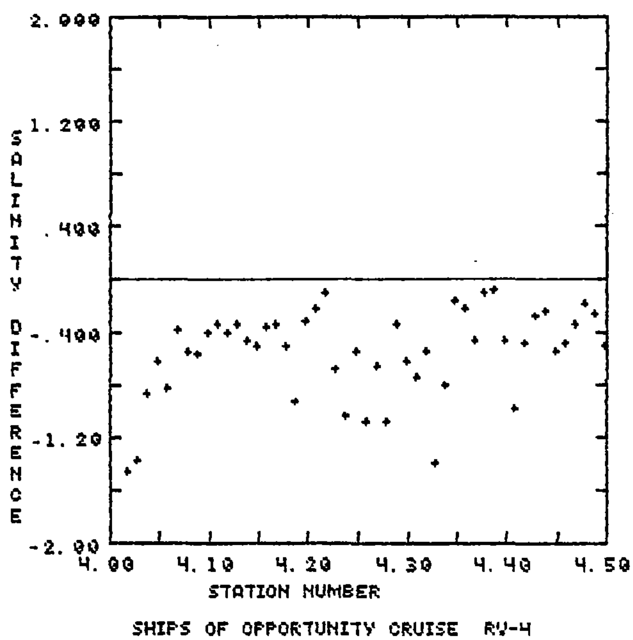


Figure 77. Salinity difference (ppt) - (discrete - sensor) - RV004.

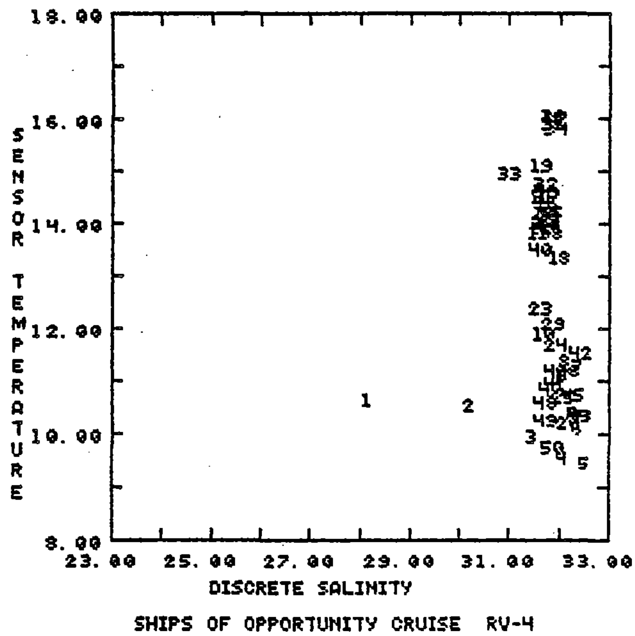


Figure 78. Sensor temperature (^{o}C) vs discrete salinity (ppt) - RV004.

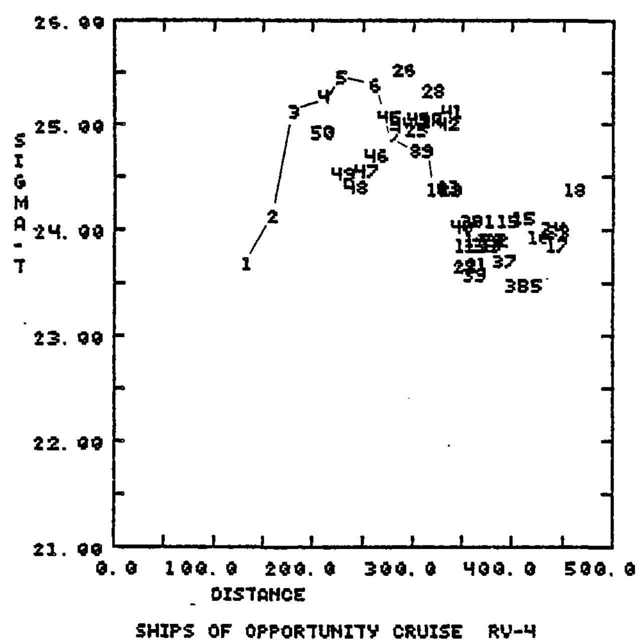


Figure 79. Sigma-t vs distance along cruise track - RV004.

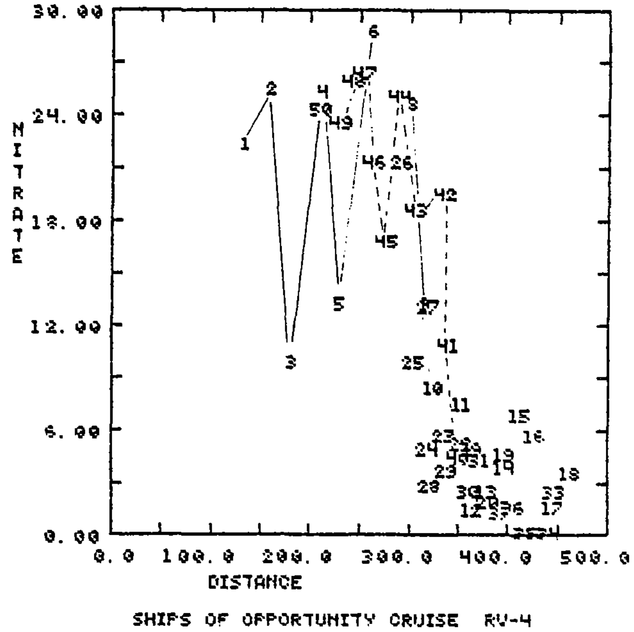


Figure 80. Nitrate concentration (µg.at/L) vs distance along cruise track - RV004.

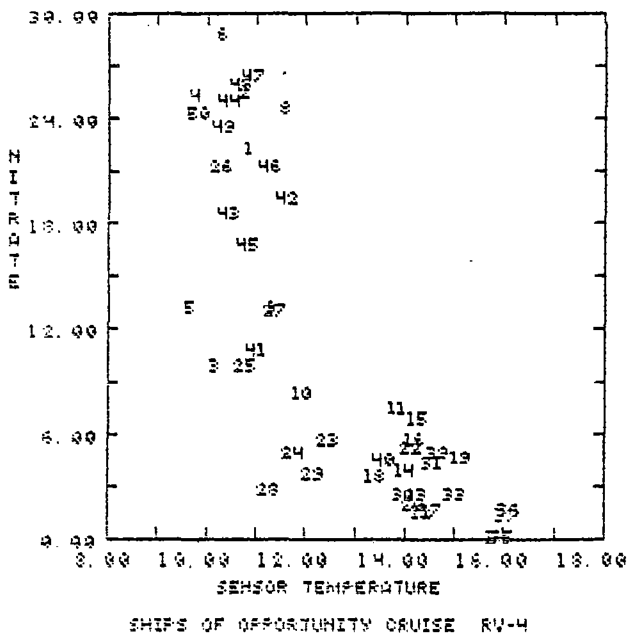


Figure 81. Nitrate concentration (µg.at/L) vs sensor temperature (°C) - RV004.

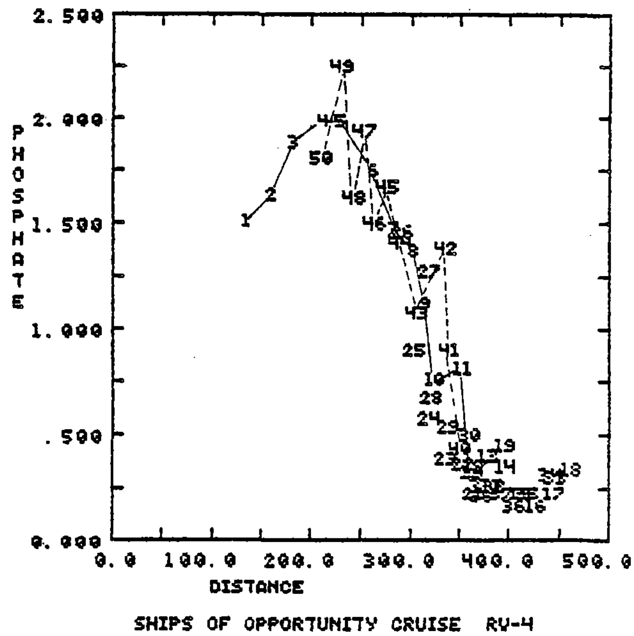


Figure 82. Phosphate concentration (µg.at/L) vs distance along cruise track - RV004.

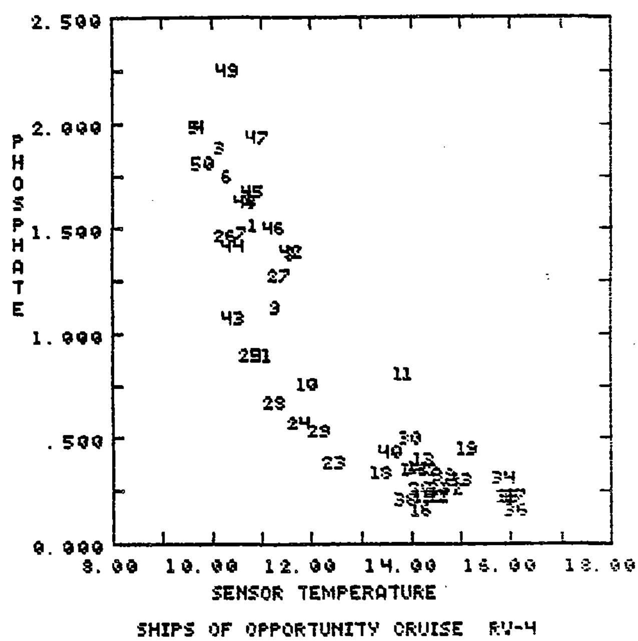


Figure 83. Phosphate concentration (µg.at/L) vs sensor temperature (^{o}C) - RV004.

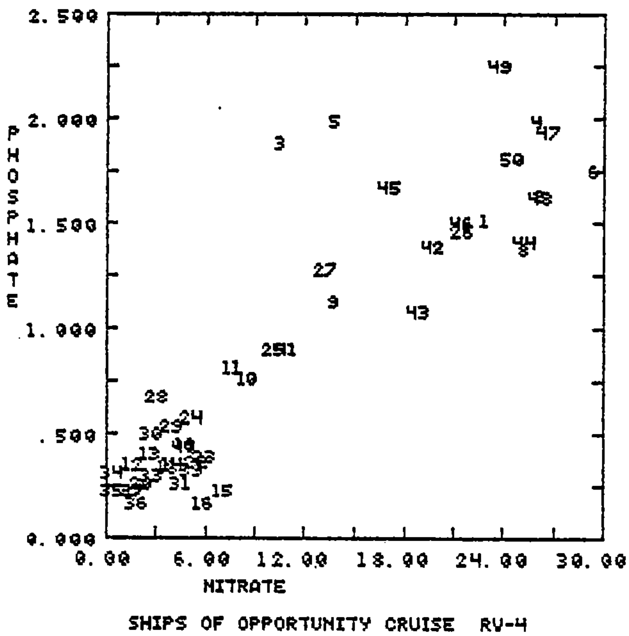


Figure 84. Phosphate concentration (µg.at/L) vs nitrate concentration (µg.at/L) - RV004.

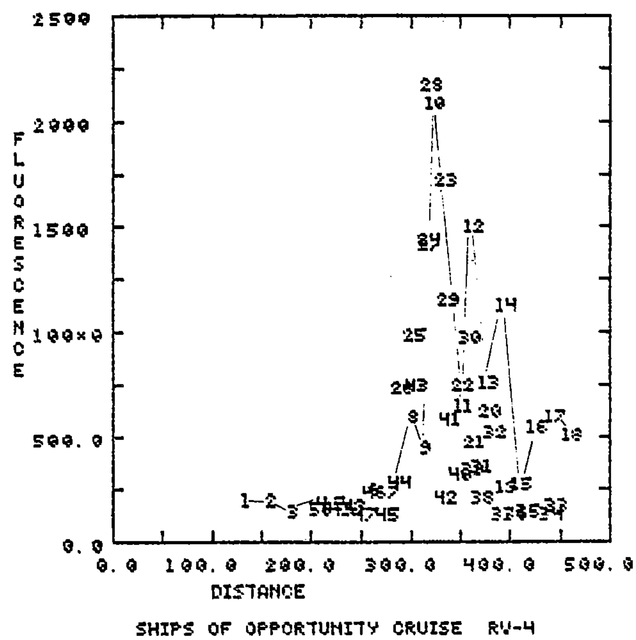


Figure 85. in vivo fluorescence vs distance along cruise track - RV004.

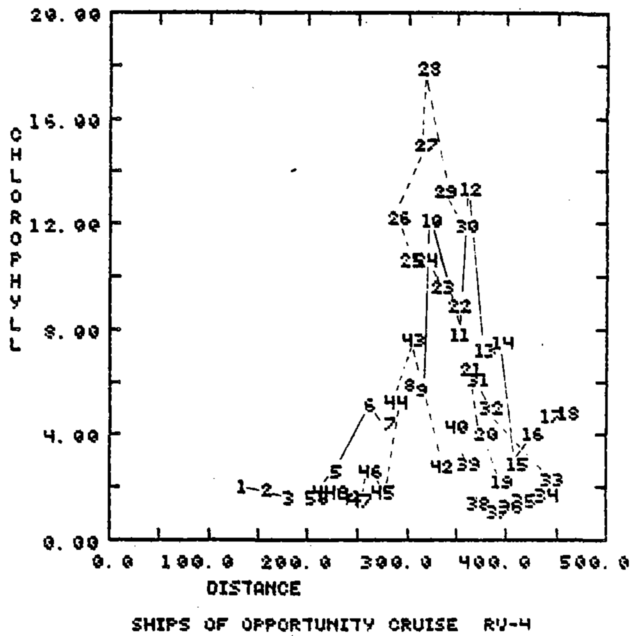


Figure 86. Chlorophyll a (mg/m^3) vs distance along cruise track - RV004.

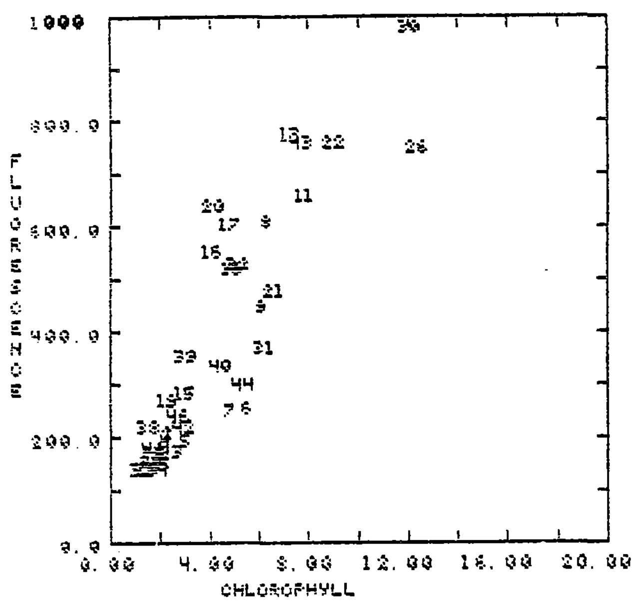


Figure 87. in vivo fluorescence vs chlorophyll a (mg/m^3) - RV004.

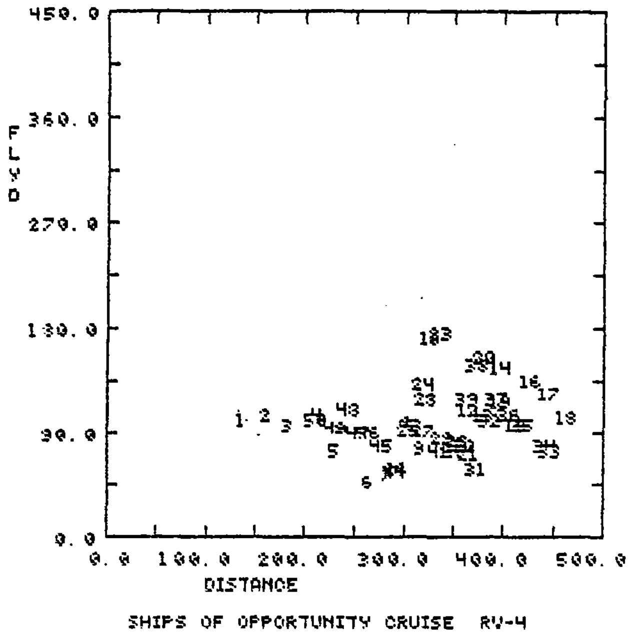


Figure 88. Fluorescence yield vs distance along cruise track - RV004.

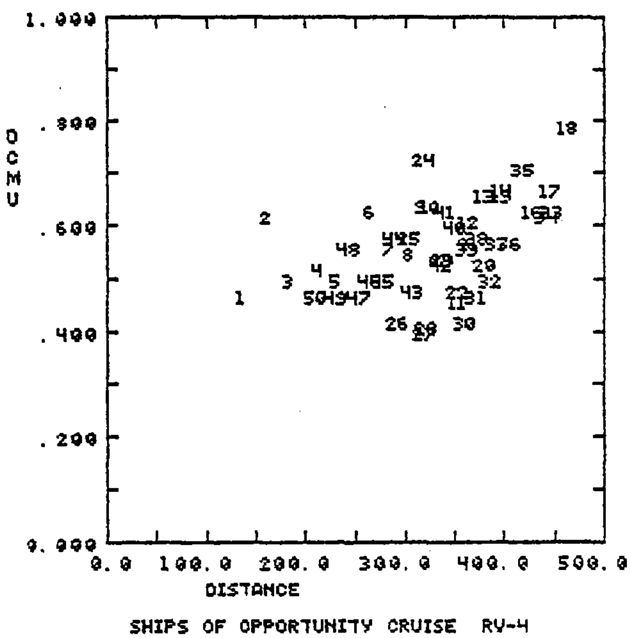


Figure 89. D.C.M.U. ratio vs distance along cruise track - RV004.

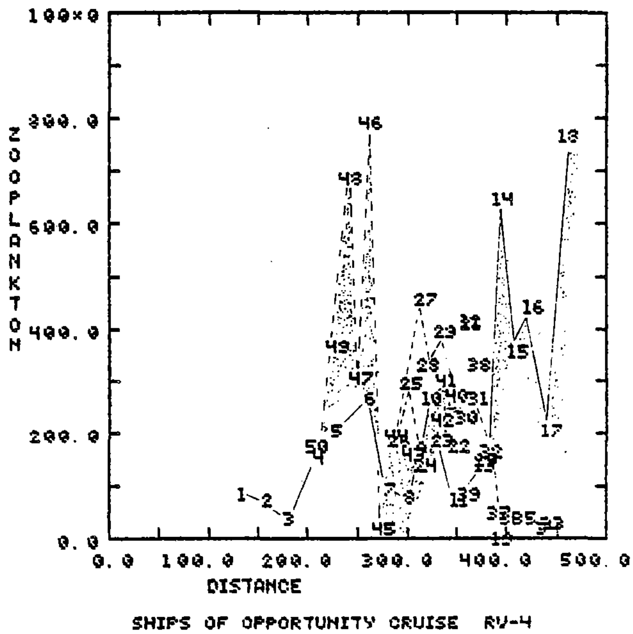


Figure 90. Zooplankton counts vs distance along cruise track - RV004.

Table 23: Multiple Correlation Table

SHIPS OF OPPORTUNITY CRUISE RV-4

	SEN T	SEN S	3 SAL	3 SIG	3 NO2	3 NO3	3 PO4	3 CHL	3 %CHL	SEN FL	3 FLYD	3 ZOO
SEN T												
SEN S	-.33											
3 SAL	-.02	.68										
3 SIG	-.85	.79	.40									
3 NO2	-.86	.31	.10	.74								
3 NO3	-.82	.10	-.09	.59	.80							
3 PO4	-.89	.22	-.04	.70	.83	.90						
3 CHL	-.08	.29	.21	.23	.09	-.23	-.21					
3 %CHL	.26	.22	.25	-.05	-.29	-.15	-.21	.21				
SEN FL	-.02	.18	.14	.13	.01	-.31	-.28	.90	.06			
3 FLYD	.23	-.27	-.12	-.30	-.30	-.36	-.36	.09	-.29	.46		
3 ZOO#	-.12	.00	.19	.09	.05	.10	.00	.22	.10	.22	.11	

2.5 Cruise RV005: September 8 - 11, 1979

2.5.1 Logistical Summary of RV005

The technicians were dispatched on the evening of September 6th, by rented float plane to Anvil Island in Howe Sound where they boarded the Rivtow Viking. The next morning gale force winds forced curtailment of the barge-loading operation for 12 hours, consequently the tug did not leave until 0200 on September 8th. The following day at 1500 the tug and barge arrived at Gold River and dumped the load of logs, then proceeded to load the Straits Logger. At 1000 hours on September 10th the barge was loaded and heading south, arriving in Vancouver for crew change late on September 11th. The technicians remained on board until the following morning when they were met by sea plane and returned to Patricia Bay.

The motion of the ship's bows in a following swell and the technicians's resulting seasickness on the northbound leg of this cruise reduced the number of discrete samples taken between Cape Flattery and Estevan Point. A total of 37 samples were taken for the cruise. DCMU numbers are available for 35 of these and 31 phytoplankton and zooplankton samples were obtained. No surface data was collected for this cruise.

2.5.2 Data Summary and Discussion

The pump and continuous monitoring gear were turned on at 0300 September 8th as the Viking passed Gambier Island on its way out of Howe Sound. Discrete sampling began 5 hours later near the southern edge of the Fraser River plume (Figure 91). Continuous data (Figures 92,93) indicated an abundance of particles and elevated chlorophyll fluorescence in this warm low salinity* water. Depressed nutrient concentrations at the low salinity stations (5.1, and 5.34 to 5.37) suggest that either the supply of nutrients of Georgia

* Figure 97 illustrates the difference between discrete and sensor salinity for cruise RV005. Continuous data are high by about .5 ppt on the northbound leg and by about half that on the southbound portion of the cruise. The scatter is about ±.3 ppt with the largest error coming in very low salinity Fraser River water.

Strait was low at this time, or that they were being depleted by large phytoplankton populations present. The latter seems more likely if the nutrient levels in Fraser River water are as high as those reported by Stockner et al. (1979). An alternative source of nutrients in the southern part of Georgia Strait might be entrainment of the deeper nutrient rich waters exiting Boundary Passage.

As was the situation during earlier cruises, the turbulent waters in Haro Strait and eastern Juan de Fuca were cold and saline, exhibiting high nutrient concentrations, low fluorescence, low chlorophyll concentration and low zooplankton populations. Seaward of Race Rocks temperatures began to increase and salinity decrease, as these waters mixed with 'oceanic' surface waters. The TS plot in Figure 98 and the continuous data (Figures 92, 93) illustrate that this boundary fell between stations 5.6 and 5.7 (near Port San Juan) on the outward trip and much further east between stations 5.29 and 5.30 (off Race Rocks) on the south side of the strait sampled on the return. Large steps in the continuous temperature and salinity records of this region are a result of the presence of eddies in this region on both transits. Figure 112, a NIMBUS-7 infrared image acquired September 11th while the Viking was off Victoria, depicts these eddies dramatically. The cold (white) water can be seen in eastern Juan de Fuca and along the Canadian shore in a narrow band extending as far as Port San Juan (the inlet near the western end of Juan de Fuca). Warm (grey) coastal waters which ship data showed possessed salinities of near 31 $^{0}/oo$, were penetrating eastward into Juan de Fuca as far as Port Angeles. These less dense waters were also spreading north in the region of Sheringham Light, making the boundary between the cold and warm waters serpentine. This is in agreement with the interpretation of earlier Viking data and of airborne remote sensing data and with the observation by Herlinveaux and Tully (1961) that cold pools, formed in Juan de Fuca east of the Victoria-Port Angeles sill and in the San Juan Islands, move west out of the strait along the northern side. As elementary calculations show, the nutrients they export to the outer coast are considerable (Mackas et al., unpublished manuscript). A priori reasoning leads one to expect high primary production and standing stocks where increasing stratification and stability in these waters decreases losses of phytoplankton through mixing. Where this occurs the increased phytoplankton growth rates resulting from elevated nutrient availability will be realized as increasing standing stocks. This apparently does not mean that the seaward boundary of the Juan de Fuca water will always exhibit large phytoplankton standing stocks, as during September, larger, chlorophyll concentrations (which were relatively low, ~4 mg/m^3) were observed in the warm coastal waters than in the cold waters. This may be related to the intensity of vertical stratification and the 'age' of a particulate parcel of Juan de Fuca water.

At the time of the northbound leg of the cruise (September 9th), the surface waters of the outer coast north of station 5.8 became progressively more saline and cooler until the effects of land drainage and warm fresh run-off waters were encountered just off Estevan Point and into Nootka Sound. The situation was similar on the 10th and 11th of September except that a body of water with salinities near 31.3 ppt was observed at stations 5.22 to 5.24 (between Cape Beale and Carmanah Point). The fact that these stations were further offshore than the northbound track is consistent with the suggestion that low salinity water travelling north along the Washington coast continues to hug the Canadian coast.

In September, as in previous months there was a high negative correlation between temperature and nutrient concentrations. The relationships illustrated in Figures 101 and 103 are much the same as earlier shown for cruises RV003 and RV004 with waters of intermediate temperatures (i.e. those areas in boundary or intermediate zones) with nutrient concentrations most anomalous. As said earlier, these stations also usually possess the highest chlorophyll a concentrations.

In September, the relationship between in vivo fluorescence and chlorophyll a (Figure 107) remained similar to that in August (cruise RV004) for some stations, but as Figure 108 shows the cold, high nutrient waters of eastern Juan de Fuca (stations 5.2 to 5.6 and 5.31 to 5.34) exhibited greatly elevated fluorescence yields. About 65% of the variation of fluorescence yield can be related to variations in nutrient concentrations or temperature (see Table 28).

There is a closer (r^2 = 77%) negative relationship with percent chlorophyll, however, Table 28 and examination of earlier data shows cruises RV003 (July) and RV004 (August) to exhibit relationships with similar slopes but poorer correlations. Slovacek et al. (1977) have shown that high fluorescence yields are observed when the algae are growing very slowly due to nutrient limitation or various sorts of inhibitation. In eastern Juan de Fuca nutrient limitation should not be a problem, however since the water column is homogeneous to the bottom (Herlinveaux and Tully,1961) cells will spend a large proportion of the time well below the compensation depth. This could be expected to result in low growth rates and high percentage of chlorophyll degradation products in the cells, (lower % chlorophyll). By this logic, eastern Juan de Fuca phytoplankton was moribund or slowly growing and that at stations 5.8 to 5.10 and 5.20, 5.21 and 5.25 which were all in the region of lower offshore salinities (discrete salinities near 30.5) were more healthy. Without other data such as primary production measurements it is impossible to be certain since the elevated fluorescence values in this region could be a result of the presence of detrital chlorophylls of other than phytoplankton origin. The DCMU ratios (Figure 109) are very erratic and offer little information to this discussion.

Zooplankton counts were lower than in August for all regions. Continuous measurements for September (Figures 92 and 93) show relatively high numbers in Georgia Strait, but decreasing in Boundary Passage - Haro Strait to very low numbers in East Juan de Fuca (Turn Point to Discovery Island and stations 5.2 and 5.3 in Figure 110). A second large concentration was encountered in Juan de Fuca between Race Rocks and San Juan Point in the transition to 'oceanic' water which was crossed in late afternoon. Very few particles were encountered during the night of the 8th along the outer coast. On the return trip counts were again low except for a small patch off Lennard Light and another area off Slip Point (around station 5.27) near dawn of the 11th. This second patch is in the same position as the one observed on the outward transit and also near the eastern most extension of the 'oceanic' surface waters. Large zooplankton populations were also counted in the warm, low salinity waters of Georgia Strait on the return trip. The large temperature and salinity changes constituting boundaries of this water relate with the distribution of zooplankton abundances and agree with observations by Parsons et al (1970) of increases in chlorophyll concentrations and zooplankton in and around the Fraser River plume using discrete samples and net tows.

2.5.3 Coincident Satellite Imagery

The thermal infra-red image in Figure 112 discussed earlier is from the Coastal Zone Colour Scanner (CZCS) on board the American NIMBUS-7 satellite taken September 11, 1979 coinciding with the September RV005 cruise. The magnetic tape for this image was received from the Scripps Institute of Oceanography receiving station by Dr. J.F.R. Gower of the Remote Sensing Section at the Institute of Ocean Sciences. The digitized radiance data on magnetic tape was printed as grey tone variations on a Versatec 1100A printer-plotter. Selected parts of the digitized radiance information from the image (which could not be geometrically corrected for distortion) corresponding to approximate station locations, were averaged to reduce effects of noise and banding. The areas averaged were 2 x 2 pixels, representing areas of 1.6 km square. The sensor temperatures recorded at cruise RV005 stations and at Sheringham and Race Rocks lighthouses, are compared to the appropriate satellite data in Figure 111 providing a field calibration for the image. Despite the uncertainties resulting from the distortion, which is worst for station 5.31, the agreement is good to about ± 1 grey scale level (omitting station 5.31, standard deviation is $0.46^{o}C$).

The CZCS also views the earth in 5 other bands at visible wavelengths disigned to allow inferences regarding chlorophyll and suspended content to be made. Unfortunately, the magnetic tape received did not include all 5 bands and this lack of data meant these inferences could not be made.

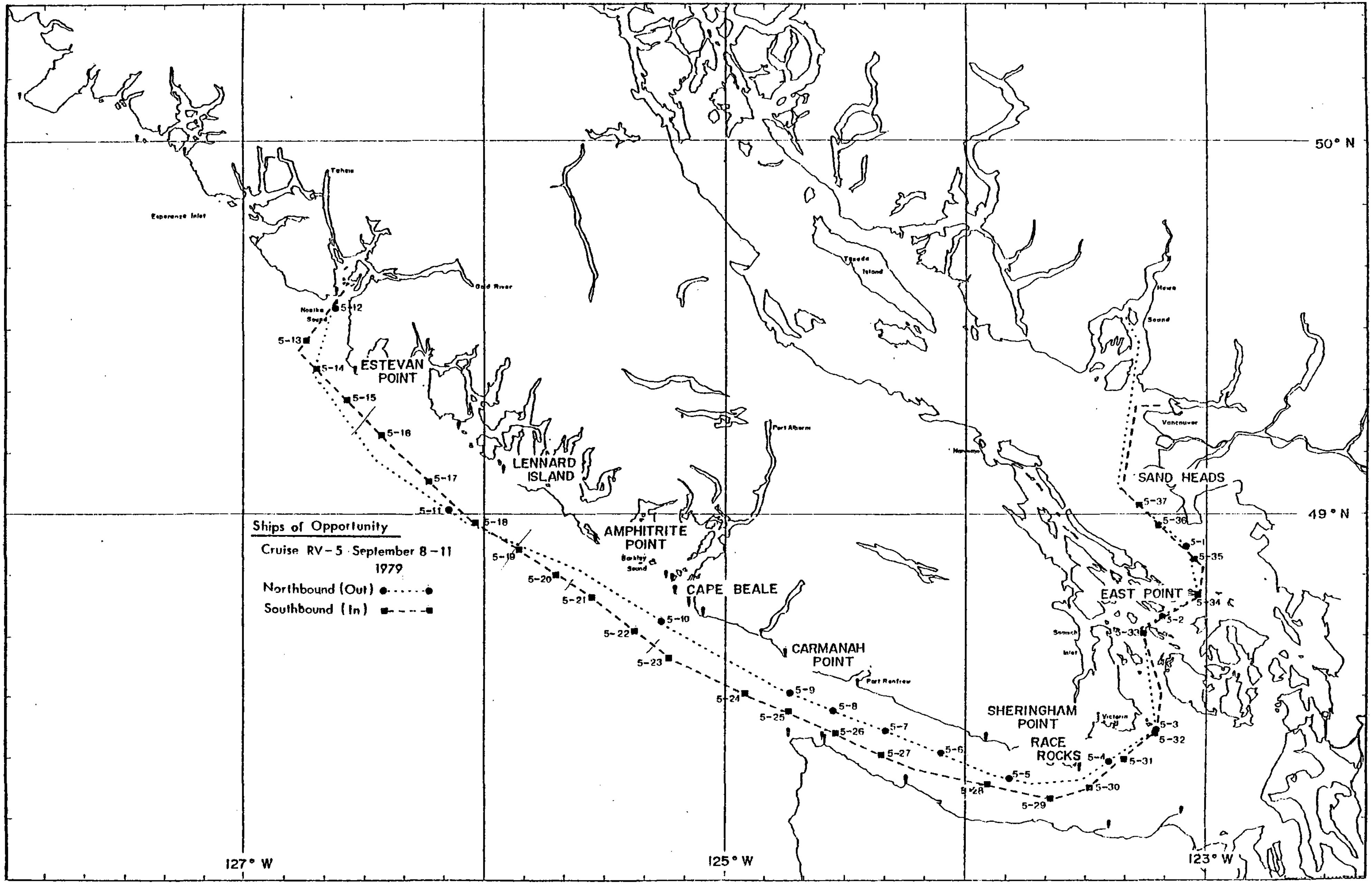


Figure 91. Cruise track and station locations - RV005.

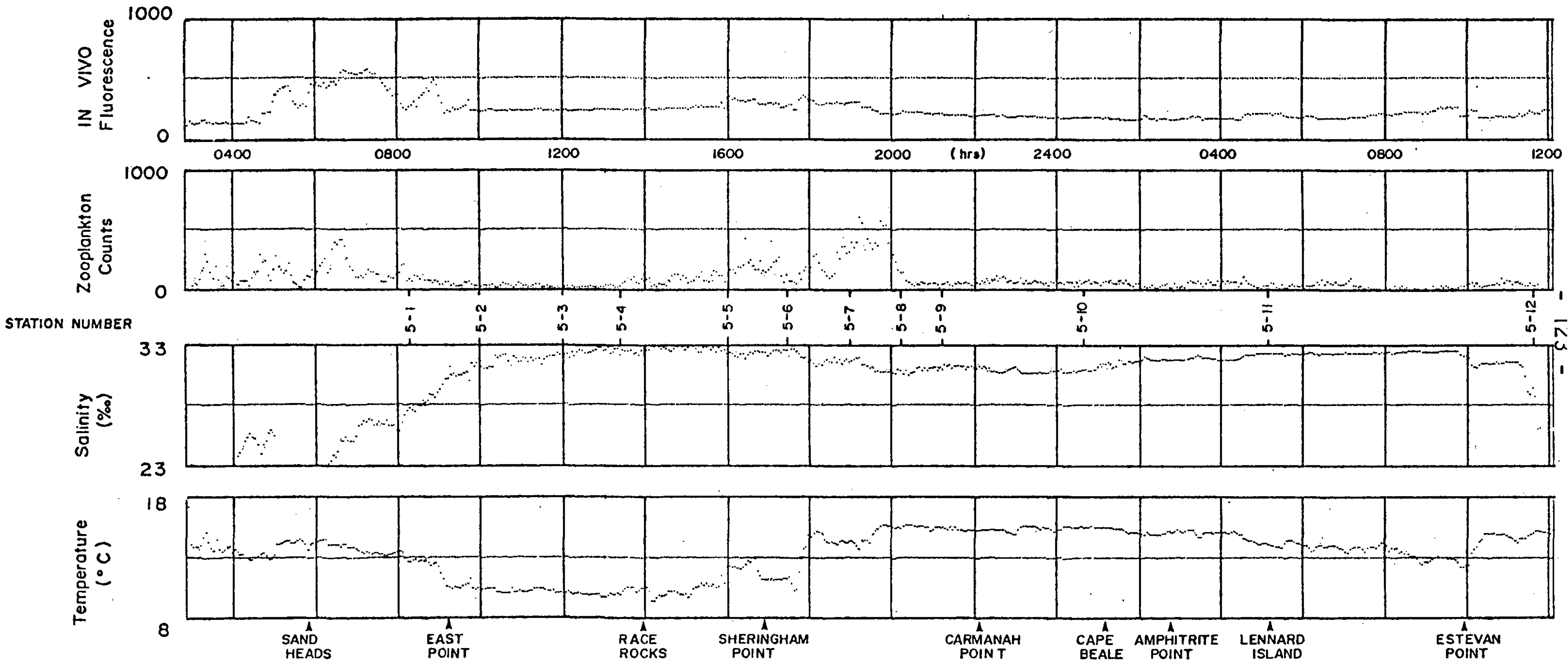


Figure 92. Continuous data record - RV005 (northbound).

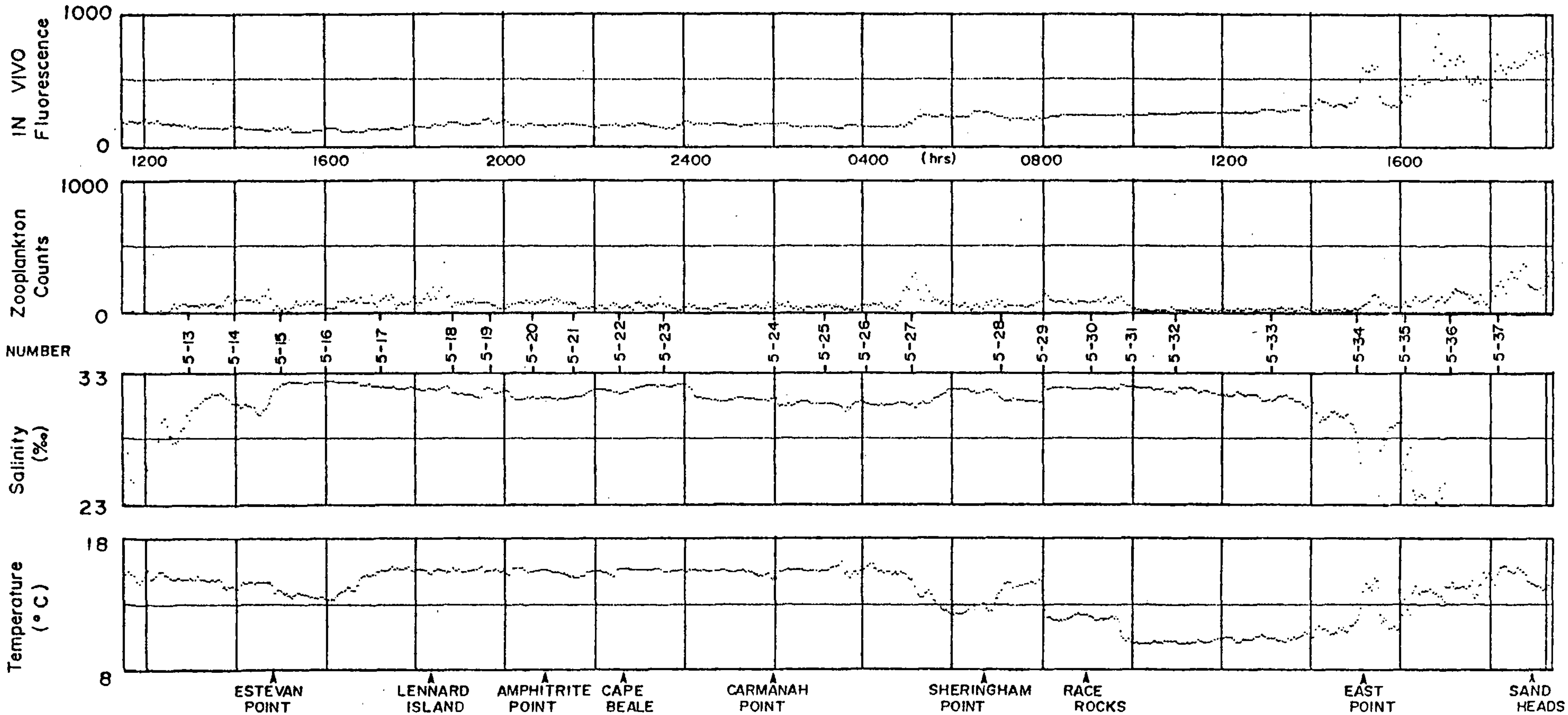


Figure 93. Continuous data record - RV005 (southbound).

Table 24;

REFERENCE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-5

STN #	CDATE	JDATE	TIME	LATITUDE	LONGITUDE	DIS
5.01	8/ 9/79	251	815	48-55.0 N	123- 5.0 W	103.
5.02	8/ 9/79	251	1000	48-43.2 N	123-11.0 W	130.
5.03	8/ 9/79	251	1200	48-24.3 N	123-12.5 W	166.
5.04	8/ 9/79	251	1332	48-18.9 N	123-24.3 W	185.
5.05	8/ 9/79	251	1600	48-16.1 N	123-49.0 W	214.
5.06	8/ 9/79	251	1730	48-20.6 N	124- 6.0 W	236.
5.07	8/ 9/79	251	1900	48-24.0 N	124-19.5 W	253.
5.08	8/ 9/79	251	2015	48-27.4 N	124-33.0 W	270.
5.09	8/ 9/79	251	2115	48-30.5 N	124-43.6 W	284.
5.10	9/ 9/79	252	33	48-42.2 N	125-16.0 W	334.
5.11	9/ 9/79	252	538	49- .5 N	126- 9.0 W	406.
5.12	9/ 9/79	252	1145	49-33.7 N	126-37.0 W	480.
5.13	10/ 9/79	253	1303	49-28.2 N	126-44.5 W	472.
5.14	10/ 9/79	253	1400	49-23.8 N	126-42.0 W	463.
5.15	10/ 9/79	253	1501	49-18.5 N	126-34.9 W	450.
5.16	10/ 9/79	253	1600	49-13.2 N	126-26.0 W	435.
5.17	10/ 9/79	253	1720	49- 5.5 N	126-14.0 W	416.
5.18	10/ 9/79	253	1830	48-58.5 N	126- 2.1 W	398.
5.19	10/ 9/79	253	1930	48-54.4 N	125-51.2 W	382.
5.20	10/ 9/79	253	2030	48-50.0 N	125-42.0 W	369.
5.21	10/ 9/79	253	2130	48-46.2 N	125-33.2 W	356.
5.22	10/ 9/79	253	2230	48-40.2 N	125-22.5 W	339.
5.23	10/ 9/79	253	2330	48-36.2 N	125-14.0 W	326.
5.24	11/ 9/79	254	201	48-29.8 N	124-55.0 W	297.
5.25	11/ 9/79	254	305	48-27.0 N	124-44.0 W	282.
5.26	11/ 9/79	254	402	48-23.4 N	124-32.5 W	267.
5.27	11/ 9/79	254	503	48-20.6 N	124-20.8 W	251.
5.28	11/ 9/79	254	704	48-15.2 N	123-54.3 W	219.
5.29	11/ 9/79	254	800	48-13.2 N	123-39.0 W	204.
5.30	11/ 9/79	254	900	48-15.0 N	123-29.0 W	192.
5.31	11/ 9/79	254	1000	48-19.5 N	123-21.0 W	178.
5.32	11/ 9/79	254	1100	48-24.5 N	123-12.0 W	166.
5.33	11/ 9/79	254	1321	48-40.0 N	123-15.0 W	138.
5.34	11/ 9/79	254	1500	48-46.8 N	123- 1.3 W	120.
5.35	11/ 9/79	254	1603	48-52.6 N	123- 2.9 W	110.
5.36	11/ 9/79	254	1705	48-57.9 N	123-11.0 W	95.
5.37	11/ 9/79	254	1804	49- 1.0 N	123-16.0 W	86.

Table 25:

INLINE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-5

STN #	SEN T	SEN SAL	DIS SAL	SIG	NO2	NO3	PO4
5.01	12.72	27.54	23.51	20.71	.24	6.55	.99
5.02	10.41	31.59	29.26	24.25	.26	–	1.59
5.03	10.09	32.26	31.48	24.83	.28	22.97	2.00
5.04	10.58	32.13	31.60	24.64	.30	24.35	2.20
5.05	12.28	32.27	31.66	24.45	.32	16.13	1.66
5.06	11.39	32.25	31.67	24.59	.29	18.74	1.70
5.07	14.52	32.20	31.32	24.54	.23	12.78	1.30
5.08	15.47	30.94	30.58	22.77	.12	5.32	.74
5.09	15.53	31.00	30.51	22.81	.10	2.40	.65
5.10	15.61	30.96	30.74	22.76	.07	4.40	.60
5.11	14.48	32.30	31.49	24.03	.09	4.41	.56
5.12	15.30	26.71	30.04	19.57	.17	15.32	.79
5.13	14.96	30.44	26.33	22.49	.18	7.12	.62
5.14	14.25	30.79	30.34	22.92	.22	3.97	1.16
5.15	14.09	32.11	30.87	23.96	.22	7.84	1.00
5.16	13.39	32.43	32.16	24.35	.25	8.60	1.29
5.17	15.62	32.00	32.03	23.56	.15	6.51	.87
5.18	15.80	31.79	31.65	23.35	.08	2.31	.67
5.19	15.96	31.22	31.14	22.88	.10	1.18	.47
5.20	15.64	31.20	31.08	22.94	.10	.29	.40
5.21	15.22	31.23	31.04	23.05	.09	2.01	.54
5.22	15.77	31.60	31.28	23.21	.08	2.45	.56
5.23	15.78	32.11	31.65	23.60	.06	2.05	.43
5.24	15.01	31.14	31.26	23.02	.05	3.23	.39
5.25	15.70	30.80	30.53	22.62	.07	1.47	.42
5.26	15.83	30.77	30.60	22.56	.06	2.47	.44
5.27	15.03	30.68	30.55	22.67	.09	2.75	.51
5.28	13.95	31.26	30.79	23.34	.15	6.79	.92
5.29	14.83	30.93	30.81	22.90	.17	7.90	.51
5.30	12.13	31.88	31.24	24.17	.14	6.18	.59
5.31	10.21	32.00	31.69	24.60	.22	13.29	1.47
5.32	10.25	31.60	31.45	24.29	.28	19.33	2.28
5.33	10.25	31.35	31.41	24.09	.30	23.51	1.87
5.34	11.63	28.81	29.88	21.89	.22	16.86	2.05
5.35	11.08	29.29	27.46	22.35	.22	11.80	1.60
5.36	14.33	21.63	24.65	15.87	.22	4.38	.45
5.37	15.20	17.89	20.06	12.85	.19	3.36	.53

Table 26;

INLINE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-5

STN #	CHL	PHAEO	% CHL	SEN FL	FL YD	ZOO #	DCMU #
5.01	2.51	1.00	.71	248.	98.82	79.	–
5.02	1.57	.96	.62	235.	149.41	43.	–
5.03	.76	.77	.50	233.	306.35	22.	.50
5.04	.88	.73	.55	243.	277.48	95.	.22
5.05	1.87	.86	.69	334.	179.00	182.	.39
5.06	1.72	.97	.64	282.	164.42	87.	.45
5.07	3.43	1.69	.67	293.	85.48	324.	.48
5.08	4.15	.83	.83	219.	52.74	141.	.48
5.09	4.36	.98	.82	210.	48.17	46.	.31
5.10	3.63	1.11	.77	179.	49.37	45.	–
5.11	1.33	.74	.64	185.	139.47	37.	–
5.12	2.23	1.13	.66	211.	94.71	21.	.50
5.13	1.84	.79	.70	149.	80.85	55.	.70
5.14	1.90	.51	.79	157.	82.67	94.	.47
5.15	1.62	.58	.74	137.	84.52	25.	.50
5.16	.98	.44	.69	141.	144.04	45.	.50
5.17	1.37	.43	.76	133.	97.07	137.	.67
5.18	1.18	.56	.68	175.	148.09	105.	.48
5.19	2.45	.67	.79	175.	71.31	92.	.41
5.20	3.74	1.50	.71	166.	44.34	121.	.42
5.21	3.30	1.01	.77	170.	51.58	72.	.55
5.22	2.46	.60	.80	170.	68.99	65.	.38
5.23	1.77	.66	.73	147.	82.94	113.	.38
5.24	2.07	.43	.83	179.	86.53	43.	.64
5.25	3.56	.87	.80	158.	44.39	47.	.38
5.26	2.41	.59	.80	156.	64.74	67.	.33
5.27	1.96	.78	.71	181.	92.32	175.	.46
5.28	1.77	.83	.68	225.	126.79	64.	.30
5.29	2.64	1.25	.68	209.	79.18	97.	.60
5.30	1.05	1.60	.40	233.	222.35	85.	.50
5.31	1.29	.58	.69	233.	180.07	36.	.50
5.32	.67	.58	.54	244.	361.82	12.	.44
5.33	.66	1.03	.39	262.	399.94	38.	.50
5.34	.87	.97	.47	335.	384.18	26.	.50
5.35	4.15	1.27	.77	288.	69.35	38.	.62
5.36	7.76	2.92	.73	644.	82.94	101.	.35
5.37	6.03	2.60	.70	520.	86.22	200.	.52

Table 27:

Extract from Ship's Log - Cruise RV005 - September 8 - 11, 1979

Date	Time	Landmark x distance abeam (nm)	Ship's Heading (° True)	Speed made since last entry	Remarks (technician's observations in brackets)
Sept. 8/ 79	0200	Away Anvil Island with loaded Logger			
	0400	Cowan Pt. x 0.7	193	6.5	S.E. 15, choppy
	0550	Sand Heads	135	6.7	S.E. 15, choppy
	0920	East Pt. x 1.0	265	8.5	Strong S.E., rough chop
	1020	Turn Pt. x 1.0	169	9.8	Lt. E., lt. chop
	1200	Discovery Isl. x 0.9	235	10.2	Lt. E., lt. chop
	1400	Race Rocks x 1.4	264	10.5	Lt. S.S.E., lt. rain
	1610	Otter Pt. x 4.3	283	6.3	Lt. W. breeze (cloudy, calm, 1' swell from west)
	2000	San Juan Pt. x 5.0	292	7.3	(cloudy, winds west 0.5, ripples, 1' swell from west period of 4 sec.)
	2145	Bouy J. x 1.0	292	7.6	Mod. Ely., low S.W. swell
	2350	Pachena Pt. x 4.3	297	8.0	Lt. S.W., low S.W. swell
Sept. 9/ 79	0245	Amphitrite Pt. x 5.4	293	7.5	Lt. S.W., low S.W. swell
	0505	Lennard Isl. x 10.4	307	7.8	Lt. S.W., low S.W. swell
	0730	Rafael Pt. x 12.3	315	7.4	
	0950	Estevan Pt. x 6.4	352	7.3	
	1200	Nootka Lt. x 0.6	Var.	7.9	
	1500	Arrive Burmon River			
	1515	Open Valves			
	1620	Dump			
	1800	Start loading			
Sept. 10/ 79	0945	Away Gold River with loaded Logger			
	1120	Atrevida Pt.			
	1215	Nootka Light x 1.0	220		(winds west 10-15, 1' waves from west 2-3' swell from west, period of 6 sec.)
	1438	Estevan Pt. x 3.7	134	7.2	Lt. S.W., low S.W. swell

Table 27: - cont'd

Date	Time	Landmark x distance abeam (nm)	Ship's Heading (° True)	Speed made since last entry	Remarks (technician's observations in brackets)
	1816	Lennard Isl. x 9.2	121	8.1	(clear, winds west 5-10, 1' waves from west, 2-3' swell from west, period of 6 sec.) Mod.
	2055	Amphitrite Pt. x 8.0	121	7.8	Mod.
	2355	Pachena Pt. x 8.5	114	7.6	
Sept. 11/ 79	0235	Bouy J. x 1.8	115	6.6	
	0540	Slip Pt. x 2.2	03	8.5	
	0810	Bouy J.A.	080	9.7	
	0900	Race Rocks	065		
	1100	Discovery Isl.	005		
	1330	Turn Pt. x 0.4	Var.	6.8	clear, calm
	1503	East Pt. x 0.7	Var.	6.7	
	1703	Tsswwassen x 3.0	314	7.2	
	1830	Sand Heads	005		
	2100	Anchorage Z English Bay			

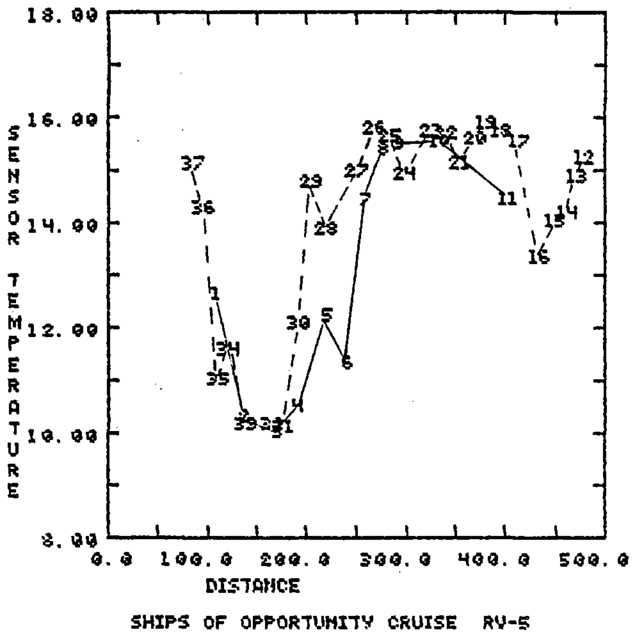


Figure 94. Sensor temperature (^{o}C) vs distance along cruise track - RV005.

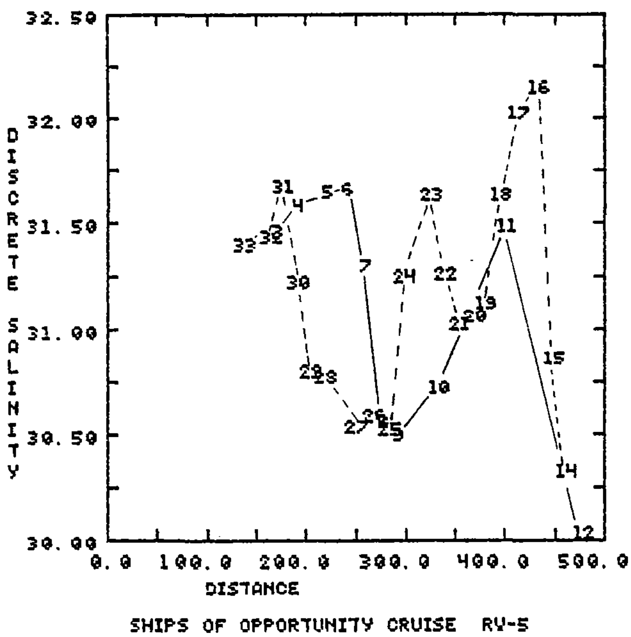


Figure 95. Discrete salinity (ppt) vs distance along cruise track - RV005.

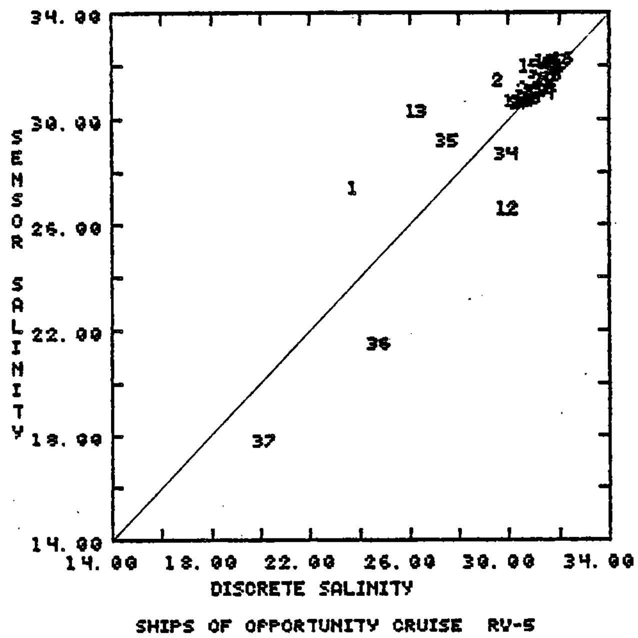


Figure 96. Sensor salinity (ppt) vs discrete salinity (ppt) - RV005.

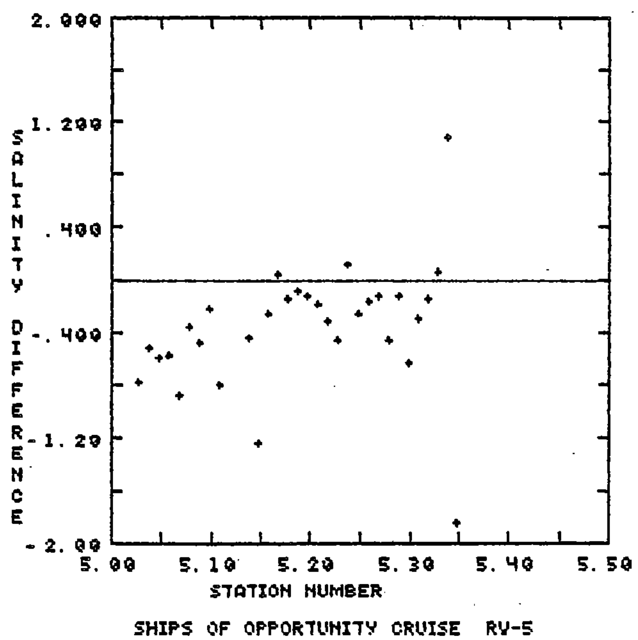


Figure 97. Salinity difference (ppt) - (discrete salinity - sensor salinity) - RV005.

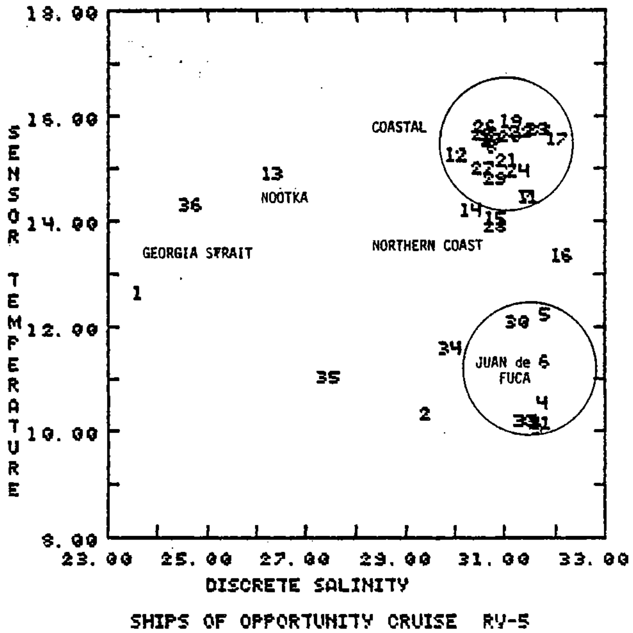


Figure 98. Sensor temperature (^{o}C) vs discrete salinity (ppt) - RV005.

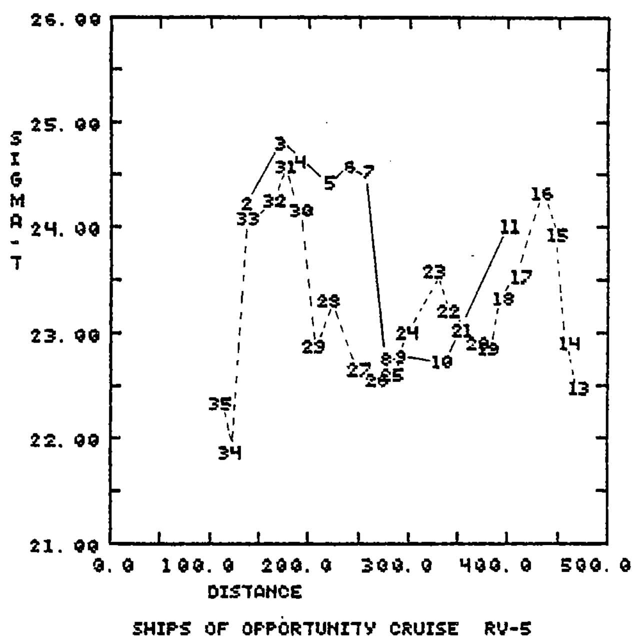


Figure 99. Sigma-t vs distance along cruise track - RV005.

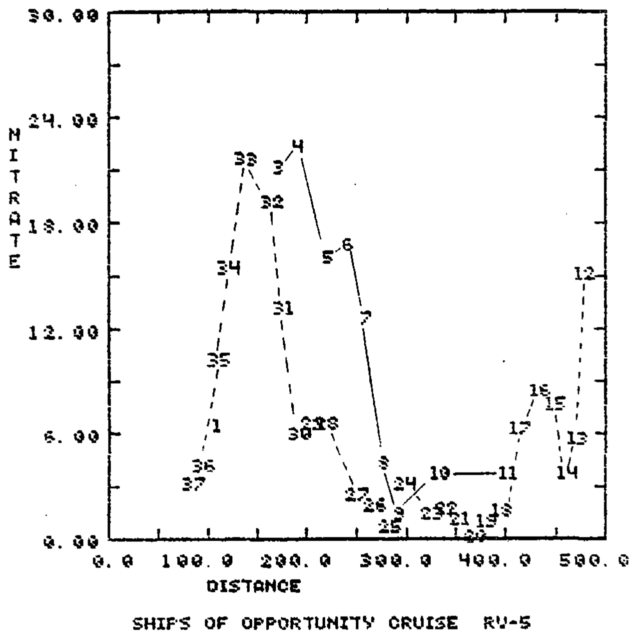


Figure 100. Nitrate concentration (µg.at/L) vs distance along cruise track - RV005.

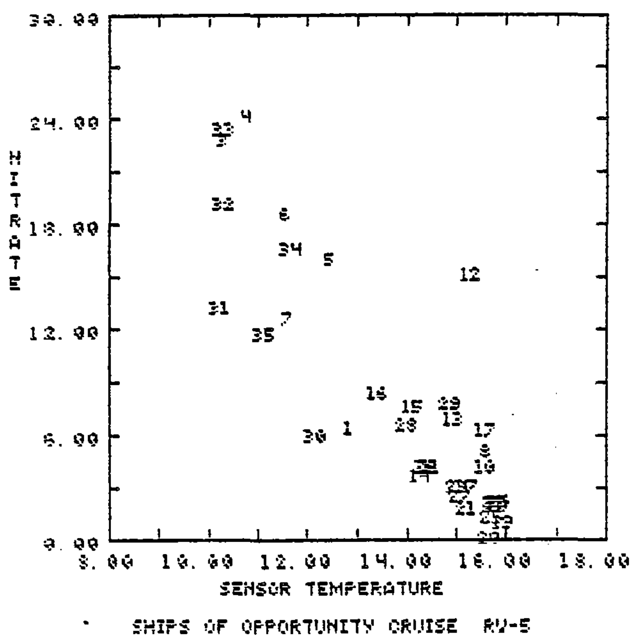


Figure 101. Nitrate concentration (µg.at/L) vs sensor temperature (°C) - RV005.

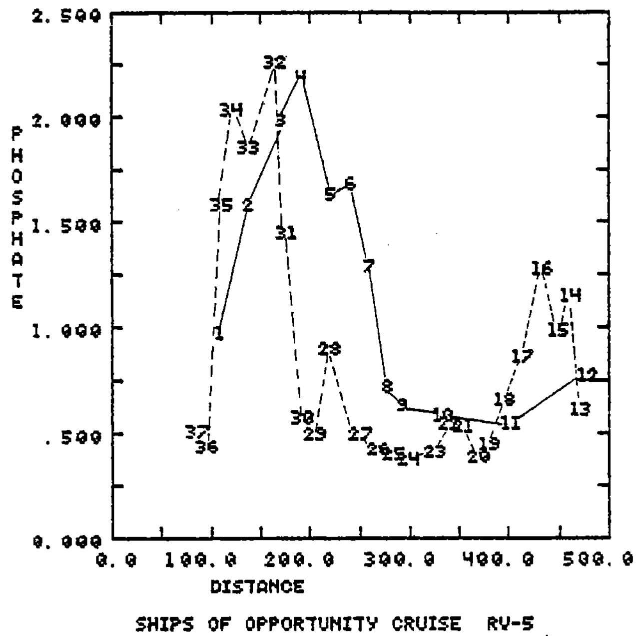


Figure 102. Phosphate concentration (μg.at/L) vs distance along cruise track - RV005.

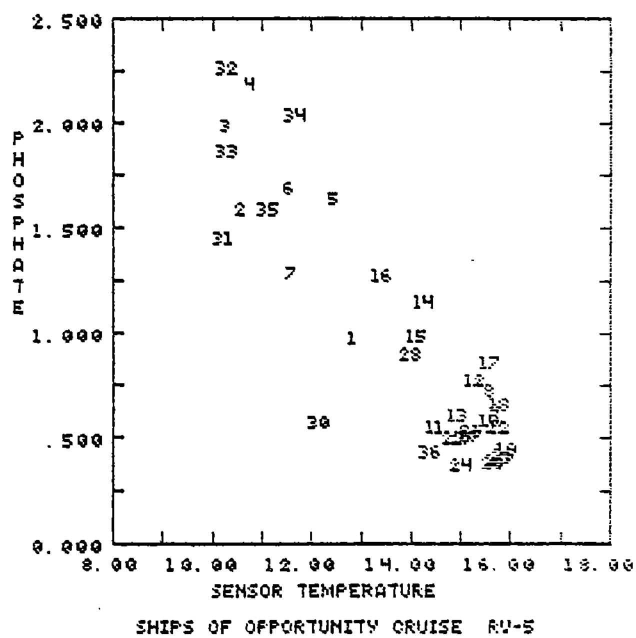


Figure 103. Phosphate concentration (μg.at/L) vs sensor temperature (^{o}C) - RV005.

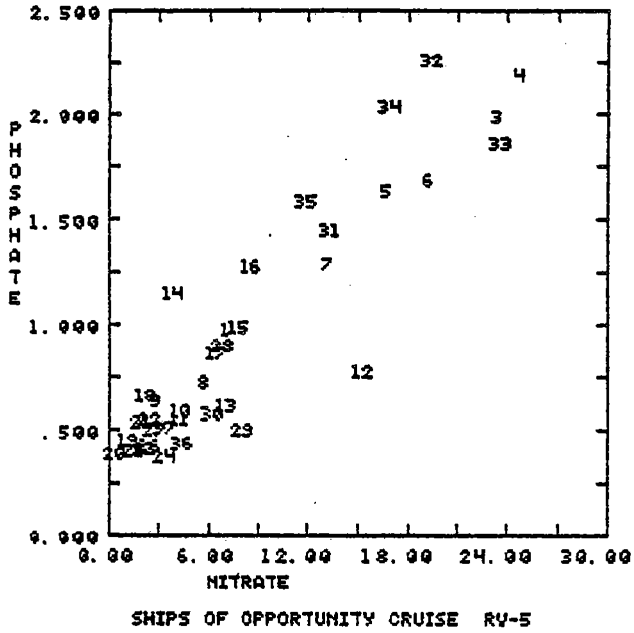


Figure 104. Phosphate concentration (µg.at/L) vs nitrate concentration (µg.at/L) - RV005.

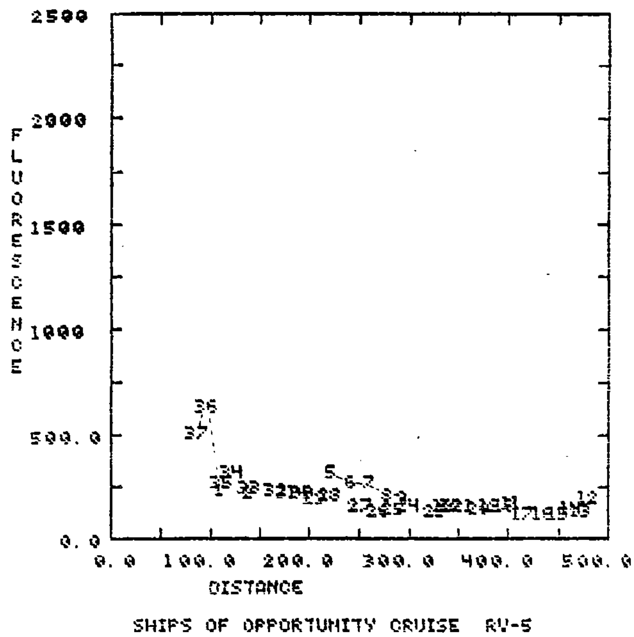


Figure 105. _in vivo_ fluorescence vs distance along cruise track - RV005.

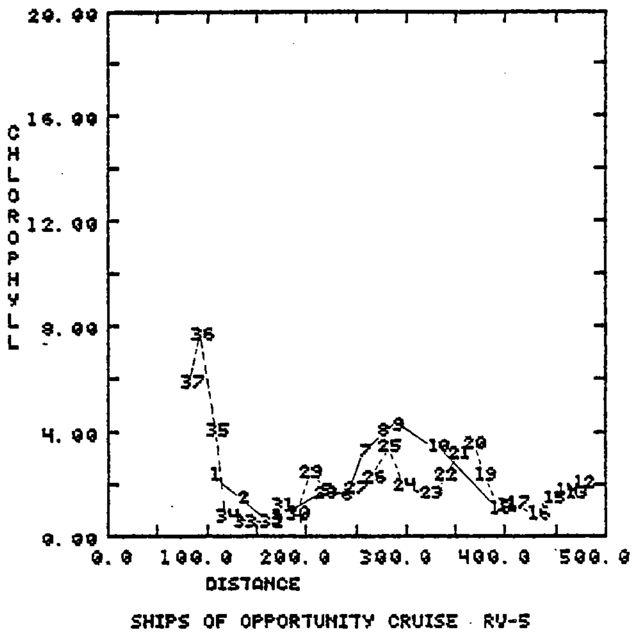


Figure 106. Chlorophyll a (mg/m^3) vs distance along cruise track - RV005.

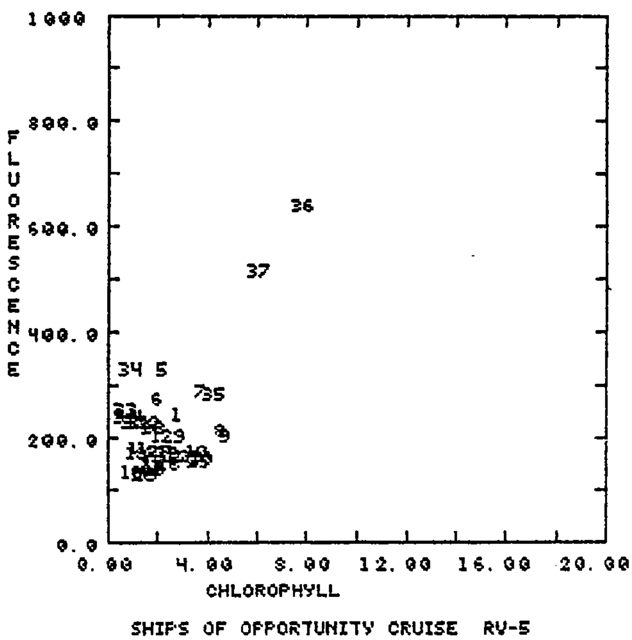


Figure 107. in vivo fluorescence vs chlorophyll a (mg/m^3) - RV005.

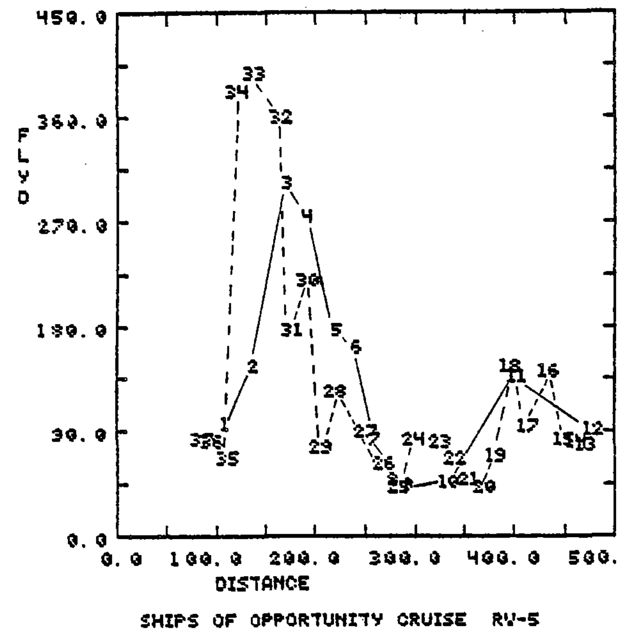


Figure 108. Fluorescence yield vs distance along cruise track - RV005.

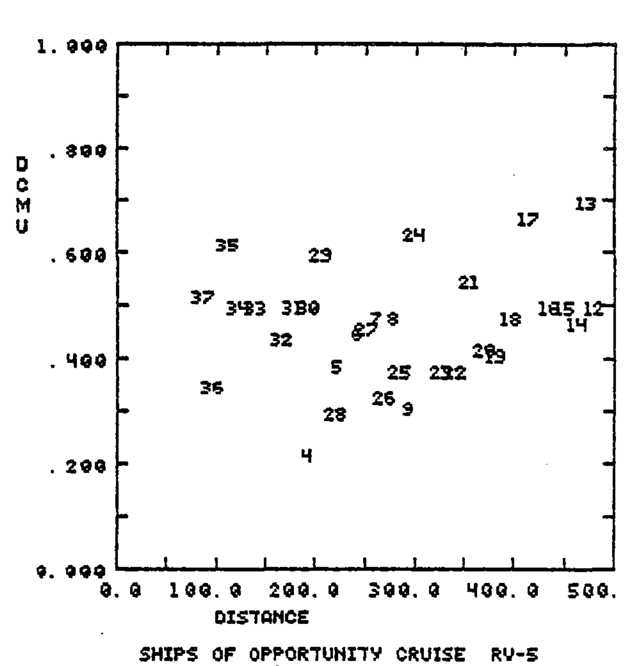


Figure 109. D.C.M.U. ratio vs distance along cruise track - RV005.

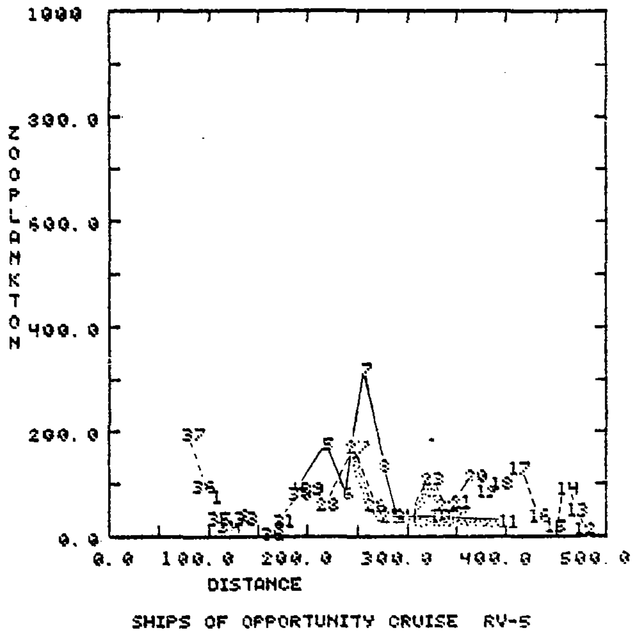


Figure 110. Zooplankton counts vs distance along cruise track - RV005.

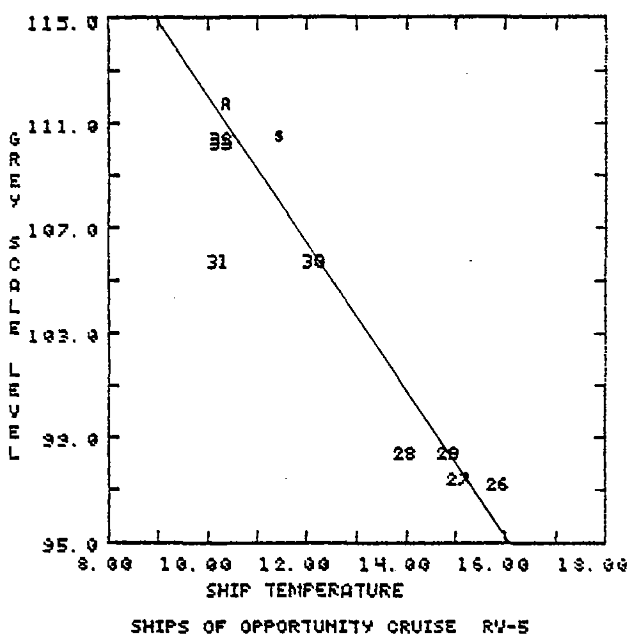


Figure 111. Satellite image grey scale number vs sensor temperature (^{o}C).

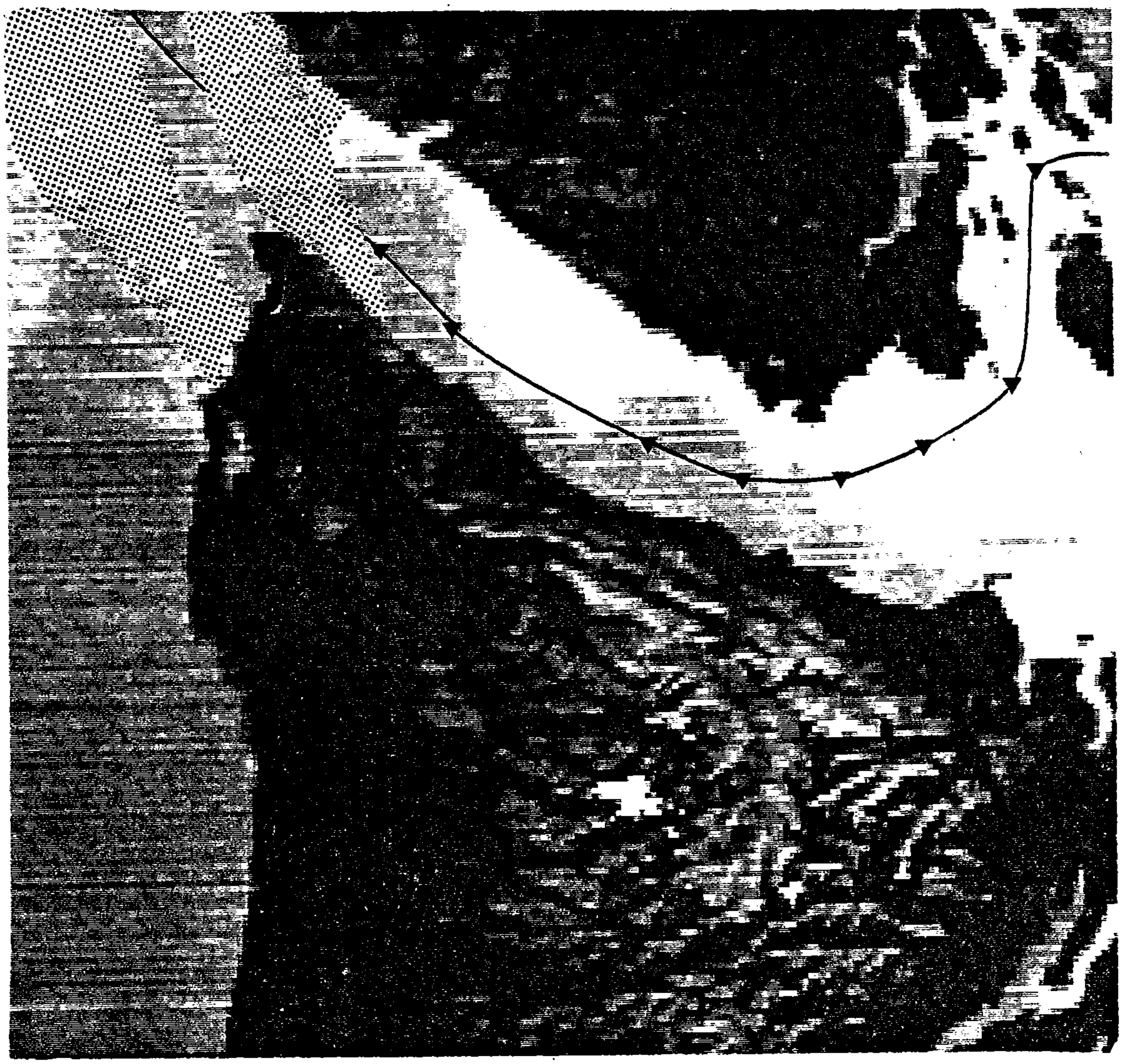


Figure 112. NIMBUS-7 thermal infra-red image for September 11,1979 (cruise RV005). Symbols indicate the approximate location of stations; stipple indicates cloud contamination. White represents coldest surface temperatures with warmer areas appearing as darker shades of gray/black.

Table 28; Multiple Correlation Table

SHIPS OF OPPORTUNITY CRUISE RV-5

	SEN T	SEN S	3 SAL	3 SIG	3 NO2	3 NO3	3 PO4	3 CHL	3 %CHL	SEN FL	3 FLYD	3 ZOO#
SEN T												
SEN S	-.17											
3 SAL	-.08	.88										
3 SIG	-.34	.99	.85									
3 NO2	-.83	-.06	-.13	.09								
3 NO3	-.86	.15	.18	.29	.83							
3 PO4	-.89	.22	.18	.37	.84	.91						
3 CHL	.40	-.70	-.61	-.74	-.23	-.45	-.48					
3 %CHL	.70	-.08	-.11	-.20	-.56	-.71	-.61	.51				
SEN FL	-.28	-.76	-.63	-.68	.42	.22	.17	.59	-.22			
3 FLYD	-.75	.16	.21	.28	.61	.80	.79	-.59	-.88	.19		
3 ZOO#	.13	-.17	-.15	-.18	.00	-.16	-.18	.33	.15	.27	-.28	

2.6 CRUISE RV006: October 20 - 30, 1979

2.6.1 Logistical Summary

The final cruise aboard the MV Rivtow Viking for the ships-of-opportunity feasibility study occurred from October 20 to 30, 1979. The tug and barge departed Center Bay bound for Nootka Sound at 0900 on October 22, 1979. As part of investigations into the problems plaguing the thermoconductivity sensor, which were thought to be partly due to ground loops between it and the fluorometer, zooplankton sensor, and ship ground, two separate data logging for conductivity and temperature were collected using Seakem's thermosalinograph and electronics while continuous data for zooplankton and chlorophyll fluorescence were collected using Seakem's monitoring equipment and Ocean Ecology's data logging system (Figure 113). Routine discrete samples were collected at regular intervals from Howe Sound to Pachena Point, where rough water caused a reduction in sampling frequency until Nootka Sound.

Following the log dump in Gold River at 0830 on October 24, 1979, the tug and barge proceeded north to Kyuquot Inlet to load in Amai Inlet. Continuous data and one discrete sample were collected in this region. Prevailing 60 knot SE winds kept the barge loaders away until 0900 on October 26, 1979. Loading was completed and the tug and barge were underway at 0800 on October 27, 1979 steaming twoard Nootka Sound. No discrete samples were collected although continuous information was again collected until about 1800 when Nootka Sound was reached. Difficulties while unloading the barge and damage to the barge generating plant delayed unloading for twenty-four hours and then forced the vessel to return to Vancouver with an empty barge, departing Gold River at 1200 on October 29, 1979. Continuous data and routine discrete samples were collected during the return voyage. The ship's cruise track and discrete station locations are plotted in Figure 114.

Discrete sampling was spread over the entire cruise length with the exception being the short leg up to Kyuquot Inlet and back to Nootka Sound. Rough weather and seasickness again produced several gaps in the routine discrete sampling program. Forty-one sets of in-line discrete samples (salinity, nitrite, nitrate, phosphate, chlorophyll, and phytoplankton) were collected. At thirty-nine stations the change of in vivo chlorophyll fluorescence following the addition of the herbicide DCMU was observed. Salinity samples were also collected, for comparison purposes, from a tap at the bubble trap air bleeder nearly cynchronously with those collected from the zooplankton net trap spigot. This tap was very near the Seakem thermosalinograph (Figure 12). A thermometer inside the bubble trap was used to record sea water temperature near the thermosalinograph.

The equipment was completely dismantled and packaged for removal on October 31, 1979. The technicians and all of their equipment were returned to Sidney via truck and ferry. The plumbing arrangements from the pitot tube into the forward hold were capped and the discharge lines were dismantled and the valve closed and plugged.

2.6.2 Equipment Malfunctions

In an attempt to explain some of the irregularities seen in previous salinity data we tested, the hypothesis that having several different power electrodes on a common seawater loop caused their respective grounds to be at different potentials. The Seakem data logger (#1 in Figure 113, powered by ship's 120 VAC, was connected to the Seakem thermosalinograph (#1) and to the Seakem digital printer (#1) which was powered by an internal nickel-cadmium battery pack). The logger and the printer were mounted in the same rack. Inputs to the Ocean Ecology data logger (#2), also powered by ship's 120 VAC, were the fluorometer and the zooplankton pulse processor (through the timed frequency counter), all of which were also powered by ship's 120 VAC. This logger output information to Ocean Ecology's digital printer (#2), powered by its own internal nickel-cadmium battery pack, and to the strip chart recorder. This logger-printer combination was fastened to the desk top adjacent to the rack. Thus, it was hoped that the thermosalinograph circuit was isolated from the fluorescence/zooplankton circuits.

During translation of the thermosalinograph magnetic tape record, the singal degenerated to the point where the translator could no longer recognize signal from noise and therefore stopped translation after about 30 hours of data. The translation of the fluorescence/zooplankton magnetic tape progressed similarly. However, eight hours into the cruise, at approximately Turn Point, the conductivity signal began to oscillate quite strongly and apparently about a mean (see Figure 115). This lasted for thirteen and one half hours whereupon this noise disappeared and the conductivity signal began to resemble that previously observed. This lasted for only four hours and the signal once again degenerated and was finally lost. The problem seems to have been with the data logger's ability to write to tape, since sensor temperature data were recorded by the digital printer at the time of the discrete sampling.

2.6.3 Data Summary and Discussion

Figures 115 and 116 show a gradual cooling from Howe Sound into Haro Strait and Juan de Fuca Strait as far as Sheringham Point (between stations 6.8 and 6.9) on the northbound passage. The cool (~10^{o}C) relatively saline (>32 ppt) waters at the western end of Juan de Fuca were separated from much warmer (~14^{o}C) coastal waters by a very sharp thermal front (Figure 115 and TS diagram Figure 118) which also marked the westward extent of the high nutrient Juan de Fuca waters (Figures 119 and 121) and the location of the largest concentrations of chlorophyll a encountered on this cruise (Figure 124). As with previous cruises, the chlorophyll a maximum occurred at the outer end of the Juan de Fuca water and straddling the boundary.

The 14^{o}C water present between Carmanah Point and Cape Beale (stations 6.9 to 6.12) contained low levels of nitrate and phosphate (Figures 120 and 122) although with decreasing temperatures north of Cape Beale, concentrations of both nutrients and chlorophyll a increased (Figure 124).

The return passage was not made until 7 days later and by this time the situation had changed somewhat, perhaps due in part to very strong southerly winds and sustained heavy rains which had been experienced in the interval. Except for cool (11.5^{o}) relatively fresh (31.85 ppt) water at station 6.16 and slightly warmer but less saline water at station 6.17 the waters along the outer coast were considerably warmer and about .5 ppt less saline than on the northbound passage. Nutrient concentrations were generally lower than on October 22, however nutrients, salinity, chlorophyll and to some extent temperature show that the waters present on October 30th were much less homogeneous. Two small areas with lowered salinity, end temperature and elevated nutrients which were present at stations 6.24 and 6.25, and at 6.29 may represent land drainage.

The position of the Juan de Fuca/oceanic water boundary at this time, and on the south side of the Strait of Juan de Fuca was considerably farther east than observed October 22 (Figure 116). In the infrared image (Figure 127) available for the following day, a large body of warm water can easily be seen hugging the Canadian shore. This warm water was not sampled on the northbound passage and it is possible that it represents coastal waters exiting the Straits after a minor incursion (this possibility is suggested by the shape of the eddy-like features in Juan de Fuca seen in the September 11 and July 14 images) associated with strong and persistent southerly winds the week previous. This image also shows cold runoff waters flowing northwards along the coast in response to the persistent southerly winds in the latter half of October. These cool (11.5 ^{o}C) less saline (31.85 ppt) waters were sampled at stations 6.15 to 6.17 off Nootka Sound).

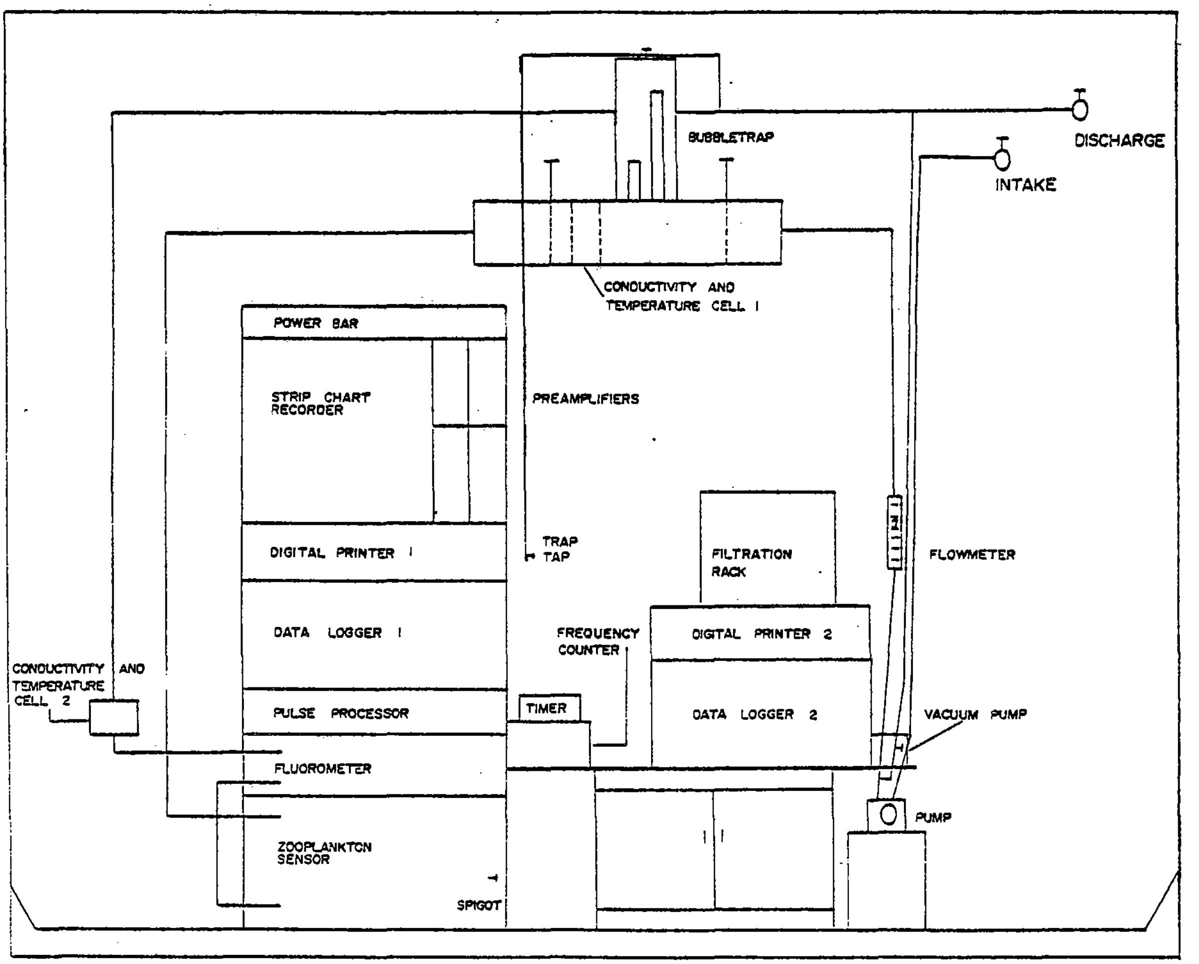


Figure 113. Instrumentation and plumbing arrangements as used for RV006.

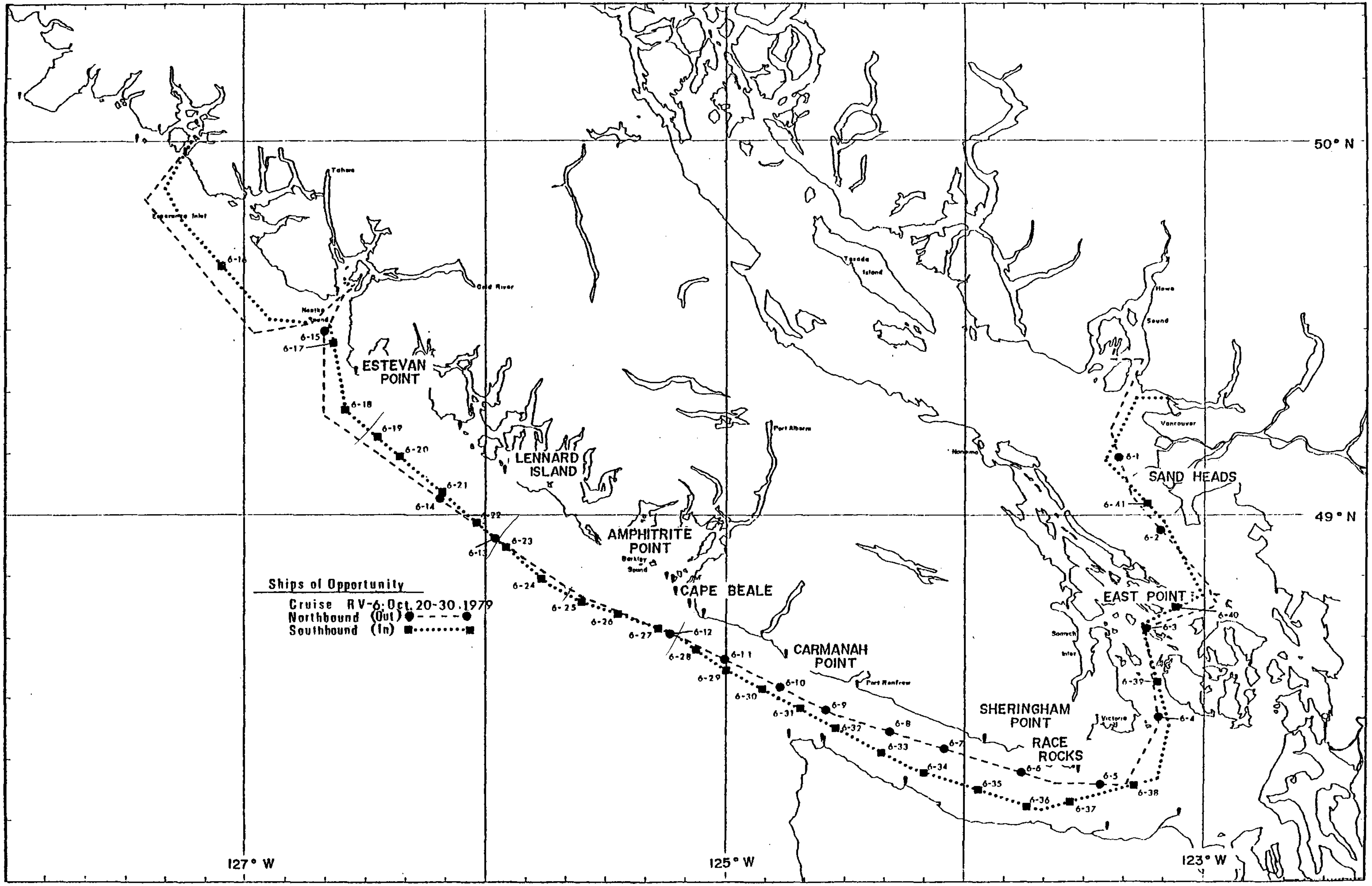


Figure 114. Cruise track and station locations - RV006.

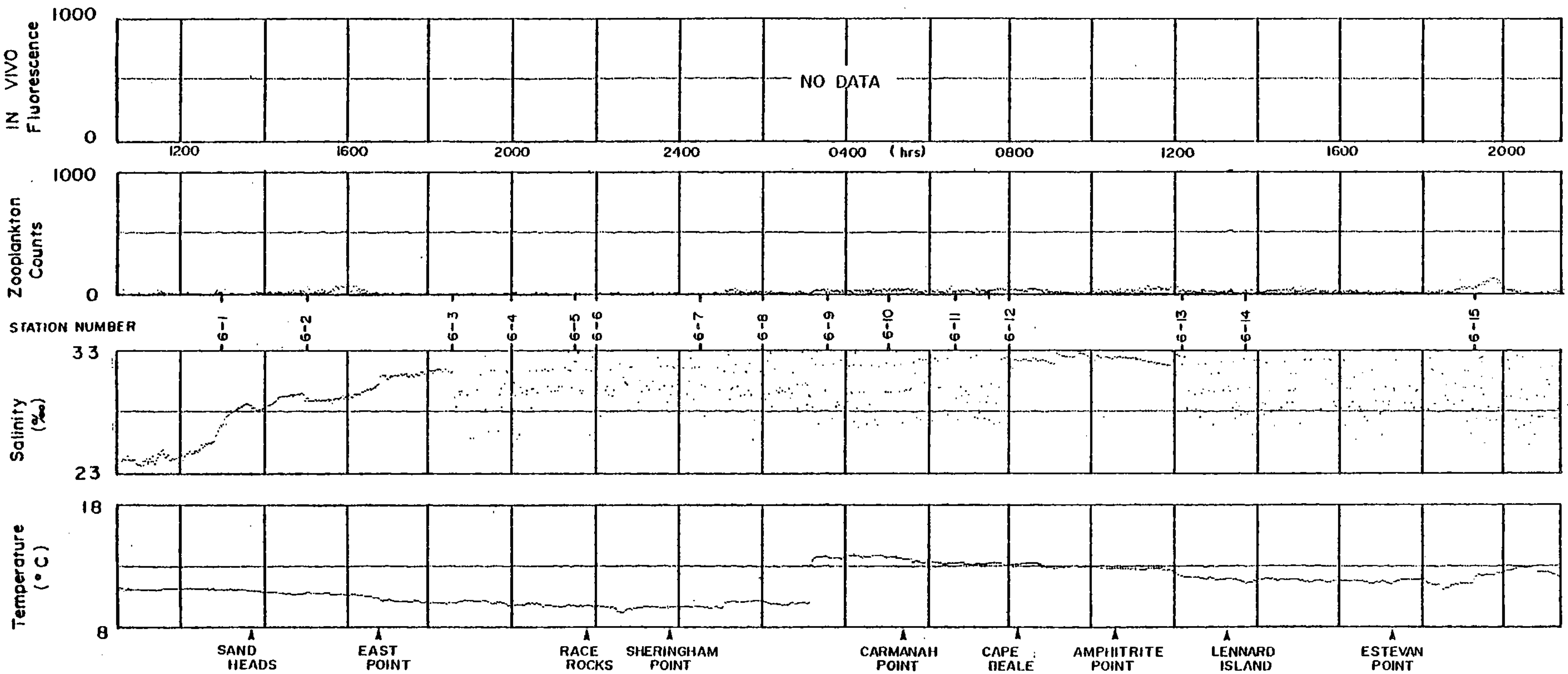


Figure 115. Continuous data record - RV006 (northbound).

Table 29;

REFERENCE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-6

STN #	CDATE	JDATE	TIME	LATITUDE	LONGITUDE	DIS
6.01	22/10/79	295	1300	49- 9.0 N	123-22.5 W	66.
6.02	22/10/79	295	1500	48-57.2 N	123-12.0 W	91.
6.03	22/10/79	295	1830	48-42.0 N	123-14.6 W	135.
6.04	22/10/79	295	2000	48-26.7 N	123-11.0 W	161.
6.05	22/10/79	295	2130	48-15.4 N	123-26.0 W	189.
6.06	22/10/79	295	2300	48-16.9 N	123-45.8 W	212.
6.07	23/10/79	296	30	48-21.2 N	124- 5.0 W	234.
6.08	23/10/79	296	200	48-24.0 N	124-20.0 W	253.
6.09	23/10/79	296	330	48-28.0 N	124-34.6 W	272.
6.10	23/10/79	296	500	48-31.6 N	124-45.0 W	287.
6.11	23/10/79	296	630	48-35.2 N	124-58.7 W	305.
6.12	23/10/79	296	800	48-40.5 N	125-13.7 W	325.
6.13	23/10/79	296	1210	48-55.6 N	125-57.5 W	388.
6.14	23/10/79	296	1344	49- 2.5 N	126-11.0 W	408.
6.15	23/10/79	296	1910	49-29.0 N	126-40.5 W	472.
6.16	24/10/79	297	1300	49-40.3 N	127-16.2 W	504.
6.17	29/10/79	302	1500	49-27.0 N	126-39.0 W	465.
6.18	29/10/79	302	1600	49-18.2 N	126-34.2 W	442.
6.19	29/10/79	302	1700	49-13.6 N	126-27.0 W	438.
6.20	29/10/79	302	1800	49-10.0 N	126-21.2 W	429.
6.21	29/10/79	302	1900	49- 4.0 N	126-11.1 W	409.
6.22	29/10/79	302	2000	48-58.8 N	126- 2.0 W	397.
6.23	29/10/79	302	2100	48-54.3 N	125-55.0 W	385.
6.24	29/10/79	302	2200	48-49.0 N	125-46.1 W	371.
6.25	29/10/79	302	2300	48-46.0 N	125-38.0 W	361.
6.26	29/10/79	302	2400	48-43.5 N	125-28.6 W	347.
6.27	30/10/79	303	100	48-41.4 N	125-18.6 W	335.
6.28	30/10/79	303	200	48-38.0 N	125- 9.8 W	319.
6.29	30/10/79	303	300	48-34.0 N	125- 1.0 W	307.
6.30	30/10/79	303	400	48-31.0 N	124-51.0 W	293.
6.31	30/10/79	303	500	48-27.6 N	124-41.8 W	281.
6.32	30/10/79	303	600	48-25.0 N	124-32.0 W	267.
6.33	30/10/79	303	700	48-21.2 N	124-21.2 W	253.
6.34	30/10/79	303	800	48-17.8 N	124-10.5 W	233.
6.35	30/10/79	303	900	48-15.6 N	123-56.0 W	221.
6.36	30/10/79	303	1000	48-13.0 N	123-42.1 W	208.
6.37	30/10/79	303	1100	48-13.8 N	123-32.0 W	196.
6.38	30/10/79	303	1200	48-15.9 N	123-18.0 W	180.
6.39	30/10/79	303	1330	48-32.6 N	123-11.3 W	151.
6.40	30/10/79	303	1500	48-44.9 N	123- 7.0 W	123.
6.41	30/10/79	303	1700	49- .4 N	123-14.5 W	87.

Table 30:

INLINE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-6

STN #	SEN T	SEN SAL	DIS SAL	SIG	NO2	NO3	PO4
6.01	11.14	–	27.33	–	.30	14.25	1.72
6.02	10.91	–	28.78	–	.35	20.76	1.89
6.03	10.10	–	30.80	–	.28	23.44	2.47
6.04	9.82	–	31.43	–	.30	29.77	2.24
6.05	9.79	–	31.54	–	.31	24.56	2.08
6.06	9.69	–	31.76	–	.31	26.72	2.94
6.07	9.70	–	31.74	–	.45	24.42	2.60
6.08	10.17	–	32.41	–	.39	26.64	3.31
6.09	13.80	–	31.80	–	.19	4.13	.95
6.10	13.88	–	31.86	–	.26	8.92	.89
6.11	13.35	–	32.22	–	.20	7.89	.76
6.12	13.22	–	32.22	–	.19	6.50	1.05
6.13	12.27	–	32.11	–	.28	9.53	1.21
6.14	11.71	–	32.26	–	.29	12.76	2.02
6.15	11.65	–	31.72	–	.42	17.80	1.73
6.16	11.49	–	31.85	–	.45	19.97	2.28
6.17	11.86	–	30.48	–	.45	13.17	1.51
6.18	12.92	–	32.11	–	.21	8.24	1.36
6.19	12.69	–	32.10	–	.23	10.18	1.23
6.20	13.26	–	31.80	–	.18	5.96	1.39
6.21	13.28	–	31.78	–	.23	6.57	.96
6.22	13.11	–	31.75	–	.23	6.51	.99
6.23	13.09	–	31.66	–	.24	6.70	.62
6.24	12.92	–	31.53	–	.24	8.75	1.55
6.25	13.84	–	31.52	–	.21	11.94	.58
6.26	13.33	–	31.78	–	.19	6.43	.63
6.27	13.46	–	31.95	–	.22	6.58	.42
6.28	13.42	–	31.69	–	.20	6.39	.57
6.29	13.10	–	30.88	–	.23	16.72	.74
6.30	13.16	–	31.45	–	.30	9.05	.51
6.31	13.13	–	30.63	–	.43	11.24	1.00
6.32	13.07	–	30.66	–	.26	7.83	.62
6.33	13.10	–	30.69	–	.25	6.69	.68
6.34	12.25	–	30.79	–	.28	11.12	1.52
6.35	13.03	–	30.79	–	.35	10.74	.74
6.36	12.88	–	30.85	–	.27	8.26	1.65
6.37	11.20	–	31.02	–	.28	13.25	2.12
6.38	10.50	–	31.53	–	.34	21.92	3.62
6.39	10.25	–	31.25	–	.38	22.47	1.62
6.40	10.12	–	30.72	–	.26	24.32	3.58
6.41	10.50	–	24.49	–	.35	16.13	1.20

Table 31:

INLINE DATA FOR SHIPS OF OPPORTUNITY

CRUISE RV-6

STN #	CHL	PHAEO	% CHL	SEN FL	FL YD	ZOO #	DCMU #
6.01	2.44	1.68	.59	143.	58.69	5.	.55
6.02	1.50	1.56	.49	127.	84.54	15.	.39
6.03	.86	.88	.50	108.	125.29	3.	.39
6.04	.64	.58	.52	120.	188.93	15.	.33
6.05	.61	.45	.58	126.	205.52	5.	.40
6.06	.61	.41	.60	137.	224.59	2.	.40
6.07	15.19	.61	.71	143.	9.41	19.	.43
6.08	12.05	.42	.74	137.	11.37	24.	.64
6.09	8.99	.45	.67	135.	15.01	33.	.59
6.10	5.49	2.95	.65	151.	27.50	39.	.62
6.11	1.98	1.23	.62	130.	65.74	45.	.55
6.12	2.25	1.38	.62	133.	59.11	39.	—
6.13	—	—	—	140.	—	32.	—
6.14	9.43	5.14	.65	143.	15.16	28.	.40
6.15	1.96	1.61	.55	161.	82.12	48.	.50
6.16	22.39	15.77	.59	144.	6.43	54.	.41
6.17	1.69	1.34	.56	139.	82.24	59.	.66
6.18	8.28	3.78	.69	141.	17.03	44.	.42
6.19	3.44	1.54	.69	132.	38.36	29.	.41
6.20	8.56	2.81	.75	141.	16.48	41.	.42
6.21	5.95	1.98	.75	131.	22.01	36.	.67
6.22	6.05	2.25	.73	131.	21.65	42.	.52
6.23	5.17	1.62	.76	132.	25.54	44.	.56
6.24	5.06	1.84	.73	133.	26.31	70.	.47
6.25	3.90	1.90	.67	143.	36.65	8.	.42
6.26	3.80	2.34	.62	124.	32.64	19.	.31
6.27	3.95	1.89	.68	125.	31.61	25.	.57
6.28	2.66	1.74	.60	128.	48.15	33.	.70
6.29	2.83	1.65	.63	127.	44.88	29.	.63
6.30	1.12	.88	.56	129.	115.64	41.	.50
6.31	11.12	3.94	.74	131.	11.78	25.	.47
6.32	4.35	1.40	.76	131.	30.11	25.	.38
6.33	2.76	.79	.78	129.	46.69	19.	.40
6.34	2.76	1.03	.73	136.	49.29	33.	.38
6.35	2.77	.87	.76	131.	47.35	30.	.52
6.36	2.09	.79	.73	134.	64.21	30.	.47
6.37	1.74	.77	.69	146.	83.95	11.	.49
6.38	2.60	2.26	.54	165.	63.38	13.	.29
6.39	1.65	.80	.67	170.	102.72	14.	.35
6.40	1.43	.79	.64	175.	122.39	10.	.62
6.41	2.44	1.90	.56	203.	83.35	28.	.39

Table 32:

Extract from Ship's Log - Cruise RV006, October 20-30, 1979

Date	Time	Landmark x distance abeam (nm)	Ship's Heading (° True)	Speed made good since last entry	Remarks (Technicians' observations in brackets)
Oct. 20, 1979	1950	Malaspina St. alongside			
	2150	Roger Curtis Run slow			
	2300	Gower Pt.			clear, calm, smooth
Oct. 21, 1979	0045	White Rocks x 1.5 run slow		4	
	0200	swing around off Trail Island			waiting for 0700 dump
	0500	Gower Pt. x 0.6		4.2	
	0615	Cotton Pt.			
	0800	Leslie Ann assist.			
	0808	valves open			
	0833	clean dump			
	1000	all secure Center Bay Smitty assist.			
Oct. 22, 1979	0900	letting go Center Bay			
	0925	away Center Bay			
	1120	Roger Curtis x 0.4	175		
	1330	T.A. Bouy x 1	135		
	1500	Tswwassen x 4.1	136	6.7	S.E. chop
	1640	East Pt. x 2	var.	6.8	fresh S.E. chop
	1830	Turn Pt. x 0.5	171		light S.E.
	1930	Kelp Reef x 0.85	176	8.3	
	2020	Discovery Island x 1	211	8.7	
	2155	Race Rocks x 2	268	7.0	calm smooth
	2225	Beechy Head			run out 7 wraps
	2345	Sheringham Pt. x 3.4	288	9.8	
Oct. 23, 1979	0255	San Juan Pt. x 5.4	292.6	7.4	E. 15 chop, low S.W.
	0507	Buoy J. x 1.9	291.6	5.1	N.E. 15 chop, low S.W.

Table 32: - cont'd

Date	Time	Landmark x distance abeam (nm)	Ship's Heading (° True)	Speed made good since last entry	Remarks (Technicians' observations in brackets
(cont'd)					
Oct. 23, 1979	0730	Pachena Pt. x 5	291	6.9	S.E. 15-20 MSWS*
	0815	Cape Beale x 7.2	295	7.9	
	1030	Amphitrite Pt. x 8.7	305	7.3	E. 15-20, MHSWS
	1320	Lennard Island x 9.3	305	7.0	
	1530	Ratall Pt. x 10.8	var.	7.2	MSWS
	1715	Estevan Pt. x 9.2	334	7.7	
	1820	Split Cape x 10.2	360	8.7	S.E. 20 & LMSWS
	2030	Nootka Light x 0.8	050	7.0	LSWS
Oct. 24, 1979	0830	clean dump			
	1014	Anderson Pt.			
	1053	Nootka Light x 0.7	225	10.2	N.E. 15-20
	1125	all clear Nootka	270		
	1150	Bajo Pt. x 5.5	312		N.E. 20, choppy
	1355	Tatcher Pt. x 6.2	338	12	
	1515	Rugged Pt. x 0.25		9.3	barometer dropping fast
	1635	anchored Amai Inlet			
Oct. 25, 1979		full anchors, waiting			Imp. Tofino reports S.E.60
Oct. 26, 1979	0900	loaders aboard			
	2200				Gale S.W.
Oct. 27, 1979	0714	away loaded barge			
	0815	Rugged Pt.	215		MSWS
	0845	Kyuquot Buoy x 0.2	197		MSWS
	1000	Rugged Pt. Big x 8	160	4.5	SSE 15-20,MSWS
	1110	Catala Island x 10	160	4.5	
	1320	Ferrier Pt. x 9.1	140	5.0	S.W.20, MSWS
	1800	Nootka x 0.7	050		
	1830	Zuciarte Channel			

* MHSWS moderate/heavy SW swell; LMSWS light/moderate SW swell

Table 32: - cont'd

Date	Time	Landmark x distance abeam (nm)	Ship's Heading (° True)	Speed made good since last entry	Remarks (Technicians' observations in brackets)
Oct. 28, 1979	0832	logs fall off top			
	0900	no dump			
	1045	loaders aboard			blow out light plant engine
	1430	start unloaded			
	1800	stop/dark			
Oct. 29, 1979	1205	underway			
	1400	Nootka Light x 1	205		
	1417	POS x 2.1	185		
	1525	Estevan Pt. x 2.8	161	9.3	S.E. 25 choppy, low SW
	1615	towline out			SE 25-30, low SW
	1735	Rafael Pt. x 8.8	134	6.8	SE 25-30, low SW
	1845	Cleveland Island x 7.3	134	7.0	SE 25-35, low SW
	1940	Lennard Island x 8.8	134	7.85	SE 20-25, low SW
	2030	Box Island x 10.25	128	7.44	SE 20-25, low SW
	2235	Amphitrite Pt. x 10	117	6.5	ESE 30-35, low SW
Oct. 30, 1979	0200	Pachena Pt. x 5.3	123.6	6.4	E 30-35 choppy
	0440	Buoy J. x 1.2	116.6	6.4	
	0750	Slip Pt. x 3	116	8.1	E 20-25, chop and swell
	0905	Tree Bluff x 3.6	093	9.2	chop and swell
	1025	Buoy J.A. x 1.3	076	9.0	E 25-30, chop and swell
	1108	Race Rocks x 3.8	076	9.2	E 20, chop and swell
	1120				in towline 2.5 wraps
	1245	Discovery Island x 3.1		10.0	E 15, choppy

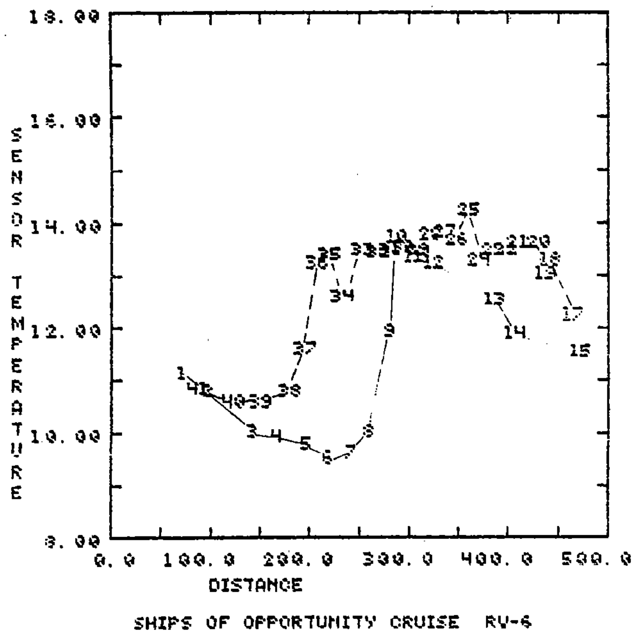


Figure 116. Sensor temperature (^{o}C) vs distance along cruise track - RV006.

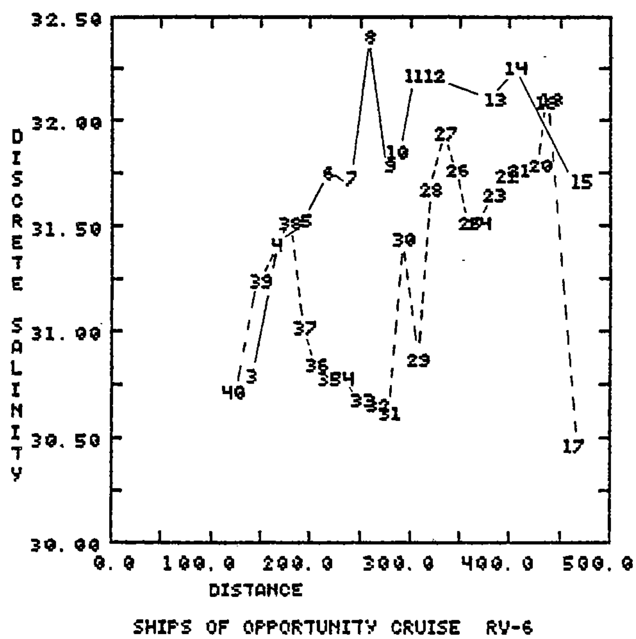


Figure 117. Discrete salinity (ppt) vs distance along cruise track - RV006.

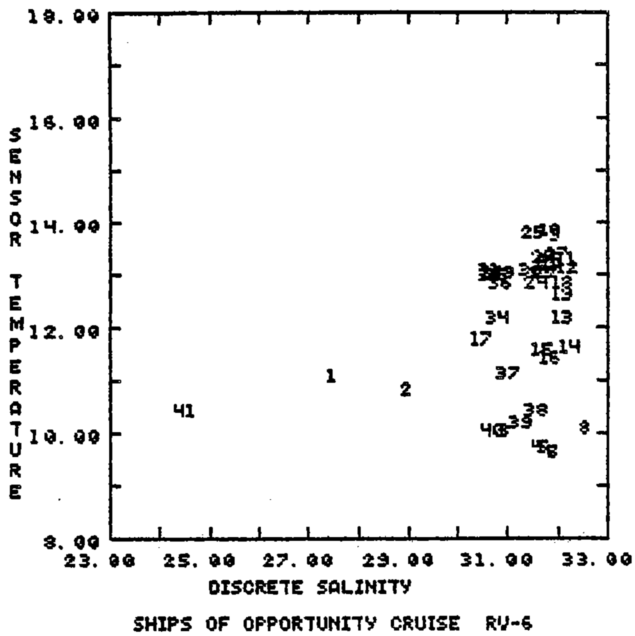


Figure 118. Sensor temperature (^{O}C) vs discrete salinity (ppt) - RV006.

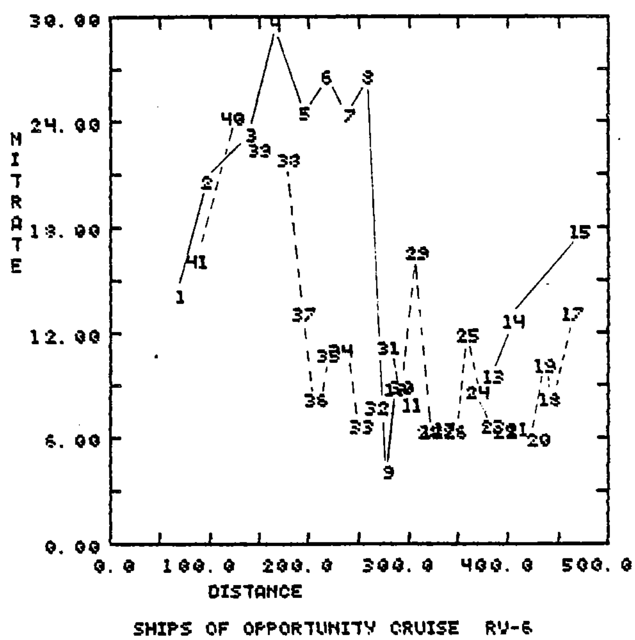


Figure 119. Nitrate concentration (μg.at/L) vs distance along cruise track - RV006.

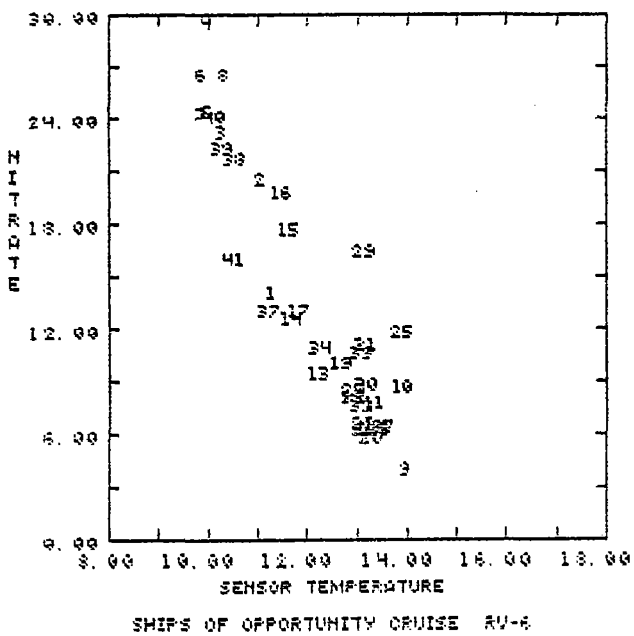


Figure 120. Nitrate concentration (μg.at/L) vs sensor temperature (^{o}C) - RV006.

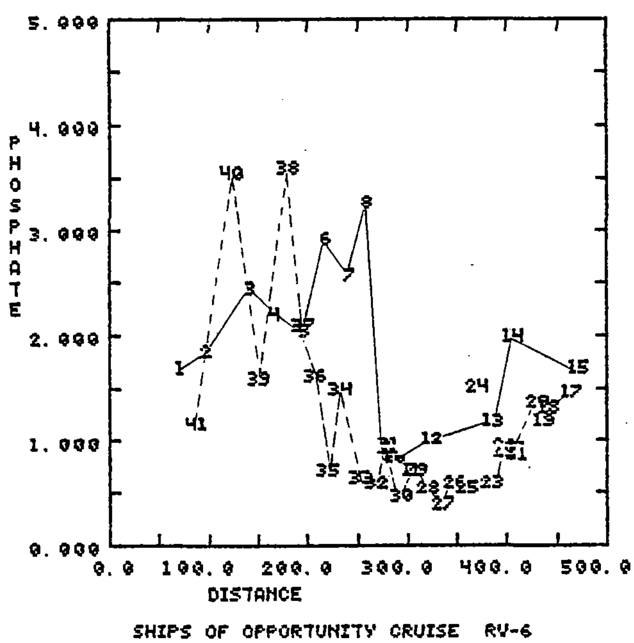


Figure 121. Phosphate concentration (μg.at/L) vs distance along cruise track - RV006.

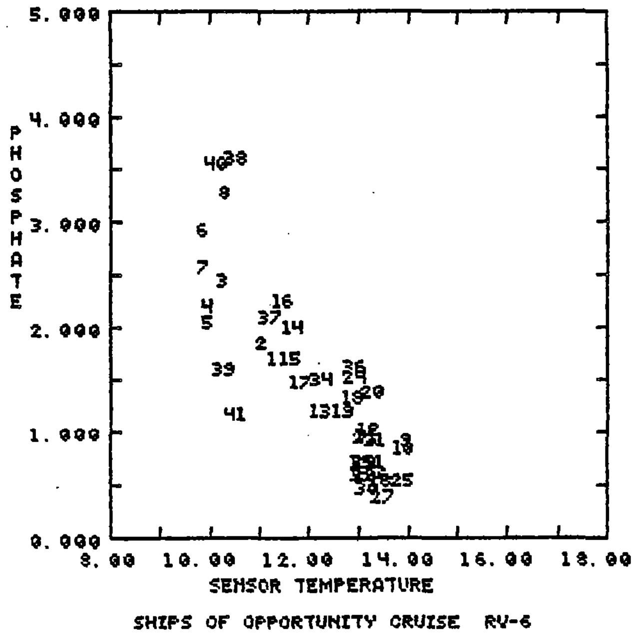


Figure 122. Phosphate concentration (µg.at/L) vs sensor temperature (°C) - RV006.

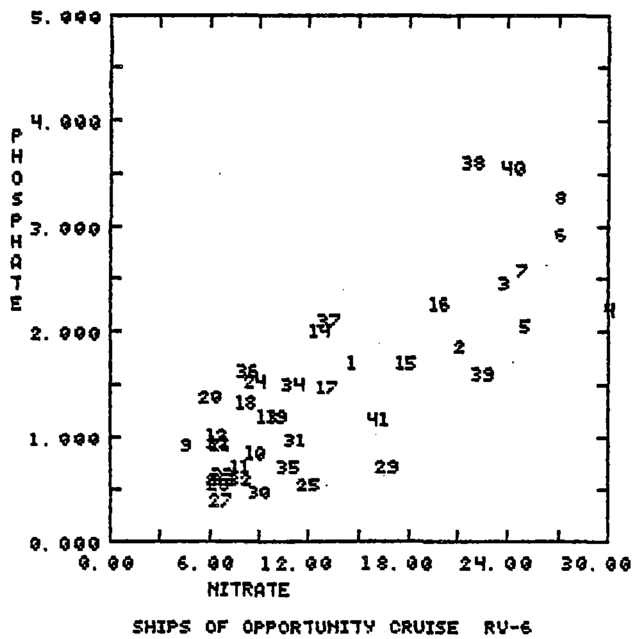


Figure 123. Phosphate concentration (µg.at/L) vs nitrate concentration (µg.at/L) - RV006.

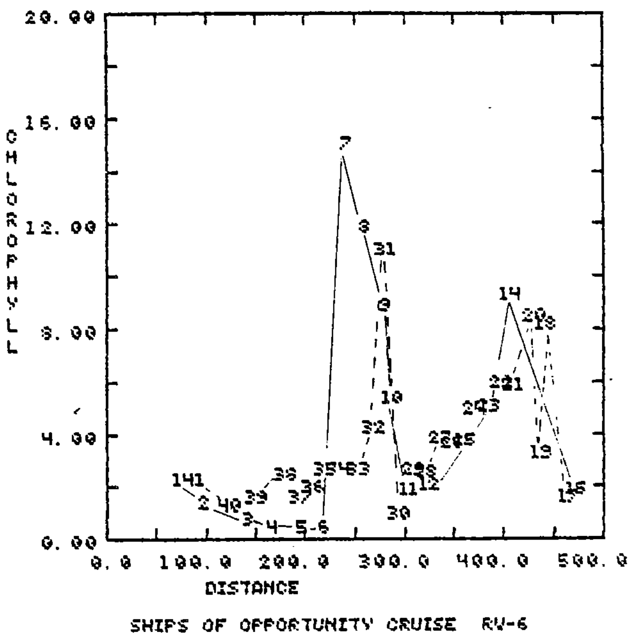


Figure 124. Chlorophyll a (mg/m^3) vs distance along cruise track - RV006.

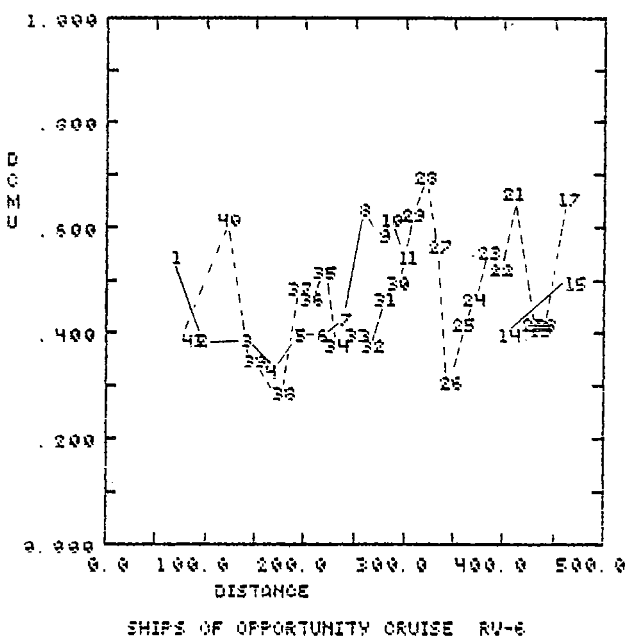


Figure 125. D.C.M.U. ratio vs distance along cruise track - RV006.

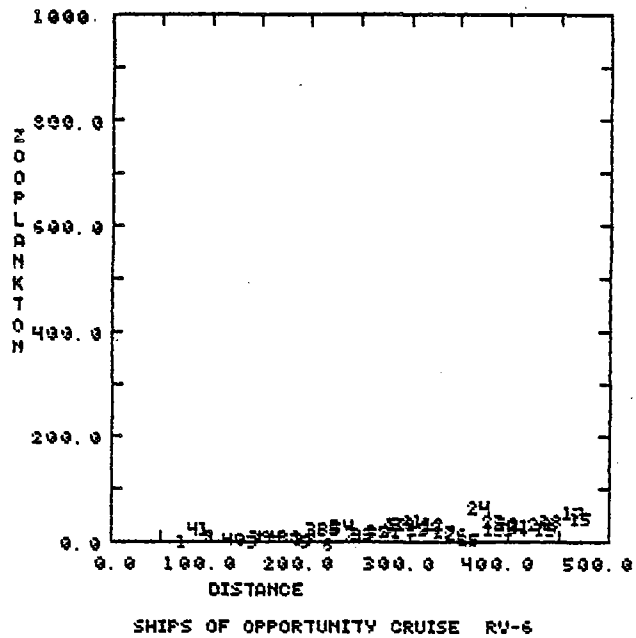


Figure 126. Zooplankton counts vs distance along cruise track - RV006.

FIGURE 127 NOAA-6 Satellite Thermal Infrared Image for October 31,1979

Table 33: Multiple Correlation Table

SHIPS OF OPPORTUNITY CRUISE RV-6

	SEN T	SEN S	3 SAL	3 SIG	3 NO2	3 NO3	3 PO4	3 CHL	3 %CHL	SEN FL	3 FLYD	3 ZOO#
SEN T												
SEN S	-											
3 SAL	.26	-										
3 SIG	-	-	-									
3 NO2	-.59	-	-.25	-								
3 NO3	-.92	-	-.13	-	.60							
3 PO4	-.84	-	.01	-	.46	.81						
3 CHL	.06	-	.25	-	.29	-.01	.12					
3 %CHL	.45	-	.27	-	-.24	-.49	-.31	.32				
SEN FL	-.31	-	-.46	-	.31	.22	.30	.02	-.10			
3 FLYD	-.61	-	-.15	-	.14	.60	.38	-.62	-.57	.01		
3 ZOO#	.52	-	.23	-	-.03	-.52	-.37	.31	.21	-.02	-.48	

3. SYNTHESIS AND DISCUSSION

A few generalizations can be made about the physical structure, nutrient chemistry and plankton biomass of Juan de Fuca Strait and the coastal areas of southwest Vancouver Island based on our observations.

The most important fact to note is the very considerable export of dissolved nutrients to the inner shelf area north along Vancouver Island by pools of cold water generated in eastern Juan de Fuca. These nutrients enter Juan de Fuca in saline deep water and become mixed into surface waters in the turbulent eastern region of the Strait (Herlinveaux and Tully, 1961) where they then are moved seaward in the surface gravitational flow. This constant supply of water having nitrate concentrations in the order of 25 µg at/L and phosphate concentrations near 2 µg at/L will have considerable effect on the productivity of the inner shelf.

In sections 2.1 through 2.6 it has been pointed out that the maximum phytoplankton development as measured by chlorophyll _a_ concentrations occurs near the boundary between the cold, saline nutrient laden waters exiting Juan de Fuca along the Canadian shore, and the warmer, less saline and nutrient-poo coastal water. Generally, chlorophyll _a_ maxima were encountered at the outer edge of the cold water although in July and September when chlorophylls less then 5 mg/m^3 constituted the maxima, these were situated on a wide area to the north of the boundary.

The continuous ship data and satellite imagery confirm the fact that the cold Juan de Fuca water moves seaward along the Canadian shore. In three months warm coastal water can be seen penetrating eastward into the straits, with varying degrees of cross channel movement apparent. This type of incursion by coastal waters has been explained by Holbrook and Halpern (1978) to be the result of wind-induced sea surface height fluctuations along the outer coast of Washington State and the mouth of Juan de Fuca. They reported strong coherence between southerly winds measured at Tatoosh Island (northwest tip of Washington State) and eastward flowing surface currents in Juan de Fuca. Strong southerly wind such as experienced at the time of RV006 (see bridge log extracts in Table 32) can be expected to raise the sea level along the coast through onshore Ekman transport. This decreases the sea surface slope in the strait slowing seaward surface flow and allows coastal waters to flow in along the American coast over time scales of 3-10 days.

These migrations and cross channel positions of the Juan de Fuca boundary can be seen graphically in Figure 128 which attempts to put all six cruises into temporal perspective. Data from light stations, other research ships and one commercial troller have been added where available for Juan de Fuca and north to Nootka Sound in a band 30 km wide. Some difficulties arise in contouring the data especially between Race Rocks and Carmanah Point where cross channel variation exists, such as evident in satellite imagery; in this region the contours represent contemporaneous as well as temporal variability along the vertical axis. Where light station data from the north side of the strait do not agree with ship data from the south side, contours follow the northern data. Keeping this in mind, it is possible to identify at least two and perhaps three incursions of warm coastal water into Juan de Fuca as far as Sheringham Point.

The first incursion appears in July. The cross channel variation at this time is visible in both this figure and in Figure 67 (the July 14 TIROS-N image). The second incursion occurred in September. The ship data suggest an eastward flow along the eastern side, followed by a cross channel flow which caused Sheringham temperatures to rise. This interpretation is supported by the shape of the warm tongue in Figure 112, the September 11 image. A third invasion was in progress at the time of the October cruise. The penetration at this time along the southern shore was almost to the latitude of Race Rocks, and seems to have been in the process of returning seaward when the image in Figure 127 was acquired on October 31st. Whether these are actually isolated, temporary phenomena or a normal occurrence in Juan de Fuca is not clear from these widely spaced cruises. Compared to the position of the boundary during the July, September and October cruises the position in August was a major extension.

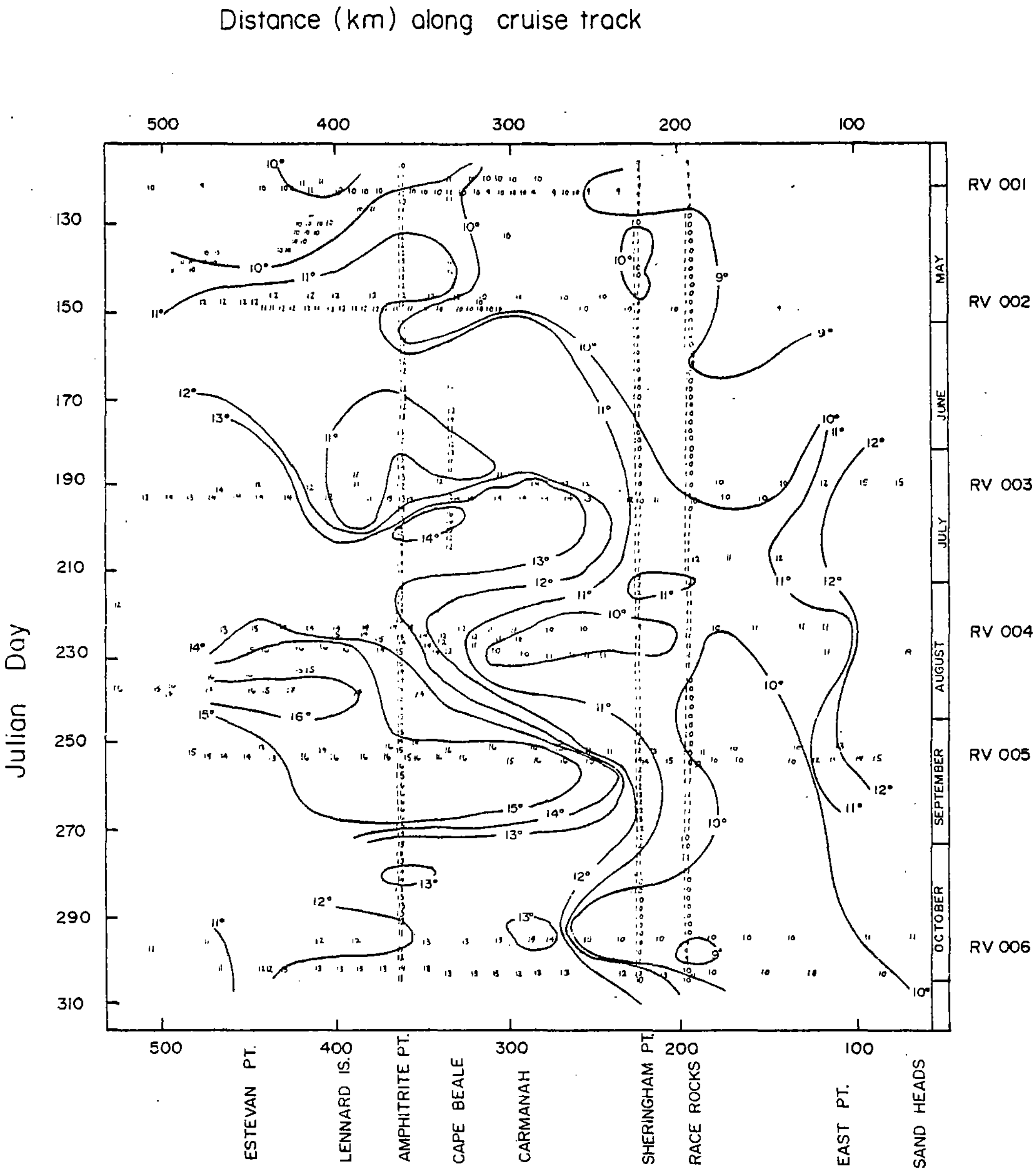


Figure 128. Variations in sea surface temperature in the study area throughout the sampling period (May - November, 1979). Data were compiled from this study and observations from P.B.S., Ocean Ecology, lighthouses and a commercial fisherman.

As expected from earlier discussions, the distribution of surface nitrate concentration in time and space (Figure 129) mirrors the temperature distribution. This is probably a result of a more direct causal relationship between nutrient concentrations and turbulence. Where turbulence is reduced, and vertical stratification is possible, such as in the waters off the outer coast, surface temperatures rise during the season. Phytoplankton growth in these stratified waters maintain the nutrient concentrations at very low levels. In the very turbulent regions of eastern Juan de Fuca, surface temperatures are low and nutrient concentrations are high due to a surface-to-bottom mixing. Sustained phytoplankton growth necessary to build up elevated chlorophyll concentrations will probably not be possible because the cells will be mixed to well below their compensation depth.

These relationships between surface temperature and nutrient concentration can of course be altered in the presence of strong phytoplankton growth. Cruise RV003 is an example of a high correlation in the absence of much chlorophyll, while cruise RV004 presents a case where most of the stations where very high chlorophyll concentrations were encountered exhibited lower nitrate concentrations than would be expected from the NO_3 vs T plot.

The NO_3 and PO_4 vs T relationship also changes throughout the season, as the surface waters off the outer coast warm up. Examining each of the NO_3 vs T plots presented earlier and Figure 129, the time/distance/nitrate plot, will show that the nitrate concentration and temperatures of the surface waters of eastern Juan de Fuca vary little (24 - 30 μg at/L and 9 - 10°C) throughout the summer. In contrast the temperatures off the outer coast near Amphitrite for example, range from 10°C in late April to 16°C or more in August and September while nitrate concentrations are less than 1 μg at/L until October. The isolated pocket of 20 μg at/L which was observed off Amphitrite - Cape Beale in early July was an upwelling-like event. Our surface data can say no more about this,however three dimensional surveys carried out by the Ocean Ecology Group, I.O.S. at this time show a doming of the isopycnals,not uplifting against the coast (K. Denman, personal communication).

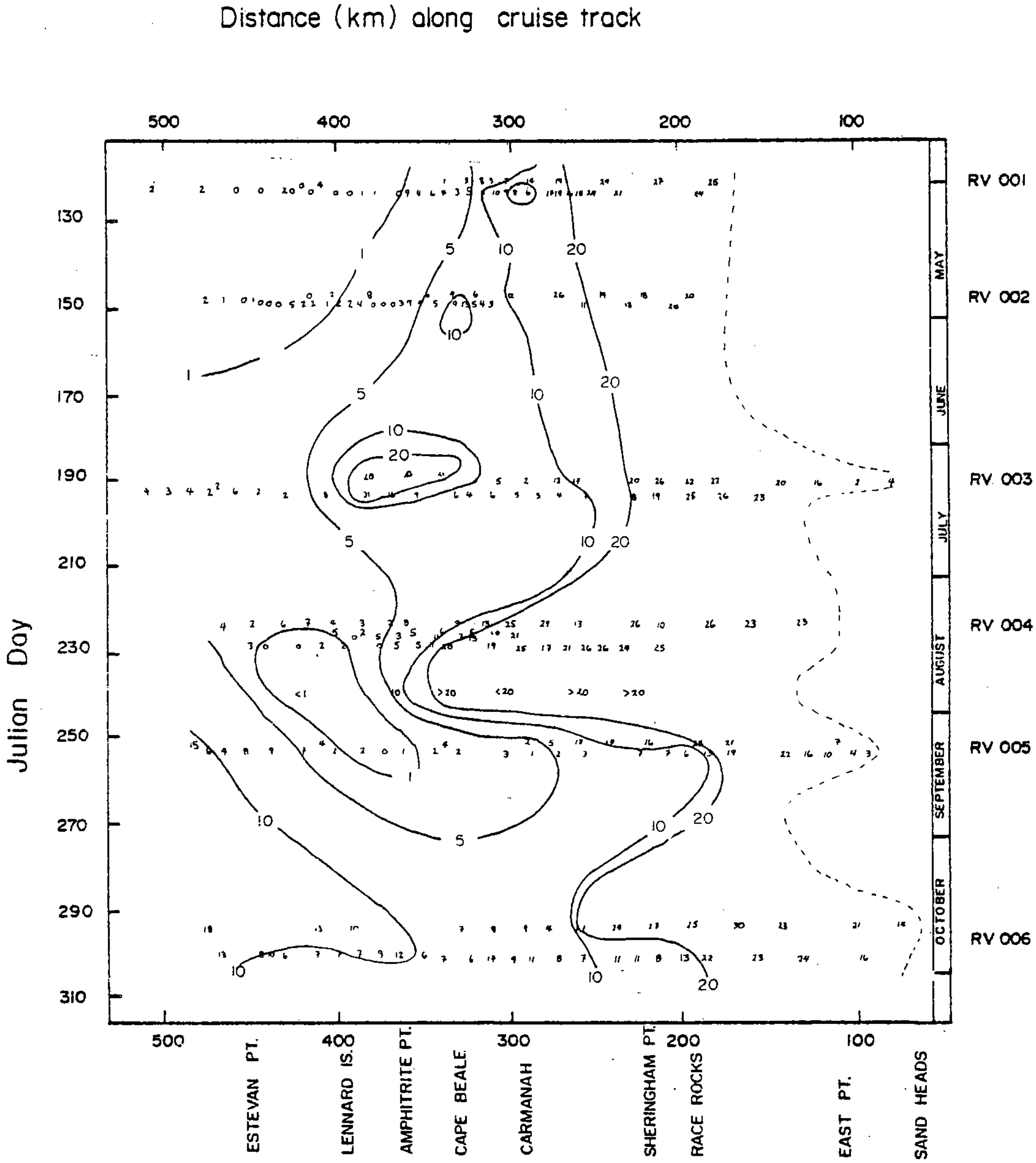


Figure 129. Variations in surface nitrate concentration (µg.at/L) in the study area throughout the sampling period (May - November, 1979).

Figure 130 summarizes the distribution of phytoplankton abundance (chlorophyll a concentrations) in the study area between April and October, illustrating the relative productivity of the waters off the mouth of the Juan de Fuca system and the changes observed during the study period.

During the first cruise at the end of April, chlorophyll a concentrations were everywhere above 2 and 3 mg/m^3 on the outer coast, with several patches above 10 mg/m^3. Nitrate concentrations were near zero at many stations north of Amphitrite Point and it is possible the generally elevated phytoplankton standing crop observed along the cruise track between Sheringham and Estevan Point represents the spring bloom along the outer coast. More closely spaced cruises beginning earlier in the year are required. Little production was evident within the cold, saline Juan de Fuca waters at this time.

In late May, similar high chlorophyll a concentrations were observed, but at that time a bloom at the outer edge of the Juan de Fuca water was responsible. Contrary to the impression given by the contouring of RV001 and RV002 data, the May chlorophyll maximum was not related to that in April, it being in a distinctly different water mass.

By the time of the July cruise, standing crops were lower (1-4 mg/m^3) over the entire area, but a small maximum was observed in conjunction with the boundary which was situated at that time just seaward of Sheringham Light. The nutrients supplied to the coastal area by the 'upwelling' event which took place in June and July, off Lennard Island - Amphitrite Point may have been responsible for a very intense bloom encountered in late July off Cape Beale by Seakem personnel carrying out other work. Since neither temperature or salinity data are available at this time it is not clear whether this bloom was in coastal or Juan de Fuca water, and the contouring around this and the cruise RV004 data may be misleading. In August there was a broad area of mixing between the coastal and Juan de Fuca waters exhibiting high chlorophyll concentration. We interpret the data from cruise RV004 and the airborne chlorophyll and temperature surveys conducted at the time (Borstad and Brown, 1979) to indicate that this was production resulting from Juan de Fuca nutrient export. A small isolated patch of

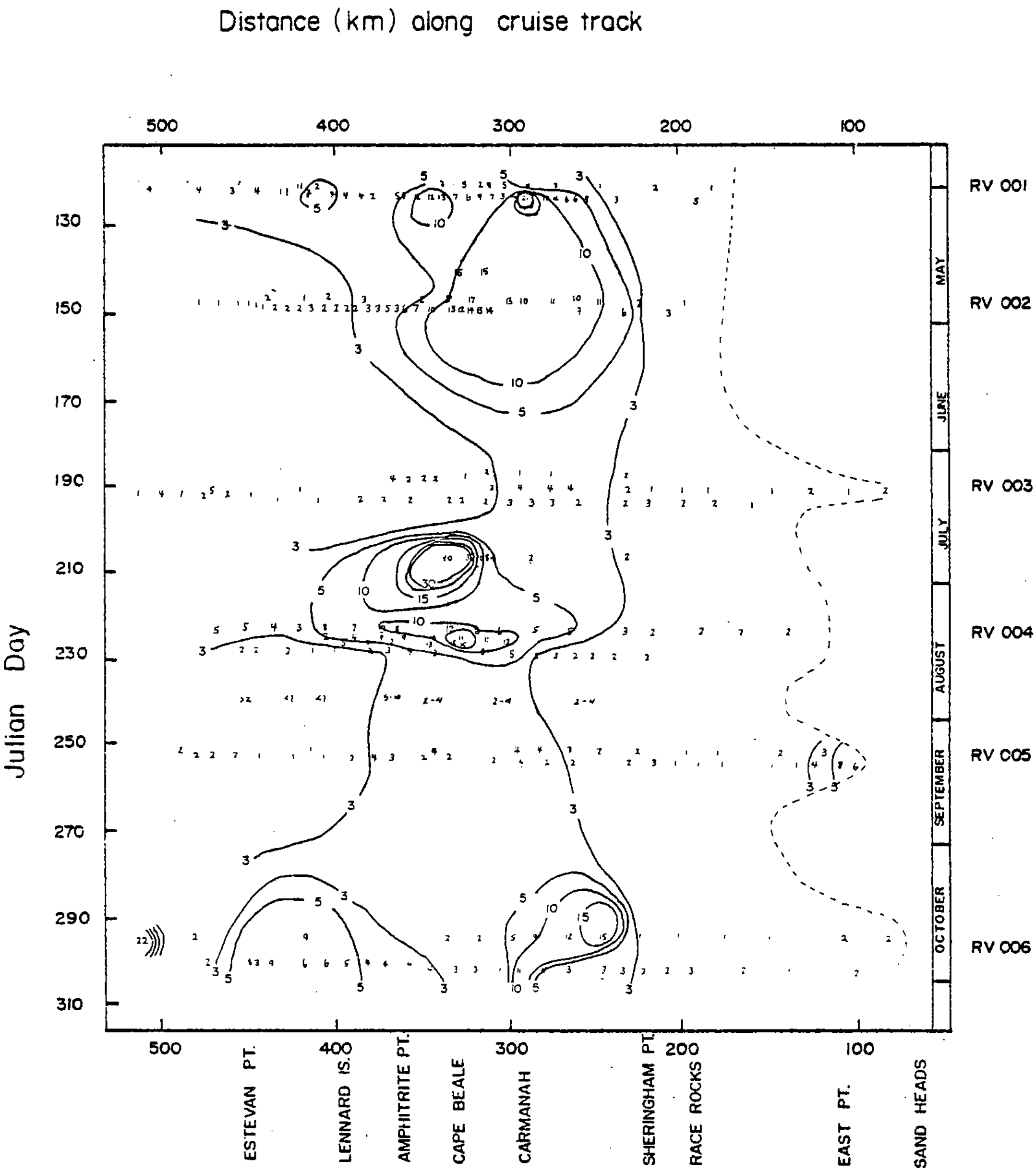


Figure 130. Variations in surface chlorophyll a concentration (mg/m^3) in the study area throughout the sampling period (May - November, 1979).

chlorophyll near 8 mg/m^3 recorded by the aircraft and Viking surveys just off Lennard Island was probably the remnants of the earlier large bloom.

In September phytoplankton stocks were low (4 mg chlorophyll $\underline{a}/m^3$ over the entire cruise track and the maximum (excluding a bloom in South Georgia Strait) was spread out along the outer coast in very warm nutrient depleted water. The September airborne survey detected cold (10^oC) water just west of the ship track off Amphitrite with chlorophyll concentrations near 5 mg/m^3 (Brown and Borstad, 1980) and indicated this water mass may have been contiguous with the cold, high nutrient water near Estevan Point which was sampled by the ship. If this constituted a second 'upwelling'-like event, the nutrients supplied to the northern part of the study area may have contributed to the general increase in nitrate concentration observed at the time of cruise RV006, and the most northerly blooms observed during this study. Another potentially more important source of nutrients to this area in October was the increasing amount of runoff, which depressed surface salinity and temperature near the coast from Amphitrite north. This water being very close to the coast (see Figure 127, the October satellite image) was responsible for the lack of agreement between Amphitrite and ship temperatures and was not sampled by the ship until near Estevan Point. Further to the south a bloom amounting to 15 mg/ chlorophyll $\underline{a}/m^3$ was situated in western Juan de Fuca Strait just east of the foundary with the coastal water and in a water mass concentrated along the Canadian shore. It was samples at only one station on the return trip along the southern traffic lane.

To sum up the discussion above, these data suggest three main sources of phytoplankton nutrients to the surface waters of the southern inner shelf region: the first is cold, saline water generated in the turbulent region of eastern Juan de Fuca and flowing seaward as initially distinct pools having sharp boundaries. These pools gradually mix with warmer less saline coastal water and flow north along the coast retaining their identity in some instances to off Amphitrite Point. Phytoplankton development probably begins in these waters shortly after they leave the Race Rocks area and continues independent of the movement of the pool, sometimes attaining maxima in the region of Sheringham, at other times further west, depending upon the speed of transport.

A second source of nutrients to the northern part of the study area is upwelling. Our data and that of Brown and Borstad (1980) indicate that this may have occurred twice during the study period, although it is difficult to distinguish this from invasion by cold waters from outside of the study area because of the lack of subsurface data.

A third source and probably of importance only in the fall and winter, in inlets and very near the coast, is land drainage from the rain forests of the west coast.

REFERENCES

Bartlett, L. and F.W. Rabe, 1974. Effects of copper, zinc and cadmium on Selenastrum capricornutum. Water Res. 8:179-185.

Borstad, G.A. and R.M. Brown, 1979. Airborne remote sensing of sea surface chlorophyll and temperature along the B.C. outer coast (July 12 and August 11, 1979). Unpubl. report by Seakem Oceanography Ltd. to Dept. Fisheries and Oceans, D.S.S. Contract 1SB79-00097.

Boyd, C.M and G.N. Johnson, 1968. Studying zooplankton populations with an electronic zooplankton counting device and the LINC-8 computer. Trans. Applications of Sea Going Computers Symposium and Marine Technology Society: 83:90

Brown, R.M., and G.A. Borstad, 1980. Airborne remote sensing of sea surface Chlorophyll and temperature along the B.C. outer coast (September 11 and October 23, 1979). Unpubl. report by Seakem Oceanography Ltd. to Dept. Fisheries and Oceans, D.S.S. Contract 1SB79-00097.

Gardner, W.S., D.S. Wynne and W.M. Dunstan, 1976. Simplified procedure for the manual analysis of nitrate in seawater. Mar. Chem. 4: 393-396.

Govindjee, G. Papageorgiou and E. Rabinowitch, 1973. Chlorophyll fluorescence and photosynthesis. In G.G. Guilbault (ed.) Practical fluorescence theory methods and techniques. Marcel Dekker Inc., New York, 664p.

Grasshoff, H., 1976. Methods of seawater analysis. Weinheim, New York: Verlag Chemie, 317p.

Herlinveaux, R.H., and J.P. Tully. 1961. Some oceanographic features of Juan de Fuca Strait. J. Fish. Res. Board Can. 18: 1027-1071.

Holbrook, J.R. and D. Halpern, 1978. Variability of near surface currents and winds in the western Strait of Juan de Fuca. In G.A. Cannon (ed.) 1978. Circulation in the Strait of Juan de Fuca, some recent oceanographic observations. NOAA. Technical Report ERL 399-PMEL29. 49pp.

Mackas, D.L., 1977. Horizontal spatial variability and co-variability of marine phytoplankton and zooplankton. Ph.D thesis, Dalhousie University, 227p.

Mackas, D.L., G.C. Louttit, and M.J. Austin. Spatial distribution of zooplankton and phytoplankton in British Columbia coastal waters (submitted to Can. J. Fish. Aquatic Sci.).

Parsons, T.R., R.J. LeBrasseur, and W.E. Barraclough. 1970. Levels of production in the pelagic environment of the Strait of Georgia, British Columbia: A review. J. Fish. Res. Board Can. 27: 1251-1264.

Saijo, Y., and S. Nishizawa, 1969. Action spectra in the fluorometric determination of chlorophyll-a. Mar. Biol. 2: 135-136.

Samuelsson, G., and G. Oquist, 1977. A method for studying photosynthetic capacitities of unicellular algae based on _in vivo_ chlorophyll fluorescence. Physiol. Plant 40:315-319.

Strickland, J.D.H., and T.R. Parsons, 1972. A practical handbook of sea water analysis. Fish. Res. Board Can. Bull. 167, 310p.

Slovacek, R.E., and P.J. Hannan. 1977. _In vivo_ fluorescence determinations of phytoplankton chlorophyll _a_. Limnol. Oceanogr. 22: 919-925.

Stockner, J.G., D.D. Cliff and K.R.S. Shortreed. 1979. Phytoplankton Ecology of the Strait of Georgia, British Columbia. J. Fish. Res. Board Can. _36_: 657-666.

SEAKEM OCEANOGRAPHY LTD

OFFERING SERVICES IN CHEMICAL, PHYSICAL
AND BIOLOGICAL OCEANOGRAPHY.

9817 WEST SAANICH ROAD
SIDNEY, BRITISH COLUMBIA V8L 3S1
TELEPHONE (604) 656-7283
TELEX: 049-7460