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PHYTOPLANKTON SUCCESSION AND PRIMARY PRODUCTION IN BABINE LAKE, BRITISH COLUMBIA

by

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TABLE OF CONTENTS

ABSTRACT

Phytoplankton production and species succession were monitored in 1973 as part of the Babine Lake Watershed Change Program. Ten stations located in six zones (sub-basins) were sampled biweekly from May to October to detect possible regional differences in production in this large, 140 km long, dystrophic lake. The spring bloom at most stations was caused by increases of diatoms, notably *Rhizosolenia longiseta* and *Cyclotella stelligera*. The fall bloom occurred only at Stations south of Topley Landing, and was caused chiefly by increases in *Tabellaria fenestrata* and *Fragilaria* spp. Chrysophyte increases followed the decline of the diatom vernal maximum. Carbon assimilation showed two peaks at south basin stations, but only one (spring) at stations north of Topley Landing. Seasonal variation in phytoplankton numbers and volume, seston, and chlorophyll a followed a pattern similar to that noted for primary production. Mean production at northern stations was 100 mg C m^{-2} day^{-1}, but was higher at stations in the south basin - 145. Annual production was estimated at 25 g C m^{-2} in the north basin and 40 in the south basin. Reasons for the regional disparities are discussed, with greatest significance given to regional variations in mixed layer depth, surface inflows (loading) and basin mean depth. The development and sustainment of the autumnal bloom of *Tabellaria fenestrata* is thought to be one of the principal factors responsible for greater production in the south basin.

A phosphorus load was computed and an estimated 0.05 g TP m^{-2} enters the lake yearly. This rate can vary depending on the return of adult sockeye salmon, whose carcasses contribute up to 20% of the annual load. An estimated 30% of the total phosphorus input is lost via the outlet, the Babine River, and it is speculated that of the remaining 70%, most is lost to the sediments. Phosphate limitation is implied as a chief factor limiting primary production in the north basin stations, but not in the south basin. On the basis of total phosphorus load the lake is classed as oligotrophic, - but in terms of annual production and its humic stained waters it is more correctly considered mixotrophic.

INTRODUCTION

Primary production studies were initiated as part of the Department of Environment's Babine Watershed Change Program. As major industries have been active in the Babine area for several years and are expected to increase their activities in the future, baseline studies were urgently needed to assess future changes in water quality. Water quality control is vital to the perpetuation of the salmon enhancement program initiated in 1965, representing an investment of over 8 million dollars by the Canadian Government. Spawning channels were constructed on Fulton River and Pinkut Creek to increase sockeye salmon fry production, and by 1973 were being utilized to maximum design capacity. In 1973 numbers of underyearling sockeye in Babine Lake were at higher levels than ever before. It is anticipated these levels will be maintained in future years and perhaps increased to even higher levels.

To assess effects of increased underyearling sockeye populations on lake production, it was necessary to initiate investigations of both primary and secondary production. The need for productivity work was emphasized by the fact that studies which initially suggested that Babine Lake was underutilized as a nursery area for underyearling sockeye salmon were based on a "uniform distribution hypothesis" (Johnson, 1961a). It has since been found that the distribution of underyearlings is not uniform (McDonald, 1969), and so previous estimates of Babine Lake carrying capacity may be incorrect.

DESCRIPTION OF STUDY AREA

Geological Setting

The major structural trend of the area around Babine Lake, as indicated by strikes of dipping beds and major faults, is northwesterly. Northeasterly trending faults, while present, are of lesser regional importance. Minor folding is apparent in some areas, e.g. Newman Peninsula. In the vicinity of the lake the oldest rocks, highly contorted and metamorphosed cherts, argillites and marbles of the Upper Palaeozoic Cache Creek Group, occur around Boling Point and on the south side of the lake. To the north exposed rocks range in age from Upper Triassic to Tertiary, and reveal a complex history of sedimentation, erosion, intermediate to acidic volcanicity, and plutonism. Scattered and sometimes economic copper deposits are locally associated with the Plutonic rocks. Pleistocene glacial and postglacial tills and drift now cover much of the area.

Morphometric and Physiographic Features

Babine Lake lies 580 km north of Vancouver on the Central Interior Plateau of British Columbia (Lat. 55^{o}N, Long. 123^{o}W). It is 155 km long, 9 km wide at the widest point, and has an area of 490 km^2. The main lake has a mean depth of over 70 m, the North Arm and Morrison Arm less than 20 m, and Hagan Arm less than 30 m (Table 1). Mean annual discharge from Babine Lake is about 47 m^3 sec^{-1}, with peak flows of 110 in June. Theoretical water renewal rate (flushing) is about 20 years.

The watershed surrounding Babine Lake totals about 10,000 km^2

and forms one of the major drainage basins of the Skeena River system. From the outlet at the northern end of the lake, the Babine River flows through Nilkitkwa Lake (10 km long) and junctures with the Skeena River at Hazelton, some 150 km downstream from Nilkitkwa Lake, reaching the sea at Prince Rupert, B.C. (Fig. 1).

Precipitation is distributed fairly evenly throughout the year, and including 2.5 - 3.0 m of snow, is about 60 cm year^{-1}. Snowfall occurs between October and May, and the lake is usually ice-covered from December to early May. The more northern reaches of the lake are subject to a more severe climate and have more snow and longer periods of ice cover. Summer temperatures range from 8° to 27°C with a mean of around 16°C. Winter temperature may plunge to - 40°C for long periods, but average only - 16°C for winter months.

The Babine Indians, a branch of the Carrier tribe, have been present in the area for hundreds of years, living a somewhat nomadic existence along the shores of the lake. Their presence over the years has led to little or no serious environmental disturbance. At present about 200 Indian people live on the shores of Babine Lake.

The first European white people to arrive were missionaries and Hudson's Bay traders in the mid-19th century, but the area remained thinly populated until the early 1960s. At that time the townsite of Granisle was developed and currently accomodates about 2,000 people, primarily associated with the mining industry. In addition to the Granisle population, about 200 - 300 people live on the lake at widely scattered locations. During the ice-free months the population increases considerably with an influx of tourists, hunters, and various seasonal workers associated with the mining, fishing and forest industries.

The Babine watershed contains extensive high-yield forests, primarily composed of white spruce (*Picea glauca*) and lodgepole pine (*Pinus contorta v. latifolia)*. Small-scale logging occurred in the area as early as 1925, but was highly selective, and did little apparent environmental damage during this period. Clear-cut logging was initiated in the 1950's, and by the late 1960's resulted in several openings in excess of 202 hectares (500 acres). At the present time the British Columbia Forest Service has restricted clear-cut openings to 80 hectares (200 acres). Since 1972 Northwood Pulp and Timber Company Ltd. of Prince George has had logging rights in the area, with an expected 1973 harvest of over 100,000 cunits (1 cunit = 100 ft^3 of wood) (Smith, MS, 1973).

Mining has occurred in the Babine area for over 50 years, but large-scale operations did not begin until the mid 1960's. Currently Noranda Mines Ltd. (Bell Copper Division) and Granby Mining Company Ltd., conduct extensive open-pit operations on Copper Island (in Hagan Arm) and on Newman Peninsula in the north basin, main lake. Both mines concentrate the ore on-site and truck concentrates to railway stations in the Bulkley Valley, some 50 km to the south of the lake. Seepage of mine wastes into Babine Lake could be a potential water quality problem, but no serious effects have as yet been observed on lake flora or fauna.

The Babine watershed supports large numbers of fish of considerable recreational and commercial importance. Babine Lake has large populations of rainbow trout (*Salmo gairdneri*), kokanee (landlocked sockeye, *Oncorhynchus nerka)*, lake trout (char, *Salvelinus namaycush)*, and whitefish (*Coregonus clupeaformis*). A steelhead sports fishery exists on the Babine River, as well as smaller chinook and coho sports fisheries.

Sockeye salmon are the primary commercial species in the Babine system, although chinook and coho are also of importance. The Skeena River is the second largest producer of sockeye in British Columbia, with Babine sockeye totalling almost 90% of the annual Skeena run (Smith MS 1973).

Prior to development of artificial spawning channels, the average annual commercial catch of Babine sockeye numbered 600,000 to 800,000 fish. However, it is expected that by 1976 the salmon enhancement project will provide an additional 1,000,000 fish to the annual commercial catch off the Skeena estuary at Prince Rupert.

METHODS

Field Procedure

Primary Production

With minor modifications, the standard ^{14}C method as initially proposed by Steeman-Neilsen (1952) was used. Water was collected from eight depths (0, 1, 2, 3, 5, 10, 20 and 30 m) in a 6 liter plastic Van Dorn bottle. Of ten stations regularly sampled, two were at depths less than 30 m. At these stations water was collected to 20 m only.

Two 125 ml light bottles and one 125 ml dark bottle were filled from each depth and inoculated with approximately 3 μCi of $NaH^{14}CO_3$ radio-isotope stock (N.E.N.). In all production sets from May to July, productivity bottles were inoculated with one ampoule (1 ml) of radio-isotope stock. From August to October, to reduce ampoule-to-ampoule variation, ampoules were mixed prior to inoculation and diluted with an equal portion of distilled water. Productivity bottles were then inoculated with 1 ml of this ^{14}C stock solution. To obtain a DPM count for each batch of diluted radio-isotope stock, 3 scintillation vials were inoculated with 1 ml each of the stock solution.

After inoculation of samples, bottles were suspended from clear plexiglass holders and incubated for four hours at the original sampling depths. After retrieval, bottles were stored in a light-tight container and transported to the laboratory for immediate filtration.

Chlorophyll a and Seston

One liter for both chlorophyll *a* and seston was collected in plastic bottles from each of the 8 depths listed above. These were transported to the laboratory for immediate filtration and storage prior to analysis.

Phytoplankton Standing Crop

Water samples (100 ml) were collected in plastic bottles from each of the 8 depths. These were preserved with Lugol's acetate solution and used for direct counts of phytoplankton.

Physical Parameters

Belfort recording pyroheliometers were placed at three locations, in the study area: Halifax Narrows, Hydro Island, and Pinkut Creek

(Fig. 1). For every station sampled the total record of the closest pyroheliometer for that date was planimetered. The record for the incubation period was also planimetered and converted to a percentage of the entire light day. These data were then incorporated into the productivity equation of Strickland (1960). A Montedoro-Whitney illuminance meter (Model LMT-8B) was available for a portion of the study and was used to measure light extinction as a function of depth. These data were plotted on a Hewlett-Packard Calculator-Plotter as the natural log of intensity vs depth. A line was regressed through the points and its slope gave mean extinction coefficient. A standard 22 cm white Secchi disc was used to measure water transparency at every set.

A bathythermograph was lowered at each station to obtain a temperature/depth profile, and surface temperature for BT calibration was measured with a standard bucket thermometer.

Chemical parameters were monitored at five stations in May, August and October, 1973. Analyses were conducted at the Fisheries Analytical Laboratory, Pacific Environment Institute, West Vancouver. Methods used are described in detail by Smith and Davidson (FRB MS report 1974, in preparation).

Laboratory Procedure

All primary production, chlorophyll a, and seston samples were filtered on the same day they were taken. A Millipore filtering apparatus was used at a maximum vacuum pressure of 20 cm Hg.

Primary Production

Productivity bottles were filtered onto 0.45 μ pore size, 25 mm diameter, cellulose acetate Sartorius membrane filters. After filtration the filters were immediately placed in scintillation vials containing 10 ml of Aquasol (N.E.N., L.S.C. fluor). Scintillation vials were shipped by air to the Vancouver Laboratory of the Fisheries Research Board of Canada for counting.

The acitivity of samples was determined on a Packard Tri-Carb Liquid Scintillation Spectrometer (Model 3375). The equation of Strickland (1960) was used to convert counts per minute to mgC m^{-3} day $^{-1}$. Loss in activity from scintillation vials during storage and transport was found to occur and a suitable correction factor was applied to TCPMs to compensate for this loss.

Profiles of mgC m^{-3} day^{-1} as a function of depth were integrated by computer to give production on an areal basis (mgC m^{-2} day^{-1}). To obtain estimates of annual production, values were plotted and planimetered over a 275 day period, representing the period from the onset of production under ice in April to the decline to negligible values in November.

Chlorophyll a

Chlorophyll samples were filtered onto 5.5 cm diameter, Whatman glass fiber filters. Two ml of saturated $MgCO_3$ solution were added to each sample to prevent acidification prior to analysis. Filters were folded, placed in aluminum weighing dishes and frozen.

During analysis of samples it was found that there was little variation in chlorophyll values in the upper depths, (0 - 5m) and thus only samples from 1, 3, 5 and 20 m were analysed. Analysis was according to methods of Strickland and Parsons (1972), with some samples analysed using methods of Yentsch and Menzel (1963). There was good agreement between methods.

Seston

Seston samples were filtered onto ashed and weighed 5.5 cm Whatman glass fiber filters. Filters were folded, placed in aluminum weighing dishes, and frozen.

Seston analysis was carried out at the Fisheries Research Board laboratories at the Pacific Environment Institute. Samples were dried at 105°C to constant weight, weighed, ashed in a muffle furnace at 500°C for a minimum of four hours, and weighed again for loss on ignition (L.O.I.).

Phytoplankton Standing Crop

Phytoplankton was counted using the Ütermohl method on a Zeiss inverted plankton microscope. In preparation for counting, a sample bottle was thoroughly shaken, and a portion used to completely fill a 25 cc settling chamber. Plankton was allowed to settle overnight before counting.

Two complete transects at 160X and 400X magnification were counted; however only those at depths above the thermocline were included in subsequent calculations. When light data were available (after September 1), only those samples enumerated at or above the compensation depth (1% of surface light) were included in calculations. In actual practice, both methods resulted almost invariably in excluding samples from 20 to 30 m from any calculations. However, under isothermal conditions which existed in May and early June, samples from all 8 depths were used in calculations.

Counts were converted to number of cells . m^{-3} and to total phytoplankton volumes (mm^3 . m^{-3}). Phytoplankton volumes were determined using values calculated by Evans and Stockner (1972) and by Nauwerk (1963), although direct volume estimates for certain species were made by the authors.

Rationale for Station Locations and Sampling Strategy

From the outset it was considered essential to sample the major basins of Babine Lake at sufficient intervals to indicate spatial and temporal changes in phytoplankton species succession. The large distances to be covered on a lake of this magnitude, as well as manpower availability, determined that 10 stations were the maximum that could be sampled at biweekly intervals.

Data interpretation for presentation of results was facilitated by dividing the lake into six zones, each with one or more stations (Fig. 1 and Table 2). Boundaries were somewhat arbitrary, but were based chiefly on known morphometric, physical and biological differences among regions (Johnson 1956, 1958, MacDonald & Scarsbrook MS 1969).

Station 1 was located in the North Arm (Zone 1), a shallow basin approximately 35 km in length which is, together with Nilkitkwa Lake, historically the most important nursery area for underyearling sockeye salmon on Babine Lake (Johnson 1958).

Station 3 was in Morrison Arm (Zone 2), a shallow basin 13 km long. The Morrison River, draining Morrison Lake, flows into the head of Zone 2 and is one of the major natural sockeye spawning areas on Babine Lake (Brett 1952).

Station 5 was situated in Hagan Arm (Zone 3), which, more than either of the previous zones, is a discrete sub-basin of the main lake, connected to the main lake by two narrow channels of less than 20 m in depth. Its maximum depth of 90 m is more than double the maximum depth of Morrison or the North Arm. There are two copper mines (Noranda and Granisle) on the shores of Hagan Arm.

The northern basin of the main lake (Zone 4) was represented by Station 2 and 4. Like most of the main lake, it is characterized by deep waters, with surface waters in summer subjected to more wind stress and mixing than the previous zones (Farmer, MS 1973). Zone 4 is located in close proximity to Noranda Mines, and the community of Granisle (2,000 pop.) is situated on the south shore.

Stations 6 and 7 were located in Zone 5, the central basin of the main lake. The small community of Topley Landing (± 100 pop.) is situated at the mouth of the Fulton River, which contains two of the three artificial spawning channels on the Babine system (McDonald, 1969).

The southern basin (Zone 6) was represented by Stations 8, 9 and 10. Pinkut Creek, the site of the third Babine spawning channel, is located in this zone. Three stations were situated in this zone to determine whether this particular region was the most productive in the lake, as had been previously suggested (Narver 1967). There was also past evidence to suggest that this zone was the primary nursery area for underyearling sockeye from the Pinkut and Fulton spawning channels (McDonald and Scarsbrook, MS 1970).

RESULTS

Physical Parameters

Light

Typical light plots in September from the extreme north and south ends of the lake are shown in Fig. 2a and 2b. Mean extinction coefficients for the fall period ranged from 0.538 to 0.879. When one compares coefficients obtained from each zone, a gradual increase in values from north to south is apparent (0.578 to 0.771), with Zone 6 in the extreme south exhibiting higher attenuation than any other zone (Table 3). Of the shallower basins, Zone 2 in Morrison Arm showed consistently higher extinction coefficients than Zone 1 in the North Arm (0.669 and 0.578, respectively).

Secchi Depth

After lows of 2.5 m in May, Secchi depths in Zones 1 and 2 increased slowly through the season, reaching values of 6.0 - 6.5 m by early October (Fig. 3a). In Zone 4 lowest values (5.0 m) occurred in late June and early July, followed by a gradual increase through the rest of the season, reaching 6.0 - 6.5 m in October. Secchi depths in Hagan Arm (Zone 3) were fairly constant (5.0 - 6.0 m) throughout the open water period, although better transparency was noted here in early August than in other zones. Secchi depths in Zones 5 and 6 in the south basin decreased from 7 m in May to 4.0 - 4.5 m in late June, increased through July and August to 5.5 - 6.0 m, and decreased again in September and early October to 4.5 - 5.0 m (Fig. 3b). The least transparent waters occurred in the relatively shallow Zones 1 and 2, where seasonal averages were 4.5 and 4.3 m, respectively. The northern basin of the main lake (Zone 4) had the highest average value among stations - 5.9 m (Table 4a). Highest Secchi values were coincident with low phytoplankton standing crops, and low values occurred during the vernal bloom at all stations and autumnal bloom at southern stations.

Temperature

The vertical and horizontal thermal structure was measured in considerable detail in 1972 and 1973 (Farmer, MS 1973). This extensive data base permitted recognition of epilimnion, metalimnion and hypolimnion depth, mean temperature and volumes of these layers, rate of hypolimnial warming, stability of density layers, current patterns (seiche characteristics), and summer heat income for all major regions of Babine Lake. These data will appear in a separate data report.

Babine Lake is dimictic, with mean hypolimnetic temperatures above 4°C in midsummer. In 1973 cool temperatures and cloudy conditions delayed the onset of thermal statification until late June (Fig. 4). Pronounced stratification occurred in most regions from July to early October, with the maximum epilimnion temperature of 18°C reached in mid-August. Autumnal winds and cool temperatures in October restored isothermal conditions which remained to the end of November and commencement of ice cover (Fig. 4). The daily variation of mixed layer depth was monitored by Farmer (MS 1973), and permitted recognition of zones of upwelling, intense mixing, and relative stability among various regions (basins) of the lake. These data were used to interpret variation in production among zones, and are discussed in detail in latter sections of this paper.

Chemical Parameters

Phosphate and nitrate concentrations showed little spatial or temporal variation (Table 5). This fact may be more related to lack of sensitivity of analytical methods than to actual observation. In June and July silicate concentrations were similar throughout the lake, but by late September were considerably lower in the south basin (Zone 6). Total alkalinity showed little spatial variation in 1973, with the exception of Zone 2, where values were lower than in the rest of the lake. Zonal variations in conductivity were insignificant. Results of chemical studies reported by Narver (1967), Stephens et al (MS 1969) and Smith and Davidson (MS 1974) showed similar temporal and spatial constancy in parameters analyzed. Nutrient variation as it relates to production will be discussed in more detail in the Discussion Section of this paper.

Biological Parameters

Seston

Phytoplankton biomass in all zones reached maximum values in June commensurate with the onset of the spring bloom (Fig. 5). In Zones 1 - 4 biomass gradually decreased for the remainder of the season, exhibiting little or no autumnal maximum. Highest mean values were recorded in the southern half of Babine Lake (Zones 5 and 6) and in the shallow basins of Zones 1 and 2 (Table 4a). Seston values in Zones 3 and 4 were notably smaller than in other regions of the lake. Prior to the onset of stratification, plankton biomass was uniformly distributed in the water column, but by July greatest concentrations occurred between 1 - 5 m, with sparse amounts noted in the 0 - 1 m layer and below 5 m. This basic pattern of phytoplankton biomass vertical distribution was maintained well into October, when winds and below freezing temperatures moved the mixed layer to below the compensation depth. In September and October in the south basin, greatest biomass occurred from 0 - 1 m when light conditions were nearly optimal during the autumnal bloom period.

Chlorophyll a

Concentrations of chlorophyll a in all zones attained maximum values during the last weeks of June, and reached mid-summer lows in late July and early August (Fig. 6). A second increase was noted in Zones 5 and 6 (Stations 6 - 10) in late September, commensurate with the autumnal bloom (Fig. 6).

Highest mean chlorophyll a values occurred in the south basin - Zone 6 (Table 4a). Values noted in Zone 5 were only slightly less than those in Zone 6, while mean concentrations in the northern basin of the main lake and in Hagan Arm (Zones 3 and 4) were considerably lower. Of the shallower basins, Zone 2 had a much higher mean concentration of chlorophyll a than did Zone 1 (Table 4a).

Vertical distribution of chlorophyll a was similar to that noted for seston with negligible amounts from 0 to 1 m and from 20 to 30 m during stratified conditions; maximum concentrations in the 1 - 5 m layer in the summer, and relatively high values in surface waters in the fall in the south basin.

Phytoplankton

Species composition

A listing of the phytoplankton species enumerated, together with a listing of the six dominant species by number and volume in each zone appears in Tables 6 and 7a,b. Diatoms, blue-greens, and Chrysophyceans were the major group found in Babine Lake in 1973. On a numerical basis, blue-greens were the most abundant group in Zones 1, 4, 5 and 6 (Stations 1, 2, 4, 6 - 10), while in Zone 2 (Station 3) Chrysophyceans were most abundant. In Zone 3 (Station 5) the three major groups were in about equal proportions throughout the season.

Common diatoms were *Rhizosolenia longiseta, Cyclotella stelligera, C. ocellata, Tabellaria fenestrata, Fragilaria crotonensis, F. construens, Melosira italica,* and *Asterionella formosa. Oscillatoria* sp. and *Chroococcus* sp. were the dominant blue-greens, although at certain times *Anabaena* occurred in considerable numbers. Of other groups present, the dominant Chlorophyte was *Ankistrodesmus* sp. and the dominant Cryptophyte, *Cryptomonas* sp. Among Chrysophyceans, *Chromulina* sp. and *Chrysochromulina* sp. were most important, with some *Mallomonas* spp. common at most all stations.

Standing crop

In early May, prior to the vernal bloom, all groups were at low levels and in about equal proportions at all stations (Figs.7 and 8). The spring bloom in all areas was caused by a substantial increase in all groups, but mainly diatoms (Figs.7 and 8). By comparing the nature of the seasonal curve of phytoplankton numbers in Figure 7 with Figure 8 it is clear that the south basin stations have considerably more phytoplankton than those to the north of Topley Landing. Also of interest is the obvious fall increase at all south basin stations, but not any of any significance, with perhaps the exception of Station 2, in the north basin.

Volume

Plots of seasonal variation in phytoplankton volume are considerably different than numerical plots, chiefly because of the very large size of common diatoms and the small size of common blue-greens (Figs. 9 and 10). In all zones peak values in the spring occurred when *Rhizosolenia longiseta* was at its population maximum, and fall increases at all south end stations were caused primarily by increases of *Tabellaria fenestrata* and *Fragilaria* spp. An increase of "other groups", apparent at all stations immediately after the spring bloom and again in the fall, was caused mainly by *Cryptomonas* sp. and *Ankistrodesmus* sp.

Phytoplankton volumes when integrated for the growing season ($cm^3 . m^{-3} .275\ days^{-1}$), show rather conclusively Zone 6 had the highest phytoplankton concentration, 66.91, closely followed by Zone 5. Zones 1 - 4 had considerably lower concentrations, ranging from 17.43 in Zone 2 to 27.70 in Zone 3 (Table 4a). Among stations, 7, off Pierre Creek, had the greatest phytoplankton volume, with 10, in the extreme south, next highest (Table 4b). There was almost 5 times as much plankton at Station 7 than at Station 3 in Morrison Arm, and 3 times as much phytoplankton at the southern most station

(10) than at the most northern station (1), which illustrates the tremendous difference in total phytoplankton biomass and their spatial distribution in this large lake (Table 4b).

Species succession

In Zone 1 (Station 1) a double spring peak occurred, the first in mid-June, the second in mid-July (Fig. 7). Diatom increases were the main cause of the double peak. The first increase was attributable to a bloom of *Rhizosolenia longiseta*, the second to *Cyclotella stelligera* and *C. ocellata*. The minor fall increase at Station 1 was caused by an increase in *Chromulina* sp. and *C. stelligera*. Chrysophyceans were most numerous in the spring and fall. Blue-greens were most numerous at the second spring peak, mainly *Oscillatoria* sp.

In Zone 2 Morrison Arm (Station 3), diatom abundance peaked in June, and a slight increase of *C. stelligera* was noted in the fall (Fig. 7). The double spring peak noted in Zone 1 was not as pronounced in this zone although, as in Zone 1, *R. longiseta* and *C. stelligera* were the chief components of the double peak. Chrysophyceans increased in mid-June, decreased until September, when they increased to an autumnal maximum. Blue-greens reached peak density in mid-July and decreased until late September, when a slight increase was again noted.

In Zone 3 Hagan Arm (Station 5) diatoms reached maximum abundance in early July, then decreased to low levels for the remainder of the season (Fig. 7). As in the previous zones, *R. longiseta* was present in greatest numbers, with *C. stelligera*, and to a lesser extent *Melosira italica* and *Tabellaria fenestrata*, showing increases in early July. Chrysophyceans in Zone 3 were most abundant in mid-June, end of July, and again in early October. Blue-greens demonstrated no significant increases or decreases, but were most abundant in the first half of June.

Phytoplankton were at maximum density at Station 2 (Zone 4) in late June, showed a smaller peak in August and again in early October (Fig. 7). The June peak was caused by an increase in all groups, the August peak by blue-greens, and the October peak by all groups, but again predominantly blue-greens. The spring diatom bloom was composed mainly of *R. longiseta,* although *Melosira italica* was also present in considerable numbers. *Cyclotella* spp. showed no significant increases or decreases throughout the season. The small autumnal diatom maximum was caused chiefly by increases in *R. longiseta.*

At Station 4 (Zone 4) diatoms and blue-greens were most abundant in late June, Chrysophyceans in late July (Fig. 7). Diatoms increased only slightly in September, while other groups increased to population levels noted in June. All diatoms except *Cyclotella* spp. reached maximum abundance in late June, *R. longiseta* was dominant. *Cyclotella stelligera* peaked in late July and again in early October.

Phytoplankton at Station 6, off Topley Landing, (Zone 5) showed two seasonal peaks, one in mid-June, and the other in early October (Fig. 8). A minor peak in mid-July was caused mainly by blue-greens. Although diatoms and Chrysophyceans increased in the fall, blue-greens were the dominant group, with a peak density noted in early October. Of the diatoms, *R. longiseta, M. italica* and *Asterionella formosa* were present in greatest numbers in mid-June, with *C. stelligera* increasing in early July. The fall diatom increase was caused primarily by *Tabellaria fenestrata* , *Fragilaria crotonensis* and *F. construens.*

Spring patterns noted at Station 6 were similar to those observed at Station 7 (also in Zone 5), although autumnal phytoplankton composition varied somewhat. Blue-greens did not increase to nearly as great an extent in the fall, and diatoms were dominant, chiefly *T. fenestrata* and *Fragilaria* spp. (Fig. 8).

Highest numbers of phytoplankton at Station 8 (Zone 6) were recorded in the latter half of June and in early October (Fig. 8). Chrysophyceans attained peak density in the spring but showed no fall increase, while blue-greens and diatoms reached highest population levels in the fall. Spring diatom increases followed the pattern of previous stations, with a June peak of most species (predominantly *R. longiseta).* In the fall *F. crotonensis* and *T. fenestrata* were most important.

Stations 9 and 10 (Zone 6) had a similar species composition and seasonal succession with Station 10 having greater densities (Fig. 8). Chrysophyceans showed slight fall increases, and similar to Station 8, *T. fenestrata* and *Fragilaria* spp. were the dominant fall species. The greatest numbers (not volume) of phytoplankton observed in Babine Lake in 1973 occurred in the extreme southern region of the lake, Station 10.

Primary Production

Temporal variation of areal rates. Production at Station 1 (Zone 1) reached maximum values in late May with a daily rate of 225 mgC m^{-2}, showed a second increase in mid-July, and decreased gradually through the remainder of the season, with no apparent fall production peak

(Table 4b, Fig. 11).

Production peaked in mid-June at Station 3 in Morrison Arm (Zone 2) and decreased steadily until late September, when a small autumnal increase occurred (Fig. 11). Both Stations 2 and 4 in the northern basin of the main lake (Zone 4) showed production peaks in mid-June, the last half of July, and again in the fall (Fig. 11). Station 6 (Zone 5) off Topley Landing attained maximum values in mid-June, maintained a high rate of production through the summer, and gradually decreased in late September and October. Station 7 in Zone 5 peaked in the latter half of June, and again in mid-September (Fig. 11). Maximum production at Station 8 (Zone 6), occurred in mid-July and in mid-September. Station 9 (Zone 6) showed peak values in late June and again in late September, exhibiting a very high autumnal peak of 417 mgC. m^{-2} day^{-1}. Station 10 peaked in late June,maintained a high rate of production through the summer, and peaked again in late September coincident with the autumnal diatom bloom (Fig. 11).

If one integrates the seasonal curves of areal production estimates for each station, an appreciation can be gained for differences among stations and zones, as well as an estimate of annual production (Table 4a and 4b). Annual production increased from a low of 25 g C . m^{-2} at Station 1 to a high of 52 at Station 10 in the south. The average annual production in the north (5 stations) was 27 g C . m^{-2}, contrasted to 40 in the south. The average of all stations was 33 g C . m^{-2}. These results are not surprising for they substantiate trends observed in Chlorophyll a, seston, phytoplankton numbers and biomass.

Vertical production profiles. Though there were marked differences in areal production rates, there was a basic similarity in the nature of the vertical profiles of carbon assimilation among zones and stations (Figs. 12 and 13). The most notable feature was that between 80 and 90 per cent of carbon assimilation occurred within the 0 - 5 meter surface layer, with only negligible values found below this layer. The production curves displayed rather consistent features among stations as the season progressed and stratification intensified. In May and early June isothermal conditions created uniform volumetric rates in the layer from 0 - 5 m, with reduced, but significant, production at 10 m. As stratification developed, by late June and early July, the greatest carbon assimilation occurred at 1 - 3 m depth, with surface light inhibition apparent at most stations on bright days (Figs. 12 and 13). Seasonal maxima were coincident with the attainment at maximum phytoplankton crops and chlorophyll a concentrations. With the exception of extreme southern stations, mid-summer lows occurred in August and early September with little or no autumnal increases noted at stations north of Topley Landing. In the south basin (Zones 5 and 6) an autumnal bloom occurred around the middle of September which was sustained well into October when stratification weakened and overturn commenced. Profiles at all stations in October resembled those observed at spring overturn with uniform rates from 0 - 5 or 10 m.

Volumetric production rates. Production rates in northern Zones 1 - 4 ranged from lows of 10 mgC m^{-3} day^{-1} to highs of 30 - 40. The highest seasonal rate occurred at Station 3, Morrison Arm on June 13, 124 mgC . m^{-3} day^{-1}. In Zones 5 and 6 in the southern basin volumetric carbon assimilation rates were considerably higher, ranging from spring lows of 20 - 30 mgC m^{-3} day^{-1}, to mid-summer and autumnal highs of 60 - 80. These obvious regional differences in volumetric rates are reflected in higher areal rates at southern stations.

Light inhibition in the surface layer (0 - 1 m) was obvious on certain days at all stations but was not a constant feature of the vertical profile (Figs. 12 and 13). Without exception the most pronounced inhibition at all stations occurred on bright calm days, producing a well developed maximum at 1 - 2 meters. On partly cloudy or totally overcast windy days little or no maximum developed, with surface values equal to or greater than values at 1 - 2 in depth.

Assimilation number, θ, (mgC mg Chl.a^{-1} day^{-1}). It is informative to normalize production on a *per* unit of chlorophyll basis so that production efficiencies at various stations can be compared. Values ranged from lows of 2 to highs of 40 (Table 8). Regional differences were also seen in the assimilation number, averaging 12 in the north stations, and 17 in the south, which means production, *per* unit of biomass (chl.*a*), was more efficient at southern stations. Highest values of θ were in June/July period when biomass was approaching seasonal highs.

Prediction of Babine Primary Production using Linear and Multiple Regression Equations

Several authors have attempted to calculate primary production using estimated environmental parameters (Ryther & Yentsch 1957), Schindler 1970, Schindler & Comita 1971). We tested a number of variables known to be either directly or indirectly related to primary production, and found that for certain stations the equation had good predictive value, while for others it provided a poor fit to observed values. These findings are undoubtedly related to differences in production noted among lake regions. Of a family of regressions tested, a number deserve special mention. The highest correlation was between areal production ($\bar{x}$ station value) for the ten stations and mean Secchi depth at each station (Fig. 14). This negative relation was not surprising, for it validates our previously stated assumption that in dystrophic lakes, Secchi variation is related directly to the abundance of autochthonous material, and that humic materials set the maximum limits, thereby reducing the range between maximum and minimum values of transparency in this type of lake.

There was a good relation between phytoplankton volume and mean chlorophyll a at all stations (Fig. 15), and between mean chlorophyll a and mean areal primary production for each station (Fig. 16). The best linear equation for predicting mean areal primary production for all regions of Babine was the relation - mean chlorophyll a X mean incident radiation/ mean Secchi depth (Fig. 17). Another equation that showed some relation to areal primary production, but a less significant fit, was chlorophyll a X incident light / K_d X $1 - e^{-kd}$ / K (Fig. 18). This equation attempted to relate production to chlorophyll a and "available" light as expressed by the equation $I_d = I_o e^{-kd}$.

A number of variables were tested simultaneously (multiple linear regression) to find an equation that would have more predictive value than offered by simple linear regression. The most significant evaluation was obtained using the following parameters:

(X_1) $\bar{x}$ Secchi, (X_2) $\bar{x}$ dry wt seston, (X_3) $\bar{x}$ chlorophyll a, (X_4) $\bar{x}$ phytoplankton volume, to predict (Y) $\bar{x}$ daily primary production (mg C. m^{-2}) (F. value = 5.40, significant 0.05 level, d.f. = 4 and 9, coefficient of multiple determination $R^2 = .88$). The agreement between predicted values, using the multiple linear equation, and the actual observed values was excellent (Fig. 19).

DISCUSSION

This section will deal with factors influencing primary production in Babine Lake. Present data will be compared with information from past investigations on Babine and on other Canadian and European temperate lakes so as to provide a better understanding of the importance of pelagic primary production to the overall health or 'trophicity' of this important underyearling sockeye producing lake.

Phytoplankton Production in Babine Lake

In 1973 the average daily rate for ice-free season (all stations) was 122 mg C m^{-2} day^{-1}. In the more productive southern basin it was higher, averaging 145 for five Stations, contrasted to only 100 for the five Stations located north of Topley Landing. In 1966, in a less intensive study, Narver (1967) estimated average production to be 55 mg C m^{-2} day^{-1}, with highest production occurring in the south basin. There are no indications from past information to suggest that primary production should have doubled over the past seven years; in fact, records of other parameters collected in 1967 by Narver and Stephen's et al. (1969) show no significant changes from 1973 conditions, e.g. chl a, nutrients. This suggests methodological rather than real differences between Narver's data and current information. Narver made no corrections for losses incurred by long-term filter storage prior to counting, nor for ampoule to ampoule variations; factors which collectively could account for the large differences between his estimates and our own (Narver, personal communications). Also, his sets encompassed on 5 depths and were done primarily in the fall. His total sets were 22 , ours totalled 93 and included the ice-out period to late October.

Based on 1973 estimates, Babine can be considered more productive than many well-studied Alaskan Sockeye producing lakes (Harry et al. 1967). Great Central Lake, a sockeye producer on Vancouver Island, is an extremely unproductive lake when compared to Babine (Stephen's et al. 1969). The average estimated daily rates vary between 1 and 5 mg C m^{-2} day^{-1}, which is nearly an order of magnitude less than average Babine Lake values.

On the basis of volumetric estimates (mgC m^{-3}) production values for Babine were considerably higher than estimates for Alaskan lakes (Harry et al.1967), and orders of magnitude higher than Great Central Lake (Stephen's et al. 1969). Average daily volumetric rates in Babine ranged from 10 - 50 mg C m^{-3} day^{-1} with an average of 20, while in Alaskan lakes, averages were closer to 5, though there was considerable variation among lakes. In Great Central Lake maximum daily values were 0.5 mg C m^{-3}, but the average was less, 0.2 (Stephen's et al. 1969).

When compared to similar estimates from other British Columbia and Canadian lakes, Babine Lake ranks as one of the more productive large Canadian lakes. It is not as productive as Kootenay Lake, which is of comparable size, but Kootenay has shown greatly increased production in recent years due to the addition of considerable quantities of phosphorus (Northcote, 1973). Babine is more productive than Okanagan Lake also of similar size, but not as productive as some of the smaller eutrophic lakes in the Okanagan Basin (Stockner & Northcote, 1974).

Babine Lake is more productive than most dimictic Shield lakes in the Kenora, Ontario, Experimental Lakes Area (Schindler and Holmgren, 1971), but less productive than Clear Lake, situated on the Shield north of Toronto (Schindler and Nighswander, 1970). On the basis of biomass (net plankton), Babine is more productive than Great Slave, Athabasca and Reindeer Lakes (Rawson 1955), but not as productive as several of the larger Churchill River Drainage Basin lakes (Rawson, 1961).

Trophic State

It is informative to compare Babine phytoplankton production to ranges established for various well-studied temperate European oligo and eutrophic lakes (Rodhe, 1969).

AUTOTROPHY
(phytoplankton)

	oligotrophic lakes	eutrophic lakes		
		natural	polluted	
mean rates in growing season	30 - 100	300 - 1,000	1,500 - 3,000	mg of C/m^2/day
annual rates	7 - 25	75 - 250	350 - 700	g of C/m^2/year

Babine Lake, with an average daily rate of <u>122</u> mg C m^{-2} day $^{-1}$ and annual rate of <u>33</u> g C m^{-2} yr^{-1}, falls between ranges established for oligotrophic and naturally eutrophic lakes, albeit closer to the oligotrophic than eutrophic category. If it were not for the prevalence of humic materials staining the waters of Babine Lake, one could conclude on the basis of the preceding, that Babine is mesotrophic, or perhaps more correctly, meso-oligotrophic.

Thienemann (1921) was one of the first to make the distinction between clear-water and brown-water lakes in his lake typology, calling the latter type - dystrophic. This type of lake was typically stained with humic material leached from the watershed, and characteristically exhibited rather low production. Jarnefelt (1925) in studies on several Finnish lakes concluded that not all dystrophic lakes are unproductive, in fact, some were very productive. These productive stained lakes he termed - mixotrophic, to distinguish them from Thienemann's nomenclature for the productive clear-water lake - mesotrophic and eutrophic. It appears then, on the basis of the preceding, that it would be correct to call Babine a dystrophic lake, thereby taking into consideration the stained nature of its water, and to classify it on the basis of phytoplankton production, as mixotrophic.

The relation of phytoplankton production to physical and chemical factors.

Light.

The remarkable similarity between the total radiation curves and carbon assimilation profiles when plotted on a semilog scale is suggestive of light limitation of production in the euphotic zone of Babine Lake, (Findenegg 1964) (Fig.20). Findenegg's description of this type of profile (termed Type 1 in his classification) fits well the general vertical production profile observed at all stations in Babine. The more notable features of the Type 1 curve being: a) seasonal differences in areal production rates, but slope of production profiles remain uniform, b) light inhibition at the surface on bright days with well developed maximums at 1 - 2 meters, c) a rapid decline in production from 2 - 5 meters, commensurate with the rapid attenuation of incident radiation in surface layers.

The nature of the production profile found in Babine is similar to the Type 1 encountered in eutrophic lakes that have an abundance of nutrients and a high standing stock of phytoplankton that self-shade to reduce light penetration. In Babine the role of stained materials must be considered as the main factor responsible for high light attenuation in surface waters, and the consequent limitation of the compensation depth(∼euphotic zone) to 5 - 6 m.

In Babine at most all stations, maximum production occurred in the layer where incident radiation was reduced to about 50% of surface values (Fig. 20). Unfortunately, more sophisticated measurements of spectral quality/quantity were not made, making further comparisons of production relative to specific wavelength penetration impossible.

Additional evidence of the significance of humic materials in attenuating light can be seen in examining the seasonal variation of Secchi disc transparency (Fig. 3a & 3b). There was some seasonal variation at all stations related to phytoplankton abundance, but the range between maximum and minimum values for all stations was small, 2.5 - 6.5, with a lake average for 1973 of <u>5.37m</u> (n = 97). Data gathered in 1947, 26 years ago, were remarkably similar to 1973 readings, ranging from 2.2 - 6.6 with a lake average of <u>5.42 m</u> (n ≃ 20). The similarity of average values indicates that transparency has changed little in 26 years, and that maximum values are set by humic materials, and minimum values by particulate autochthonous material.

Nutrients

Phosphorus, nitrogen, and silicate measurements in 1973 were too infrequent to allow meaningful relations to be made between nutrients and seasonal production. Though there were obvious inverse relations between NO_3, PO_4, SiO_2 and chlorophyll a concentrations and production, seldom did values for NO_3 and PO_4 drop below analytical detection limits. In 1963 and again in 1969, Stephen's et al (1969) conducted nutrient and chlorophyll a analyses. Again measurable quantities of NO_3 and PO_4 were always present, even during periods of chlorophyll maximums. Lowest values for NO_3 and PO_4 occurred in the North Arm, Morrison Arm, and opposite Old Fort Babine, in the north basin of the main lake. Generally higher values prevailed in more southern locations (Stephen's et al. 1969). Nitrate seldom fell below 0.15 mg liter^{-1} and phosphate 0.001 mg liter^{-1}. It is reasonable to assume that phosphate, and perhaps in certain situations, nitrate limit phytoplankton growth during calm conditions where little or no water movement occurs in the euphotic zone. These physical conditions occur more frequently in the sheltered north basin of the lake and it is here that nutrient limitation undoubtedly influences production the most (the interaction of nutrients and mixed layer depth will be discussed in later sections).

Since diatoms are the dominant phytoplankton group (by volume) in Babine, silicate concentrations could conceivably limit their growth. According to Lund (1950, 1954) *Asterionella formosa* and *Melosira italica* cannot grow sufficiently to maintain populations if external supplies fall below 0.5 mg liter^{-1}. In Babine, at most stations, values ranged from 5.6 - 1.4 mg liter^{-1} and never fell below 1.5 (Table 5). Though there was a measurable decline in silica commensurate with the autumnal bloom in the southern region (values fell from 4.0 to 2.5 mg liter^{-1}), values did not approach what could be considered critical limits for controlling growth. Thus, it appears unlikely that SiO_2 is a limiting factor to diatom phytoplankton growth in Babine.

For diatoms, carbon is the element needed in largest quantity after silica (Lund, 1954). In Babine pH fluctuated from 6.8 - 7.6, and alkalinity from 25 - 35 (expressed as mg $CaCO_3$ liter $^{-1}$). It is improbable that a potential carbon supply of this magnitude is ever limiting to algal growth. If it were diurnal pH readings would fluctuate widely, reaching values as high as 9 - 10 at mid-day during bloom conditions. Such conditions have never been observed in Babine Lake (Stephen's et al 1969).

Of a variety of other elements, only iron, manganese, and calcium have been shown to be of importance to phytoplankton if present in significantly reduced levels. Analyses of Babine waters for these constituents shows sufficient concentrations for plankton growth (Lund, 1950) (Table 9), and it seems unlikely that they would exert a rate controlling influence over phytoplankton production in Babine.

Mixing.

The depth of the mixed layer varied through the season; reduced as the lake warmed and stratification developed in mid-June, spatially transitory and unstable during summer months, and increased by autumn winds and cooler temperatures in September-October. Mixed layer depth in 1973 also showed a striking regional variation. In the North, Hagan and Morrison Arms, due to greater wind protection, a stable stratification and greatly reduced mixed layer (usually < 6 m) was typical, while from Topley Landing southward, greater exposure to strong summer winds created a less stable stratification and a greatly increased mixed layer (usually > 15 - 20 m).

In Babine the spatial differences in mixed layer depth strongly influenced phytoplankton production. There are both positive and negative effects to phytoplankton of increasing and/or decreasing the depth of the mixed layer:

Condition	Unstratified or strong mixing (deep epilimnion)	Stable Stratification or little mixing (shallow epilimnion)
Light	Little surface photoinhibition Average light available at any depth (I ave) $\frac{I_o}{D} \int_o^D \exp(-kz)\, dz$	Surface photoinhibition Light depth dependent and = $I_o \exp(-kz)$ Light decreases with increasing depth.
where:	I_o = light intensity at $z = o$; D = mixed layer depth k = extinction coefficient z = depth with respect to surface	
Nutrients	No shortage	Nutrient limitation
Temperature	Generally lower with uniform depth distribution	Generally higher, with greatest temperatures near surface, decreasing with depth.

Some general physical features of the various regions of Babine considered to be of importance to phytoplankton production are summarized in Table 10. It is quite likely that collectively, these differences among regions, and their attendant influence on chemistry (vertical and spatial distribution), are responsible for observed differences in primary production among regions (zones) of Babine Lake. For example, the lack of autumnal blooms in North, Morrison and Hagan Arms and the main basin of the lake north of Topley Landing, is likely attributable to a more stable and shallower mixed layer (5 - 7 m), common throughout the summer months in these regions. This more stable condition minimizes the entrainment of sufficient nutrients from the hypolimnion to sustain an autumnal maximum. By contrast, in the south basin where depth and volume of epilimnion are nearly double north basin values, upwelling commonly occurs at numerous locations throughout the summer after strong wind episodes, and nutrients from entrained hypolimnetic waters, as well as those recycled from the deeper epilimnion, are of sufficient concentration to sustain an autumnal bloom of considerable magnitude, assuming sufficient light during this period. The principal algal species responsible for the fall bloom is *Tabellaria fenestrata*, a large chain-forming diatom with an average cell volume of $3000\mu^3$, requiring turbulence to maintain its position within the euphotic zone. The same species exhibits lesser numbers in the lake north of Topley Landing, with the exception of Hagan Arm. This finding lends credence to our hypothesis, that the depth and stability of the mixed layer, with its more favourable nutrient regime, accounts for the marked regional differences in production, most notably the presence of the autumnal maximum of *Tabellaria fenestrata*.

Morphometric-edaphic considerations.

Other factors that may also account for regional differences in production are lake morphometric, watershed edaphic, and regional climatic influences. Babine lies in a NW-SW axes, with major outflow to the north west. Surrounding mountain ranges are a conspicuous feature of the north basin, creating an increase in both total precipitation and per cent cloud cover. To the south of Topley Landing a more gently rolling landscape is common with thousands of acres of forest land and upland plateau visible in all directions. Here less cloud and lighter precipitation occur. These physiographic differences create small, but perhaps significant, climatological differences. The prevalence of more wind of greater velocity and its effect on lake turbulence in the south basin has already been mentioned as an important factor.

Another important factor is differences in surface run-off. The main basin from Topley southward receives the major surface water inflow to Babine, comprising some 60 - 70% of total inflow. The north basin, excluding Morrison Arm, by contrast receives only 5 - 10% of annual inflow. Thus, differences in surface nutrient loads from these inflows contribute substantially to the total lake load which in concert with strong mixing, undoubtedly boosts production in the southern main lake region.

Mean depth in Zone 6 of the south basin, where production was highest, was 87.5 m, contrasted to 18.7 and 11.4 m in Zones 1 and 2, (North and Morrison Arms) (Table 1). It is difficult to conceive how the tremendous differences in hypolimnetic volume, mixed layer depth, and regional disparity of surface inflow, cannot have a strong influence on production among regions.

The Phosphorus Budget

No attempts have been made in the past to relate annual phosphorus input to trophic state of Babine Lake, presumably due to a lack of sufficient information. Enough data now exists, however, to provide a first order estimate that can be compared to similar estimates from other lakes. A recent hydrometeorologic inventory (Water Survey of Canada, 1974) provided sufficient data to compute a water balance for 72-73, which was essential to preparation of the phosphorus budget (Table 11). It must be kept in mind that the budget is based on relatively few stream nutrient observations and uses mean values which increase the confidence limits of their estimates.

The majority of the total phosphorus input to Babine comes from the major tributaries, notably the Fulton River. Altogether, up to 81% of the total 24,134 kg was contributed by surface stream flows and precipitation; salmon carcasses contributed only 19% to the total load (Table 11). It is important to note that by far the greatest portion of this surface inflow nutrient load is received in the middle and south basins of the lake.

About 7500 kg of TP or 30% of the total load leaves the lake yearly via the Babine River, which means that about 70% is retained, the majority of this no doubt lost to the sediments. It is interesting to note that of a total phosphorus load to Nilkitkwa of 7500 kg year^{-1}, 47% is retained, despite a 13% increase in flow of the Babine River as it meanders through the lake. Only about 3900 kg leaves Nilkitkwa which indicates this lake serves a very effective phosphorus sink and helps to explain the productive nature of its biocoenosis(Narver 1967, Stephen's et al. 1969).

Loading data to both Babine and Nilkitkwa when expressed on an areal basis and plotted on a log/log scale as a function of mean depth over theoretical residence time provides a basis for comparison of trophic state among lakes (Vollenweider, MS 1973) (Fig. 21). Babine sits comfortably in the oligotrophic range while Nilkitkwa lies close to the mesotrophic condition. The very short residence time (± 7 days) of Nilkitkwa with its luxurious growth of rooted aquatic macrophytes, which tie up considerable quantities of nutrients, no doubt protects this lake from experiencing severe water quality problems associated with phytoplankton blooms.

Additional evidence of regional differences in production

In the Results Section it was shown that among biological parameters assessed, namely, phytoplankton volume, numbers, chlorophyll a, ^{14}C assimilation, and seston, that there was an obvious regional disparity in production, the north exhibiting values often less than half those found at Stations to the south of Topley Landing. Annual mean values for primary production showed similar trends, and it was clear at the early stages of data analysis that the south portion of the main lake basin was considerably more productive than the north basin, which for analysis includes the discrete basins of Hagan and Morrison Arms. Results of statistical tests for means from Stations 1 - 5 in north and 6 - 10 in south have shown these differences to be significant (Table 12). Explanations to account for these differences based on the interplay between mixed layer depth, mean depth, nutrients, surface inflow, and the autumnal diatom maximum have already been advanced. However, if such large differences in spatial patterns of production have occurred historically, then other components of the biocoenosis should also reflect these differences. Moreover, the absolute abundance of diatoms in the sediments should mirror the 1973 diatom plankton time series record, which showed higher diatom population densities at southern stations (Figs. 7 & 8).

Zooplankton and Fish.

The zooplankton and underyearling sockeye populations of Babine have been well studied, as well as the predator-prey relations between their populations (Johnson 1956, 1958, Johnson and Groot 1963, Narver 1969, McDonald 1969). No attempt will be made to review this information in any detail here, rather to select information that might show regional differences in density or growth to substantiate or refute our findings.

By the June/July period 1956-63, there was a greater concentration of zooplankton ($mg.m^{-3}$) at stations south of Topley Landing that in the North Arm, and the densities in Hagan and Morrison Arms were also higher than the average North Arm value (Johnson 1964). In 1957-58 the mid-June to mid-October zooplankton mean dry weight in the 0-5 m layer was over a 100 mg. m^{-3} at locations south of Topley Landing, but averaged less than 50 in the North Arm (Johnson 1961). Corresponding data for the weight of age 0 sockeye populations in respective regions in mid-October were 4.7 and 3.5 g, respectively. The relation of food supply to predator growth rate cannot be ignored however, and could in part, but certainly not totally, account for these regional disparities.

McDonald (1969) has shown that mainlake fry from Fulton River disperse rather quickly to the south (Zone 6) and over the summer gradually move northward, with the population center just off Fulton River in October. The northern basin of the main lake (Zone 4) had the lowest fry densities. Spring migration route of Fulton fry seems to place them in an advantageous position in the most productive region of the lake, and, whether by coincidence or design, the lowest fry densities appear in one of the lowest production zones. In the past it was assumed that the carrying capacity for juvenile sockeye per unit of lake nursery area was similar throughout the lake "uniform distribution hypothesis" (Johnson 1961), but based on our findings, and on zooplankton density estimates, production per unit of lake area is unequal, being far greater in the region south of Topley Landing.

Paleolimnological Evidence. If diatom production is greater in the south because of the sustainment of the autumnal bloom of *Tabellaria fenestrata* (as we have shown to be true in 1973), and if this has occurred historically for decades, then the diatom micofossil record should substantiate our 1973 findings, as well as the observations of others. Johnson (M S 1965) noted an abundance of this diatom in net collections from the Clarke-Bumpus zooplankton tows taken in southern regions in the fall from 1956-63. Similar fouling of nets by *Tabellaria fenestrata* in fall zooplankton tows was noted in southern stations in 1973 (P. Rankin, personal communication).

Figure 22 illustrates the difference in total diatom production between Station 1 (core B1) in the North Arm and Station 8 (core B8) in the South Basin just off Donald's Landing. The integral value for the top ten cm of sediment show Station 8 to have produced over 3 times as many diatoms, spanning a time period of about 30 years (Stockner 1974). Of even greater significance is the paucity of *Tabellaria* frustules at Station 1, (North Arm), 7 million cm^{-3}, as opposed to 169 million cm^{-3} of wet sediment at Station 8 (Stockner 1974). With the exception of Morrison and Hagan Arms where a sizeable number of *Tabellaria* frustules appear in the sediments, no significant increase in *Tabellaria* is seen in the main lake until sediment core B6, taken just off Topley Landing. These findings substantiate our 1973 plankton counts and show rather conclusively that a regional disparity of production has occurred for decades and probably longer. It also illustrates the utility of paleolimnological studies done in conjunction with phytoplankton time series studies.

SUMMARY

The summary will consist of two parts, the first devoted to general lake-wide findings, the second summarizing main points by zone.

General

-The spring bloom was dominated by *Rhizosolenia longiseta,* followed closely by *Cyclotella stelligera. Melosira italica* and *Asterionella formosa* also exhibited peaks in June but of lesser magnitude.

-The fall bloom, where it occurred, was mainly *Tabellaria fenestrata,* with some increases of *Fragilaria* spp. also common.

-*Ankistrodesmus, Cryptomonas, Chromulina* and other flagellated Chrysophytes tended to increase following the decline of the diatom spring bloom.

-*Oscillatoria* and *Chroococcus* were the only blue-greens present in significant numbers, although *Anabaena* attained lesser prominence in the latter part of the season.

-Seston, chlorophyll a, and phytoplankton volume and numbers, followed the general pattern noted for primary production; namely, a spring peak, a second smaller increase in late June, summer decline and an autumnal peak at Station 6 - 10 at the south-end. Northern stations showed no autumnal maximums.

-It was common for all production parameters (chl. a, seston, ^{14}C) assimilation, phytoplankton numbers and volume, and nutrients) to indicate higher production in the south basin of the main lake (Zones 5 & 6).

-Disparity in regional production hypothesized to be related to lake physics and surface inflow disparity, notably the mixed layer depth, upwelling and attendant entrainment of hypolimnetic waters resulting from an unstable and highly variable thermocline depth common in south section of main lake coupled with a higher surface nutrient inflow. To the north greater stability of mixed layer, paucity of surface inflow, shallow thermocline, and much reduced mean depth leads to strong influence of nutrient limitation of phytoplankton growth.

-Babine Lake is classed dystrophic on the basis of humic materials, and mixotrophic in terms of annual primary production.

-Most phosphorus load comes from major surface inflows to the South Basin with salmon carcasses contributing a significant quantity of total phosphorus to the lake. On the basis of mean depth/residence time vs total phosphorus load (Vellenweider criteria) Babine classed as oligotrophic, Nilkitkwa as mesotrophic.

Zones

Zone 1 (Stn.1) North Arm

- Shallow basin, forms outlet of lake.
- Highest density of age 0 sockeye fry in lake.
- First area to freeze, last to thaw.
- Blue-greens dominate by number, diatoms by volume.
- Double spring peak in plot of numbers vs time caused almost exclusively by *Rhizosolenia* in first peak and *Cyclotella* in second.
- Spring peak in plot of volume vs time caused mainly by *Rhizosolenia*.
- In September has clearest water in lake - mean ext. coeff. 0.578.
- Has peak production in spring, no fall increase.
- Lowest annual production in lake.

- Plot of Secchi vs time shows Zones 1 and 2 to be very similar, with the lowest spring Secchi depths in the lake.
- Mean Secchi depth is considerably lower than in main lake, although this is due to very low spring values, as main lake Secchi's are lower than Zone 1's (or Zone 2's) in the fall.
- Has highest spring seston values and also highest mean seston value.
- Has lower mean chl.a and lower annual chl.a than Zones 2, 5 & 6, but higher than Zone 3 or 4; exhibited slight fall increase.
- Production curves show highest increase in spring; no fall peak observed.
- Next to Zone 2 had lowest phytoplankton volume in lake.

Zone 2 (Stn. 3) Morrison Arm

- Shallow basin; one of the major rivers of the watershed flows in to this basin.
- Freezes earlier than main lake and thaws later.
- Chrysophyceans dominant by number, diatoms by volume.
- Secchi variation similar to Zone 1.
- In fall had lower transparency than all zones but Zone 6.
- Small fall peak (numbers) caused mainly by Chrysophyceans. Fall peak (volume) caused by increase in other species, mainly *Ankistrodesmus* and *Cryptomonas*.
- Seston values peaked in spring. Mean seston values were higher than Zones 3 and 4, but lower than other zones.
- Primary production was highest among north basin zones (1 - 4).
- Chl. a was highest of all north basin zones (1 - 4).
- Slight autumnal phytoplankton increase.
- Phytoplankton volume lowest in the lake.
- Total alkalinity lower than lake average.

Zone 3 (Stn. 5) Hagan Arm

- Isolated from main lake and only true, discrete basin.
- Numerically, major groups (Chrysophyceans, blue-greens, and diatoms) were in almost equal proportions.
- By volume, diatoms were the major group.
- *Cyclotella* and *Rhizosolenia* were only diatoms present in considerable numbers, with *Cyclotella* considerably more abundant than *Rhizosolenia* from end of June onward.
- Secchi values showed little variation through the season, and mean Secchi was higher than all areas but Zone 4.
- Seston peaked in spring. Mean seston value was lowest in lake, except Zone 4.
- Chl. a values were lowest in lake.
- Phytoplankton volume was similar to that noted in Zone 4.
- Primary production was higher than in Zones 1 and 4, but lower than the remainder, no fall peak apparent.

Zone 4 (Stn. 2 & 4) North basin, main lake

- Blue-greens dominant by numbers, diatoms by volume.
- Spring peak occurred 2 weeks later than any other north end zones.
- Diatoms and blue-greens were most abundant at the end of June; Chrysophyceans at the end of July.
- Fall phytoplankton increase (numbers) consisted mainly of blue-greens and Chrysophyceans, *Oscillatoria, Chromulina, Chroococcus.*
- Fall increase (volume) mainly diatoms *Cyclotella, Rhizosolenia, Tabellaria.*
- Mean extinction coefficient in fall only slightly greater than Zone 5, and lower than Zone 1.
- Chl. a values peaked at end of June and again in mid-September.

- Lowest Chl. a values in lake, albeit similar to Zone 3.
- Phytoplankton volume similar to Zone 3.
- Primary production peaked mid-June and again at the end of September.
- Primary production lowest in lake next to Zone 1.
- Mean Secchi highest of entire lake, but high variance.
- Mean seston value lowest of entire lake.
- Seston values peaked in spring, then decreased for the remainder of season.

Zone 5 (Stns. 6 & 7) Middle south basin, main lake.

- Blue-green dominant by number, diatoms by volume.
- Phytoplankton abundance showed a peak of three major groups in mid-June, and a second blue-green peak in late July.
- Fall peak (numbers) was at end of September and caused predominantly by blue-greens.
- Spring peak (volume) was in mid-June, composed mainly of diatoms - *Rhizosolenia, Cyclotella, Melosira,* and *Asterionella.*
- Fall peak (volume) caused primarily by diatoms (*Fragilaria & Tabellaria*)
- Mean extinction coefficient lowest in lake, with exception of Zones 2 and 6.
- From 7.0 m in mid-May, Secchi values decreased to 4.5 m by end of June, increased to 5.5 m through summer, and decreased to 5.0 m in early October.
- Mean Secchi was similar to Zone 6, and was lower than those of Zone 3 or 4.
- Seston peaked at the end of May and decreased through remainder of season.
- Mean seston highest in lake (although similar to Zone 6).
- Chl. a peaked at the end of June and again at end of September.
- Mean Chl. a was only slightly less than Zone 6, and was higher than any other Zone.
- Phytoplankton ($\bar{x}$ $mm^3 . m^{-3}$ and $cm^3 . m^{-3}$ .275 $days^{-1}$) volume was slightly less than Zone 6 and considerably higher than any other Zone.
- Primary production peaked in latter half of June and again in mid-September.

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TABLES

TABLE 1. Babine Lake Morphometry by Zone

ZONE	AREA[1] Km^2	VOLUME m^3 x 10^6	$\bar{z}$ MEAN DEPTH m	Z_m MAX.DEPTH m	L Km	D_L	l Km	$\bar{X}$ ANNUAL DISCHARGE m^3 sec.$^{-1}$	Theoretical Resident Time
1	53.40	1,076	18.7	46	-	-	39.8		
2	17.72	202	11.4	31	-	-	13.4		
3[2]	49.25	931	25.0	83	-	-	9.0		
4[2]	73.32	5,090	62.8	144	-	-	25.5		
5[2]	164.26	8,065	51.9	141	-	-	39.5		
6	132.76	11,646	87.5	186	-	-	45.5		
LAKE TOTAL	490.71	27,010	55.1	186	364.7	7.19	150	47.01[3]	18.22 yrs.

1. After Johnson (1965b)
2. Extropolated from Johnson (1965b)
3. From 1945 - 1970 (Water Survey Data)

Table 2: Station locations, maximum depth, and number of production sets in phytoplankton program 1973.

Production Station No.	Zone	Location	Maximum Depth (m)	No. of Production Sets May - October
1	1	300 m NNW of Wolverine Point	28	9
2	4	1.5 km WNW of Old Fort	65	9
3	2	Mid-channel; 4.0 km from head of Morrison Arm	28	9
4	4	6.5 km ESE of Old Fort	130	9
5	3	6.0 km from head of Hagan Arm; 400 m from east shore	88	9
6	5	2.0 km NE of Topley Landing	105	9
7	5	5.0 km NW of Pierre Creek	110	9
8	6	2.0 km NNE of Donald's Landing	175	10
9	6	1.2 km S of Boling's Point	185	11
10	6	1.8 km NNW of Four-Mile Creek	140	9
			Total	93

TABLE 3. Mean extinction coefficients for Babine Lake during the September-October period.

Zone	Mean Extinction Coefficients (k)	#of OBS.
1	.577	2
2	.669	3
3	.593	2
4	.593	4
5	.598	4
6	.771	6

Table 4a. Seasonal average values by Zone of selected parameters: (as in title 4b - see 4b).

Zone	$\bar{x}$ Secchi Depth	$\bar{x}$ Dry Seston $g \cdot m^{-3}$	$\bar{x}$ mg Chl.a $\cdot m^{-3}$ g Chl.a $\cdot m^{-3} \cdot 275\ days^{-1}$	$\bar{x}$ Phytopl. Vol. $(mm^3 \cdot m^{-3})$ $cm^3 \cdot m^{-3} \cdot 275\ days^{-1}$	$gC \cdot m^{-2} \cdot 275\ days^{-1}$
1 (1)[a]	4.5	1.74	1.64 0.28	159.19 24.67	23.20
2 (3)	4.3	1.47	2.08 0.33	105.02 17.43	29.70
3 (5)	5.8	1.35	1.51 0.26	175.52 27.70	29.30
4 (2,4)	5.9	1.21	1.42 0.26	164.99 29.70	27.70
5 (6,7)	5.4	1.63	2.17 0.37	373.28 65.26	36.80
6 (8,9, 10)	5.5	1.57	2.18 0.38	381.67 66.91	42.0

[a] number in parentheses indicates station which occurs in zone

Table 4b. Seasonal average values by <u>Station</u> of selected parameters: Secchi depth, seston, chl <u>a</u>, phytoplankton volume, areal production (season total).

Station	$\bar{x}$ Secchi Depth (m)	$\bar{x}$ Dry Seston $g \cdot m^{-3}$	a. $\bar{x}$ mg Chl. <u>a</u> $\cdot m^{-3}$ b. xg Chl <u>a</u> $\cdot m^{-3} \cdot 275$ days^{-1}	c. $\bar{x}$ Phytopl. Vol. ($mm^3 \cdot m^{-3}$) d. $cm^3 \cdot m^{-3} \cdot 275$ days^{-1}	$gC \cdot m^{-2} \cdot 275$ days^{-1}
1	4.5	1.74	1.64[a.] 0.28[b.]	159.19[c.] 24.67[d.]	23.20
2	5.8	1.21	1.23 0.24	138.31 25.55	25.60
3	4.3	1.47	2.08 0.33	105.02 17.43	29.70
4	6.0	1.20	1.60 0.27	191.66 33.84	29.80
5	5.8	1.35	1.51 0.26	175.52 27.70	29.30
6	5.4	1.61	2.00 0.35	269.81 49.11	42.80
7	5.4	1.64	2.10 0.38	476.74 81.40	30.70
8	5.9	1.55	1.89 0.33	344.38 63.28	34.70
9	5.3	1.76	1.70 0.31	324.49 59.90	38.60
10	5.3	1.40	2.95 0.50	476.13 77.54	52.60

Table 5. Seasonal variation of selected chemical parameters (after Smith & Davidson, MS 1974).

Station No. and Location.	Date 1973	TPO_4 g.m^{-3}	PO_4 g.m^{-3}	NO_2-NO_3 g. m^{-3}	SiO_2 g . m^{-3}	Cond.	T. Alk. g · m^{-3} $CaCO_3$
1(10)[a] (zone 6)	5/6	<.01	<.02	.05	2.0	91.4	37.5
	18/7	<.01	<.02	.07	3.9	78.0	-
	30/9	<.01	<.02	.07	3.6	97.3	-
	$\bar{x}$	<.01	.02	.06	3.2	88.9	37.5
2(9) (zone 6)	6/6	<.01	<.02	.06	2.0	86.8	34.3
	18/7	.01	<.02	.07	3.9	86.0	-
	30/9	.01	<.02	.07	3.6	84.8	-
	$\bar{x}$	.01	<.02	.07	3.2	85.9	34.3
3(8) (zone 6)	6/6	<.01	<.02	.05	1.9	91.7	36.4
	18/7	.02	<.02	.08	3.8	79.0	-
	30/9	<.01	<.02	.06	3.2	65.9	-
	$\bar{x}$	.01	<.02	.06	3.0	78.9	36.4
4(7) (zone 5)	6/6	<.01	<.02	.05	1.9	91.8	36.7
	18/7	.016	<.02	.07	3.8	77.0	-
	30/9	.016	<.02	.07	3.9	85.0	-
	$\bar{x}$	.014	<.02	.06	3.2	84.6	36.7
5(4) (zone 4)	6/6	<.01	<.02	.05	1.9	92.0	36.2
	18/7	.012	<.02	.08	3.8	82.0	-
	30/9	<.01	<.02	.07	4.1	72.3	-
	$\bar{x}$	.01	<.02	.07	3.3	82.1	36.2
6(3) (zone 2)	6/6	.034	<.02	.03	2.0	74.7	30.8
	13/7	<.01	<.02	.08	3.7	78.0	-
	30/9	<.01	<.02	.06	4.1	100.3	-
	$\bar{x}$	.018	<.02	.06	3.3	84.3	30.8
7(1) (zone 1)	6/6	-	-	-	-	-	-
	13/7	-	-	-	-	-	-
	1/10	<.01	<.02	.07	4.3	119.5	-
	$\bar{x}$	<.01	<.02	.07	4.3	119.5	-

[a] number in parentheses indicates the closest production station.

TABLE 6. Major Algal Species in Babine Lake.

I. CYANOPHYTA

Anabaena sp
Chroococcus sp.
Gloeocapsa sp.
Merismopedia sp.
Oscillatoria sp.

II. PYRRHOPHYTA

DINOPHYCEAE

Gymnodinium sp.
Ceratium sp.
Peridinium sp.

III. CRYPTOPHYTA

Cryptomonas sp.

IV. CHLOROPHYTA

CHLOROPHYCEAE

Gloeocystis sp.
Ankistrodesmus sp.
Oocystis sp.
Quadrigula sp.
Golenkiniopsis sp.
Raphidonema sp.
Closterium sp.
Cosmarium sp.
Staurastrum sp.

V. CHRYSOPHYTA

CHRYSOPHYCEAE

Chromulina sp.
Chrysocapsa sp.
Dinobryon sp.
Mallomonas sp.
Synura sp.
Chrysochromulina sp.

BACCILARIOPHYCEAE

O. BIDDULPHIALES

Coscinodiscus spp.
Melosira italica
Melosira distans
Stephanodiscus astrea
Stephanodiscus spp.
Cyclotella stelligera
C. bodanica
C. ocellata
C. comta

O. BACCILARIALES

Asterionella formosa
Achnanthes spp.
Cocconeis spp.
Cymbella spp.
Fragilaria crotonensis
Fragilaria construens
Gomphonema spp.
Epithemia spp.
Navicula spp.
Nitzschia spp.
Rhopalodia spp.
Rhizosolenia longiseta
Rhizosolenia sp.
Tabellaria fenestrata
Tabellaria flocculosa
Synedra spp.

Table 7a. MAJOR SPECIES BY NUMBER

ZONE 1	ZONE 2	ZONE 3
Chroococcus sp.	Chromulina sp.	Chroococcus sp.
Chromulina sp.	Chroococcus sp.	Chromulina sp.
Oscillatoria sp.	Cyclotella spp.	Cyclotella spp.
Cyclotella spp.	Oscillatoria sp.	Oscillatoria sp.
Rhizosolenia longiseta	Chrysochromulina sp.	Chrysochromulina sp.
Asterionella formosa	Rhizosolenia longiseta	Rhizosolenia longiseta

ZONE 4	ZONE 5	ZONE 6
Oscillatoria sp.	Oscillatoria sp.	Oscillatoria sp.
Chroococcus sp.	Chroococcus sp.	Chroococcus sp.
Chromulina sp.	Chromulina sp.	Chromulina sp.
Cyclotella spp.	Cyclotella spp.	Fragilaria spp.
Rhizosolenia longiseta	Rhizosolenia longiseta	Cyclotella spp.
Melosira spp.	Chrysochromulina sp.	Chrysochromulina sp.

Table 7b.

MAJOR SPECIES BY VOLUME

ZONE 1

Rhizosolenia longiseta
Tabellaria fenestrata
Chromulina sp.
Asterionella formosa
Cyclotella spp.
Ankistrodesmus sp.

ZONE 2

Rhizosolenia longiseta
Chromulina sp.
Tabellaria fenestrata
Cyclotella spp.
Ankistrodesmus sp.
Chrysochromulina sp.

ZONE 3

Rhizosolenia longiseta
Chromulina sp.
Tabellaria fenestrata
Cyclotella spp.
Ankistrodesmus sp.
Chrysochromulina sp.

ZONE 4

Rhizosolenia longiseta
Tabellaria fenestrata
Chromulina sp.
Melosira spp.
Cyclotella spp.
Fragilaria spp.

ZONE 5

Rhizosolenia longiseta
Tabellaria fenestrata
Chromulina sp.
Fragilaria spp.
Cyclotella spp.
Melosira spp.

ZONE 6

Tabellaria fenestrata
Rhizosolenia longiseta
Fragilaria spp.
Chromulina sp.
Chrysochromulina sp.
Melosira spp.

TABLE 8. Summary of maximum, minimum and mean assimilation number (mg C .mg Chl a^{-1}. day^{-1}) by Station in Babine Lake[1]

	Station	No.	Maximum	Minimum	Mean
NORTH	1	8	17.79	2.82	9.83
	2	8	24.61	6.26	13.66
	3	7	14.01	4.30	9.12
	4	7	22.14	6.92	11.93
	5	8	29.55	5.09	14.89
					11.89 AVE.
SOUTH	6	8	28.00	5.90	15.96
	7	7	52.60	5.39	17.74
	8	8	46.67	4.90	17.97
	9	9	38.69	7.66	17.04
	10	7	38.52	6.67	16.08
					16.96 AVE.

1. The values given here are *in situ* on a daily basis, and were not computed at saturation in an incubator. The number θ was computed from values of production in the 0 - 20 m range and Chl. *a* values on the same day and similar depth range, thus

$$\theta = \frac{\bar{x}\ \text{mgC .m}^{-3}\text{. day}^{-1}}{\bar{x}\ \text{mg Chl. a .m}^{-3}} \quad \text{, and}$$

represents the rate of primary production per unit of chlorophyll *a*.

TABLE 9. Analysis of selected ions at four stations in Babine Lake, August 3, 1972.

Mg liter^{-1}

Station	Depth	Ca	Na	Zn	Cu	Fe	Cd	K	Mn	Al
S. Pinkut	0	5.3	.83	.04	<.01	.07	<.03	.35	.01	5.8
(Zone 6)	5	2.8	.45	.08	<.01	.07	<.03	-	.01	3.4
	20	8.5	1.70	.02	<.01	.03	<.03	.66	.08	9.2
Port Arthur	0	9.5	1.75	.02	<.01	.03	<.03	.60	.01	11.0
(Zone 5)	5	6.3	0.91	.01	<.01	.03	<.03	.30	.01	7.2
	20	9.5	1.80	.04	<.01	.03	<.03	.55	.03	10.0
Old Fort	0	9.1	1.40	.05	<.01	.03	<.03	.55	<.01	11.0
(Zone 4)	5	9.7	1.60	.02	<.01	.04	<.03	.60	<.01	11.0
	20	9.1	1.50	.02	<.01	.03	<.03	.55	<.01	11.0
Black Point	0	9.0	1.40	.02	<.01	.03	<.03	.50	<.01	10.0
(Zone 5)	5	8.8	1.45	.02	<.01	.03	<.03	.55	<.01	10.0
	20	9.1	1.70	.02	<.01	.03	<.03	.55	<.01	11.0
	Ave.	8.1	1.37	.03	<.01	.037	<.03	.52	.017	9.22

TABLE 10. Physical features of importance to primary production.

Location	Characteristics
North Arm (Zone 1)	- First to stratify, first to turn over in autumn; stratification more stable than main lake Zones. - Average summer thermocline, 5 - 7 meters. - A warmer surface layer in summer than other Zones. - In winter, warmer deep water. - Less wind, more protected. - Receives little surface inflow.
Morrison Arm (Zone 2)	- One of the first to stratify and first to turn over in autumn; stratification more stable than main lake Zones. - Average summer thermocline, 5 - 6 meters. - Warm surface layer. - Less wind, more protected. - Received substantial inflow from Morrison River.
Hagan Arm (Zone 3)	- Stratification early, but not as soon as North or Morrison Arms, same for fall overturn. - Stable stratification. - Average summer thermocline 5 - 6 meters. - Less wind, more protected. - Receives no surface inflow.
North basin - main Lake (Zone 4)	- Stratification much later than previous Zones. - Mixed layer depth variable. - Some wind effect, more turbulence in epilimnion. - May receive some nutrients from Town of Granisle. - Receives insignificant surface inflow.
South basin - main Lake (Zones 5 & 6)	- More wind, of greater strength, pronounced wind mixing. - Unstable thermocline, upwelling common. - Ice-out first, in last. - Receives major inflow to lake - Fulton, Pinkutt, Sutherland Rivers.

Table 11. Total phosphorus budget, 1972-73 Babine Lake

	$m^3 \times 10^9$ $year^{-1}$	Total Phosphorus $mg. m^{-3}$	Load TP Kg $year^{-1}$	%TP From all sources
Inflow[a]				
Fulton R.	.6929	10.0[d]	6,929	29
Pinkut R.	.2604	10.0[d]	2,604	11
Morrison R.	.2027	7.5[d]	1,489	6
Remaining tributaries[b]	.9640	7.5[d]	7,230	30
Precipitation[c]	.2920	4.8[e]	1,392	6
Salmon carcasses[e]	--	--	4,490	19
Total	2.3000		24,134	
Outflow[a]				
Babine R.	2.1200	3.5[f]	7,428	31
Evaporation[c]	.1800			
Total	2.3000		7,428	

- Incipient TP concentration in Babine 0.89 mg. m^{-3}
- Percentage TP lost *via* outflow 31%
- Percentage TP retained 69%
- Areal loading rate 0.05 g TP. m^{-2}. $year^{-1}$

a. May 72 to May 73 (Water Survey of Canada, 1974)

b. Obtained by difference

c. Babine Lake Steering Committee, Annual Report, 1973

d. Avg. from low flow determinations - values increased to account for increases during spring freshet

e. From Donaldson (1967) f. avg. from Stephens *et al*. (1969)

TABLE 12. Results of "t" test statistic[a] testing the significance of north/south regional production disparities.

Parameter	Degrees Freedom	Significance Level
PROD. - t = 3.11 (gC.m^{-2} .275 day^{-1})	df = 8	$p < .02$
PHYTOPL. - t = 6.24 (cm^3 m^{-3} .275 $days^{-1}$)	df = 8	$p < .01$
CHL a - t = 2.665 (g CHL a m^{-3} .275 $days^{-1}$)	df = 8	$p < .05$
SESTON - t = 1.710 ($\bar{x}$ g.m^{-3})	df = 8	$p < .2$

[a] "t" = $\dfrac{(\bar{x} - \bar{y})}{s\sqrt{\frac{1}{n} + \frac{1}{m}}}$ (n + m - 2) d.f.

FIGURES

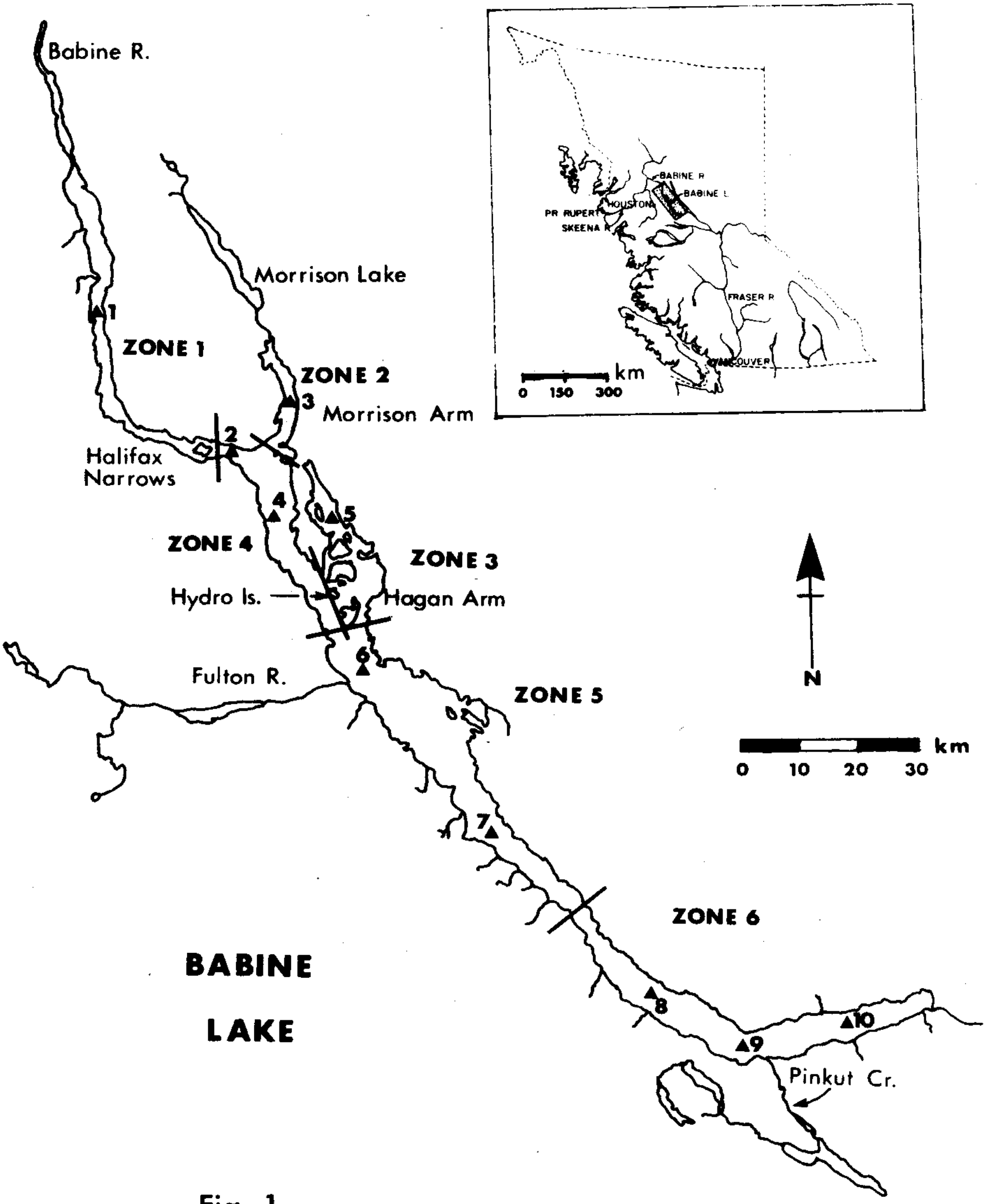

Babine R.
Morrison Lake
ZONE 1
ZONE 2
1
2
3
Morrison Arm
Halifax Narrows
4
5
ZONE 4
ZONE 3
Hydro Is.
Hagan Arm
6
Fulton R.
ZONE 5
7
ZONE 6
BABINE LAKE
8
9
10
Pinkut Cr.
N
km
0
10
20
30
BABINE R
BABINE L
HOUSTON
PR RUPERT
SKEENA R
FRASER R
VANCOUVER
km
0
150
300

Fig. 1

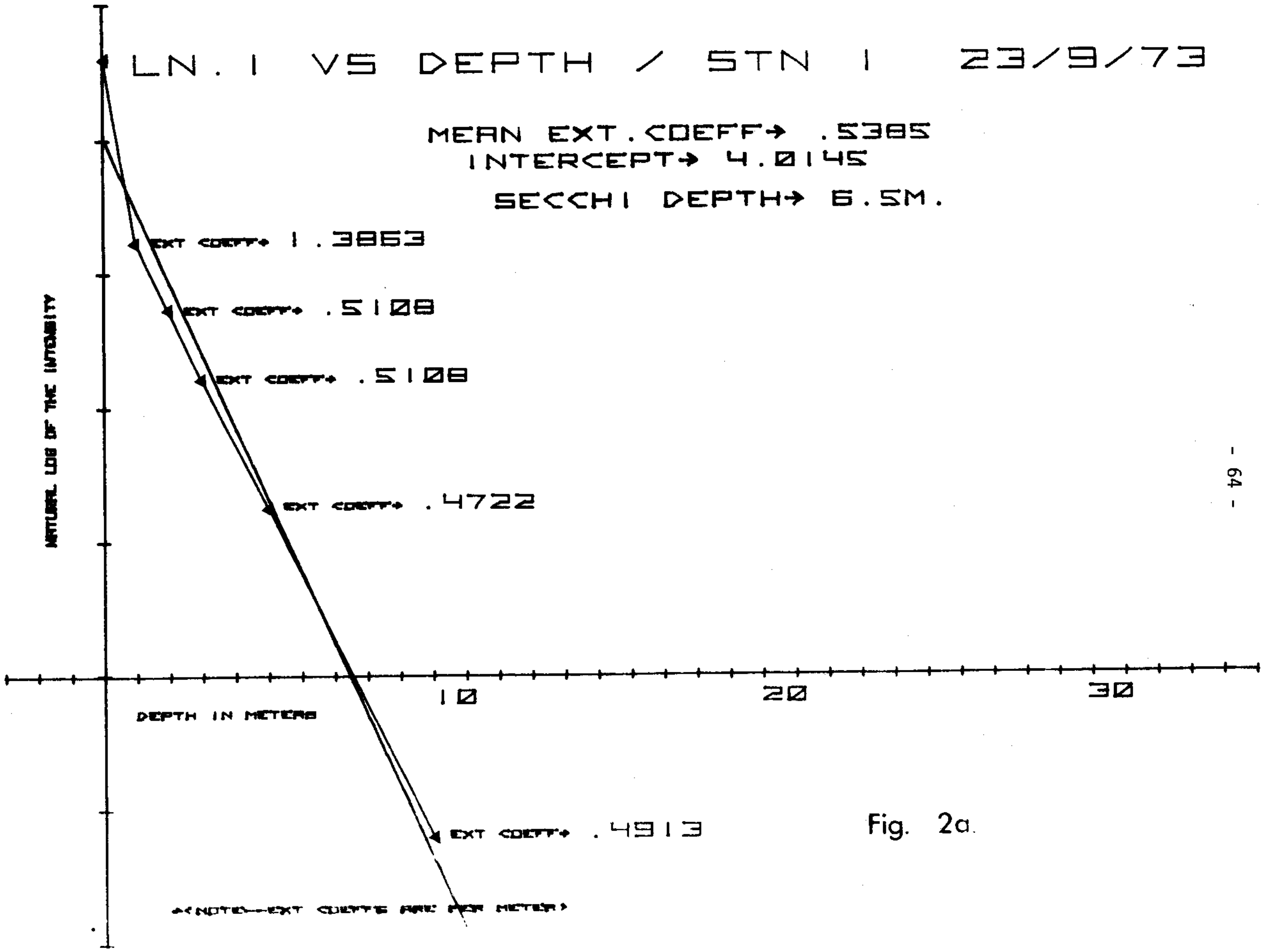

LN. I VS DEPTH / STN 1 23/9/73
MEAN EXT.COEFF→ .5385
INTERCEPT→ 4.0145
SECCHI DEPTH→ 6.5M.
EXT COEFF→ 1.3863
EXT COEFF→ .5108
EXT COEFF→ .5108
EXT COEFF→ .4722
EXT COEFF→ .4913
NATURAL LOG OF THE INTENSITY
DEPTH IN METERS
10
20
30
←<NOTE--EXT COEFFS ARE PER METER>

Fig. 2a.

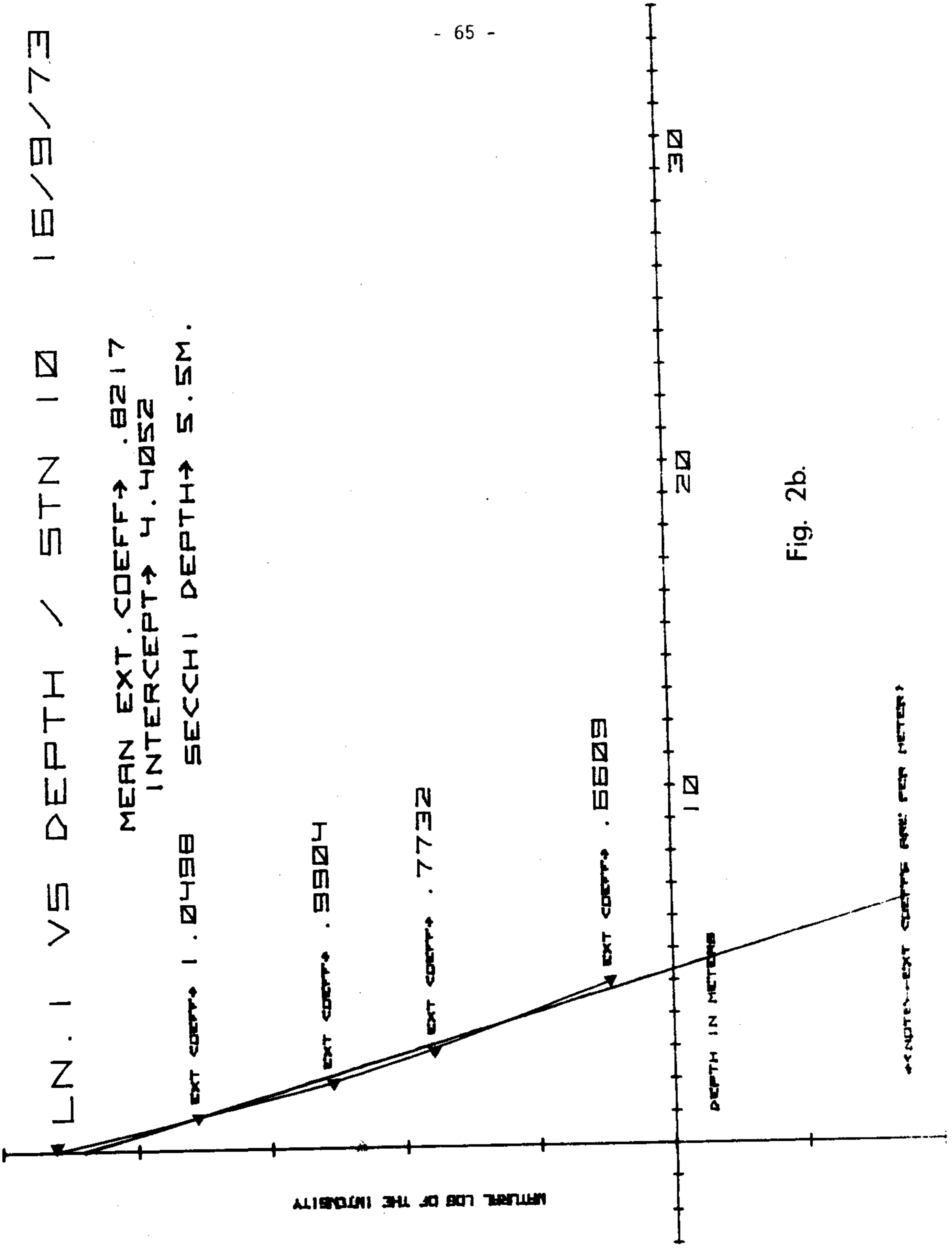

LN. I VS DEPTH / STN 10 16/9/73
MEAN EXT. COEFF→ .8217
INTERCEPT→ 4.4052
SECCHI DEPTH→ 5.5M.
EXT COEFF→ 1.0498
EXT COEFF→ .9904
EXT COEFF→ .7732
EXT COEFF→ .6609
10
20
30
DEPTH IN METERS
NATURAL LOG OF THE INTENSITY
*<NOTE>--EXT COEFF'S ARE PER METER>

Fig. 2b.

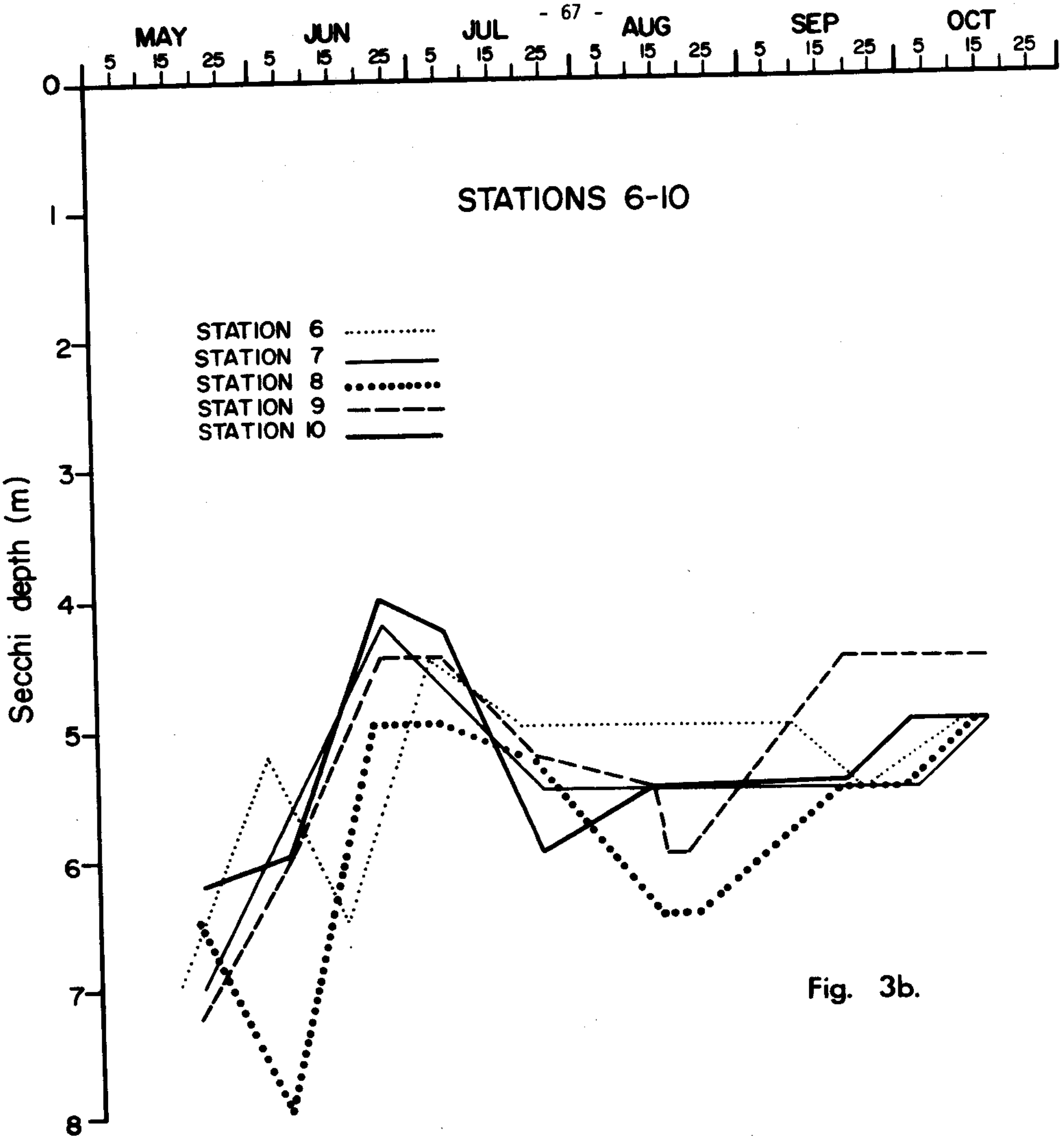
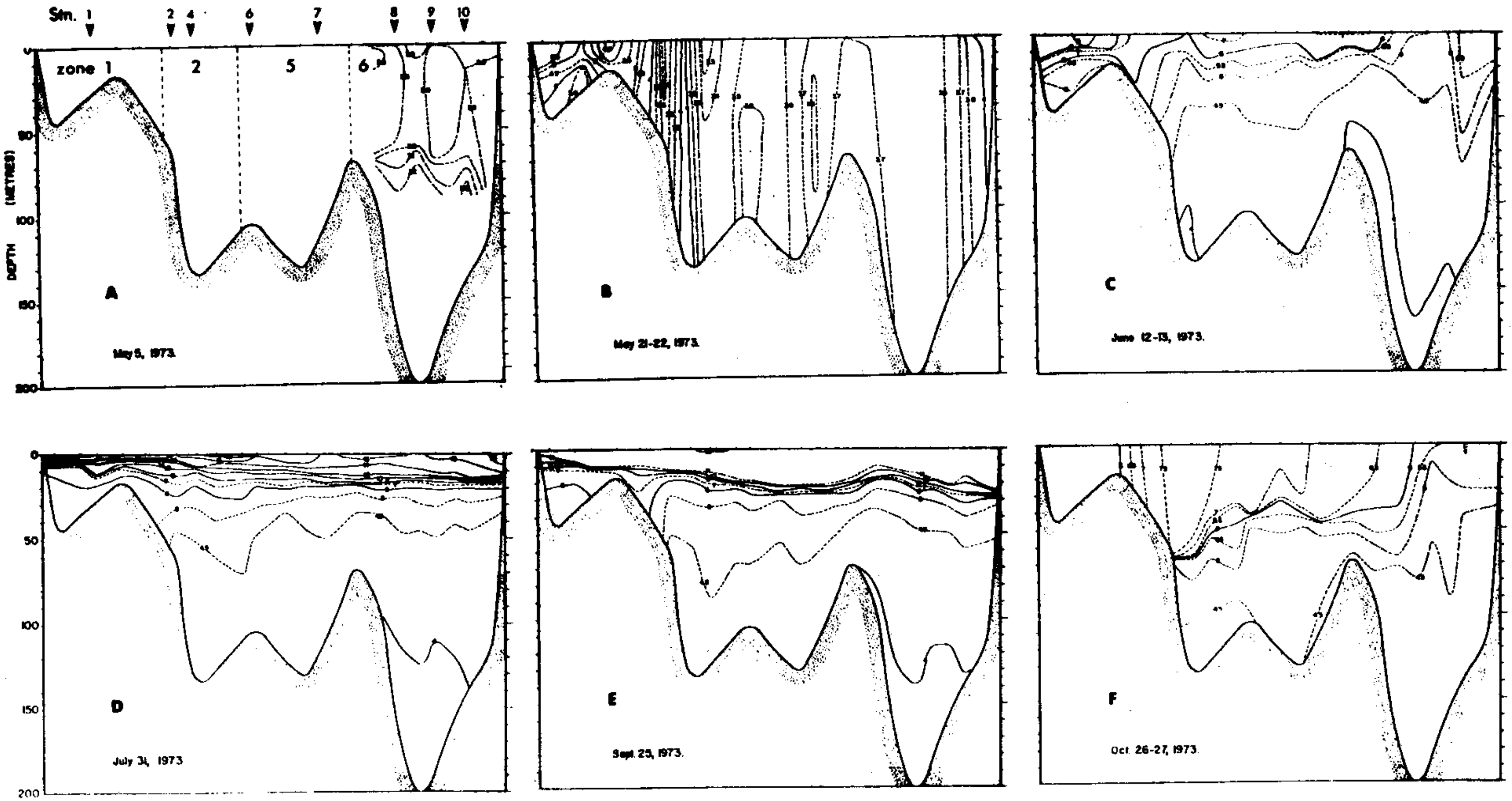

MAY
JUN
JUL
AUG
SEP
OCT
5
15
25
0
1
2
3
4
5
6
7
8
Secchi depth (m)
STATIONS 6-10
STATION 6
STATION 7
STATION 8
STATION 9
STATION 10

Fig. 3b.

Fig. 4


Stn. 1
2
4
6
7
8
9
10
zone 1
2
5
6
DEPTH (METRES)
0
50
100
150
200
A
May 5, 1973.
B
May 21-22, 1973.
C
June 12-13, 1973.
D
July 31, 1973
E
Sept. 25, 1973.
F
Oct. 26-27, 1973.

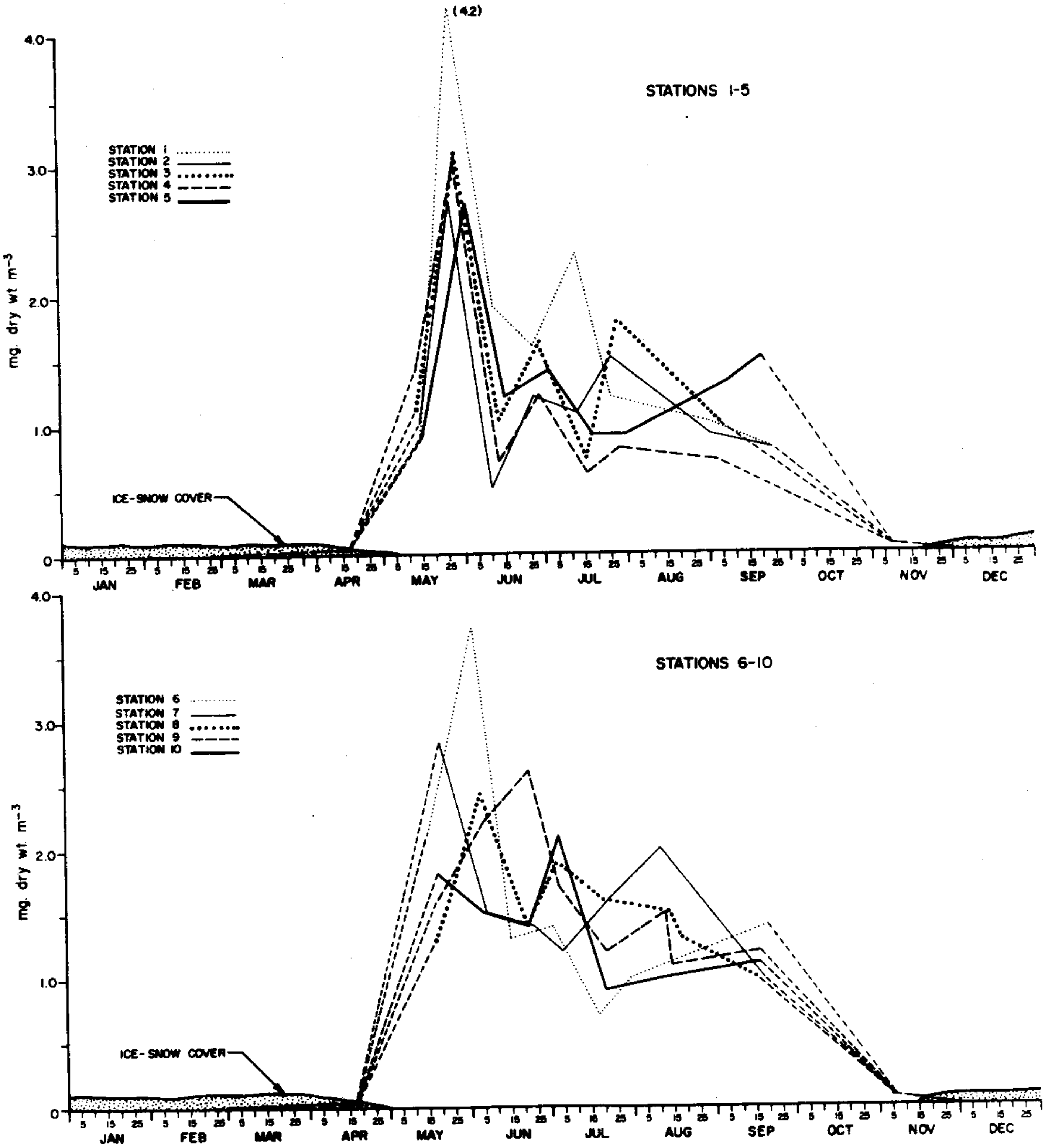

(4.2)
STATIONS 1-5
STATION 1
STATION 2
STATION 3
STATION 4
STATION 5
mg. dry wt m-3
4.0
3.0
2.0
1.0
0
ICE-SNOW COVER
5 15 25
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
STATIONS 6-10
STATION 6
STATION 7
STATION 8
STATION 9
STATION 10

Fig. 5

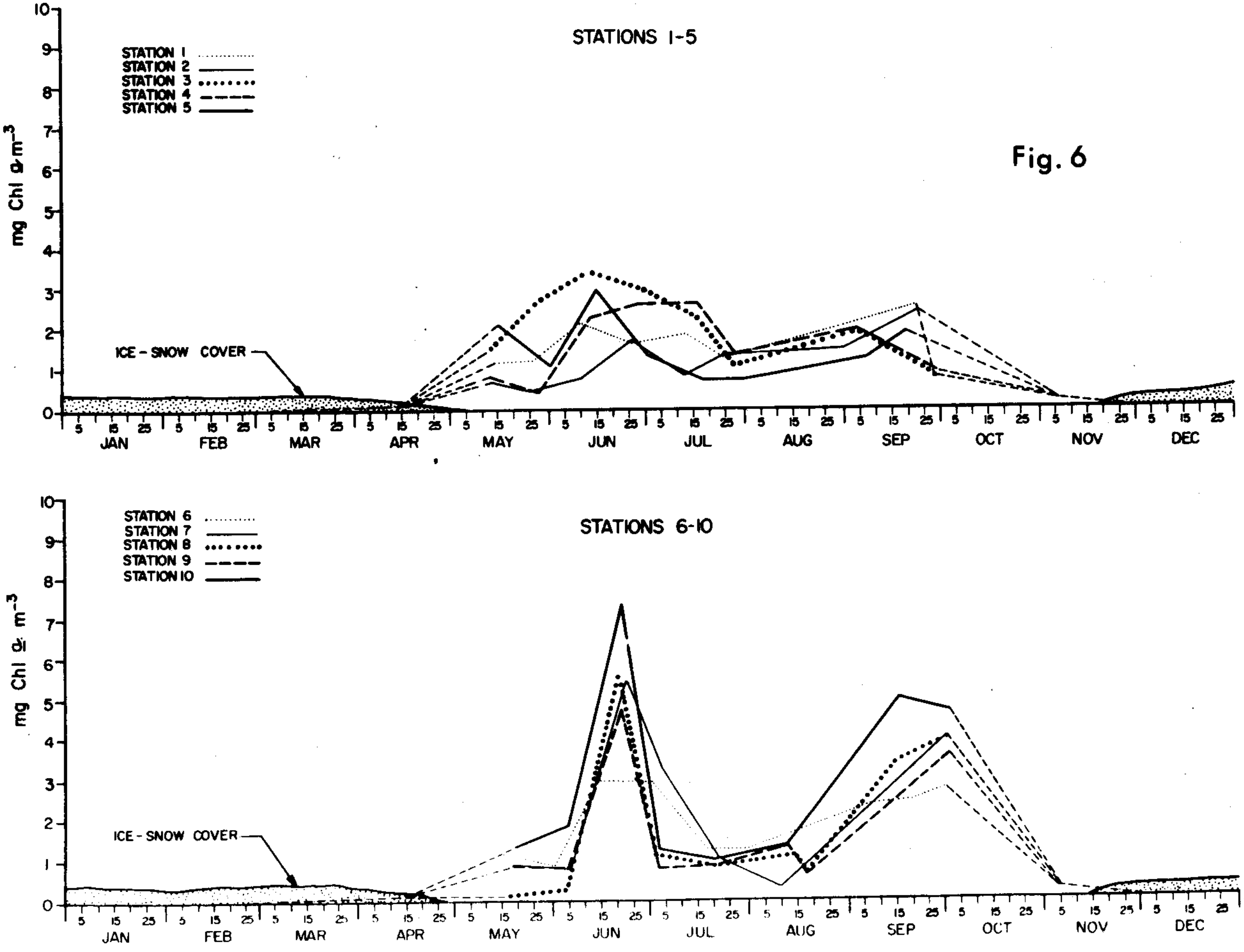


Fig. 6

STATIONS 1-5
STATION 1
STATION 2
STATION 3
STATION 4
STATION 5
ICE - SNOW COVER
mg Chl a m^{-3}
0
1
2
3
4
5
6
7
8
9
10
5 15 25
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
STATIONS 6-10
STATION 6
STATION 7
STATION 8
STATION 9
STATION 10
ICE - SNOW COVER
mg Chl a m^{-3}

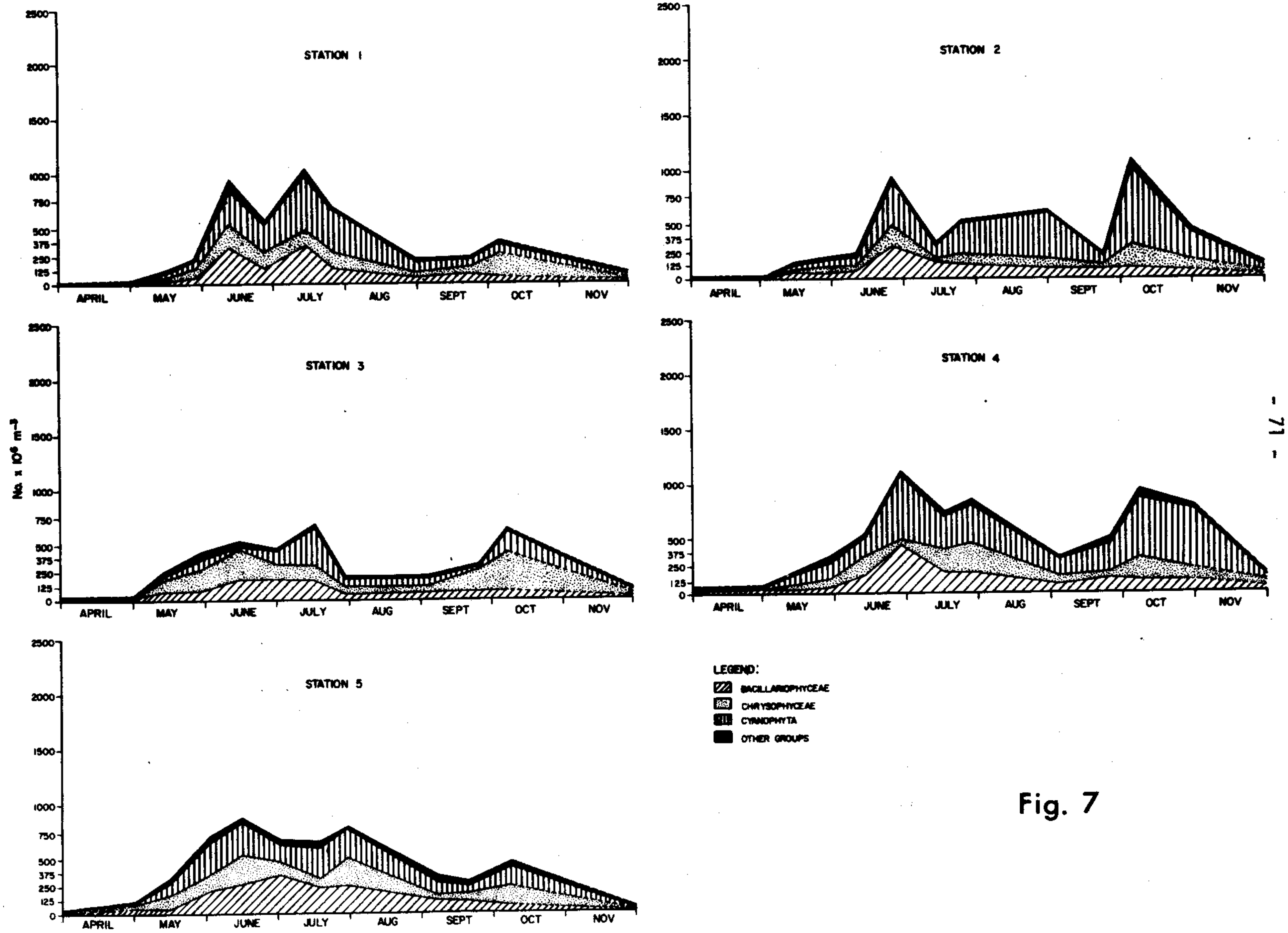

STATION 1
STATION 2
STATION 3
STATION 4
STATION 5
No. x 10^6 m^{-3}
2500
2000
1500
1000
750
500
375
250
125
0
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
LEGEND:
▨ BACILLARIOPHYCEAE
▒ CHRYSOPHYCEAE
▥ CYANOPHYTA
■ OTHER GROUPS

Fig. 7

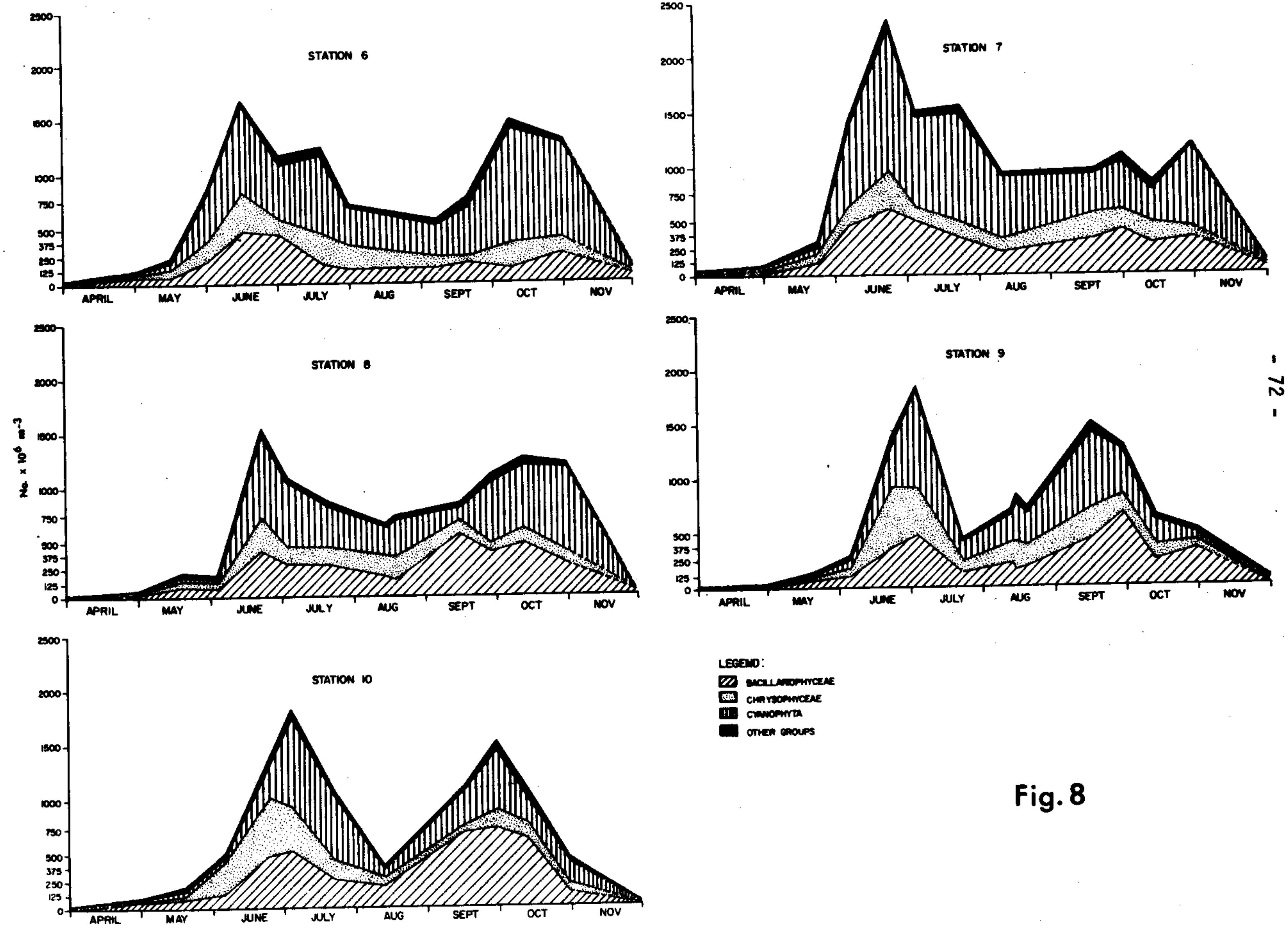

STATION 6
STATION 7
STATION 8
STATION 9
STATION 10
No. x 10^6 m^-3
2500
2000
1500
1000
750
500
375
250
125
0
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
LEGEND:
BACILLARIOPHYCEAE
CHRYSOPHYCEAE
CYANOPHYTA
OTHER GROUPS

Fig. 8

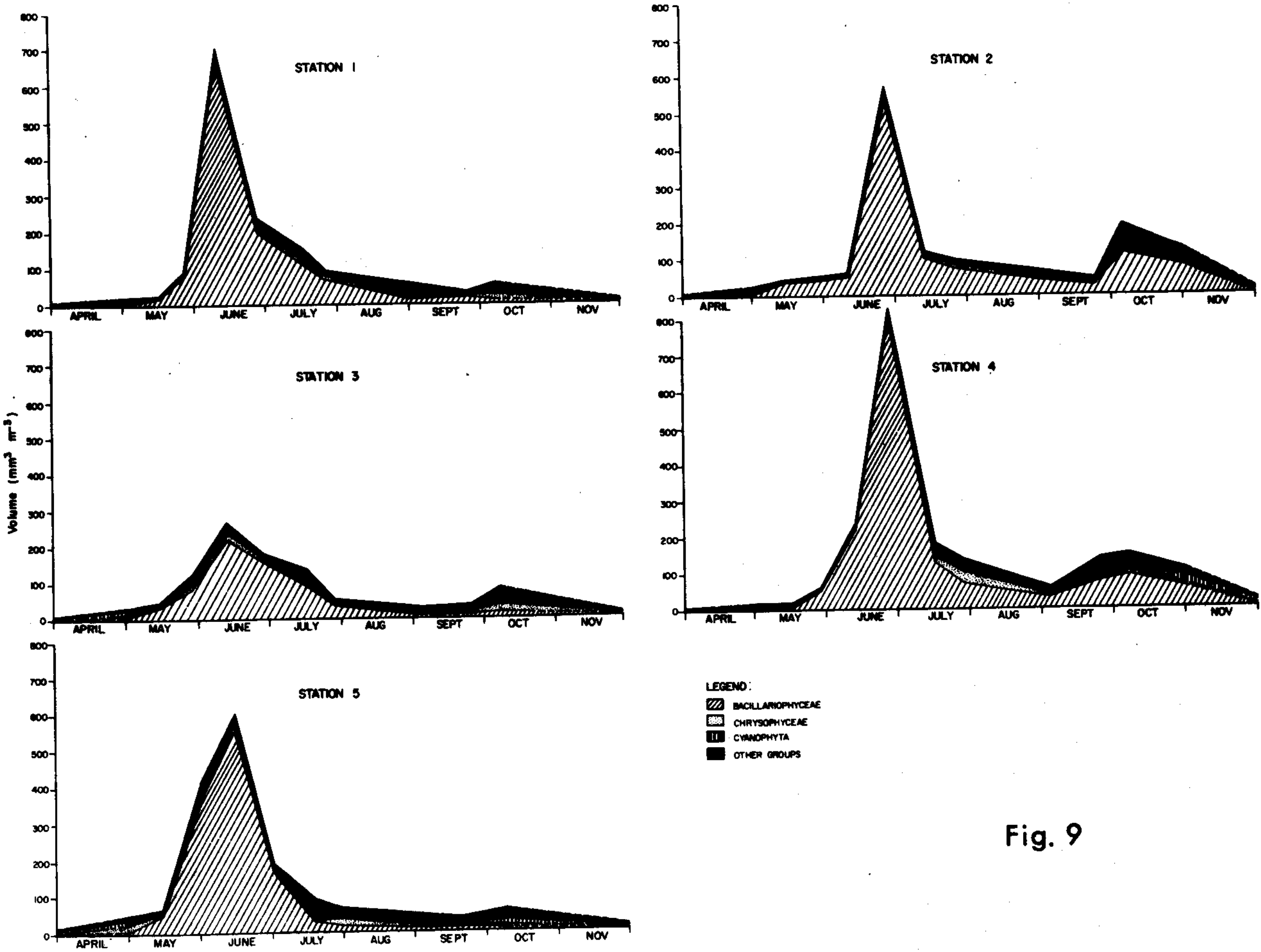

STATION 1
STATION 2
STATION 3
STATION 4
STATION 5
Volume (mm³ m⁻³)
0
100
200
300
400
500
600
700
800
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
LEGEND:
▨ BACILLARIOPHYCEAE
▒ CHRYSOPHYCEAE
▥ CYANOPHYTA
■ OTHER GROUPS

Fig. 9

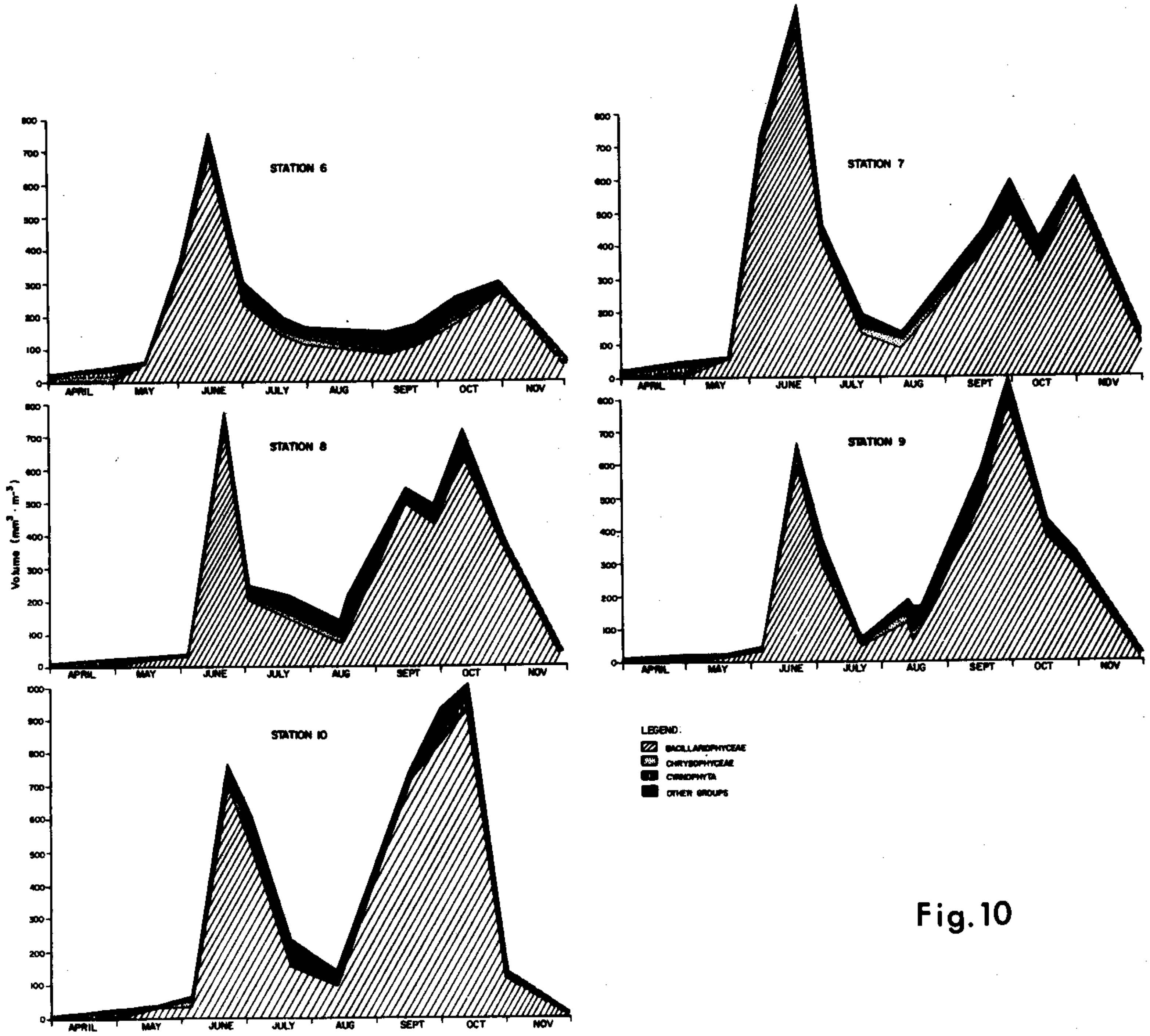
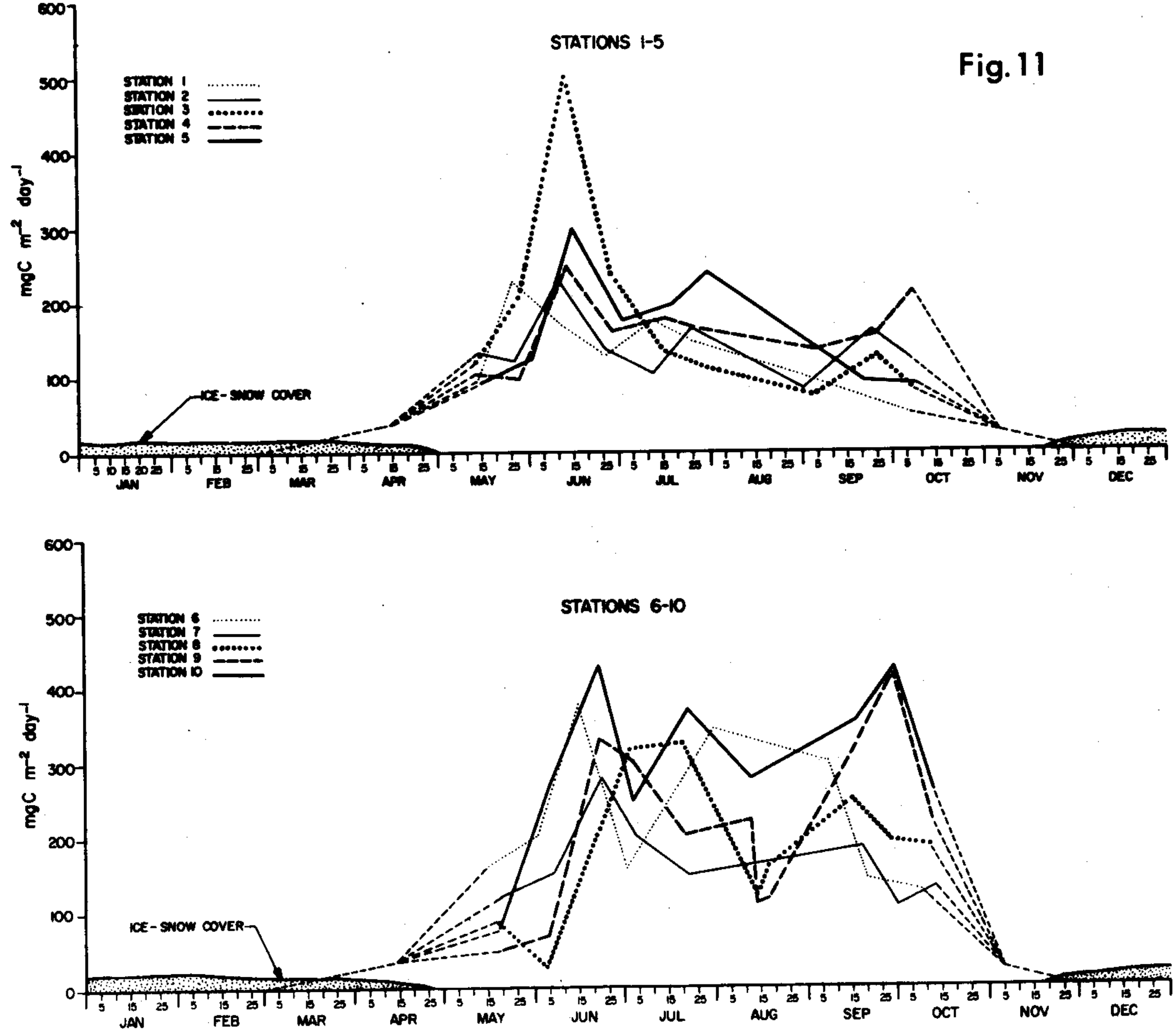

STATION 6
STATION 7
STATION 8
STATION 9
STATION 10
Volume (mm³ · m⁻³)
0
100
200
300
400
500
600
700
800
900
1000
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
LEGEND:
BACILLARIOPHYCEAE
CHRYSOPHYCEAE
CYANOPHYTA
OTHER GROUPS

Fig.10

Fig. 11


STATIONS 1-5
STATION 1
STATION 2
STATION 3
STATION 4
STATION 5
ICE-SNOW COVER
mgC m^{-2} day^{-1}
600
500
400
300
200
100
0
5 10 15 20 25
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
STATIONS 6-10
STATION 6
STATION 7
STATION 8
STATION 9
STATION 10
ICE-SNOW COVER
mgC m^{-2} day^{-1}
5 15 25

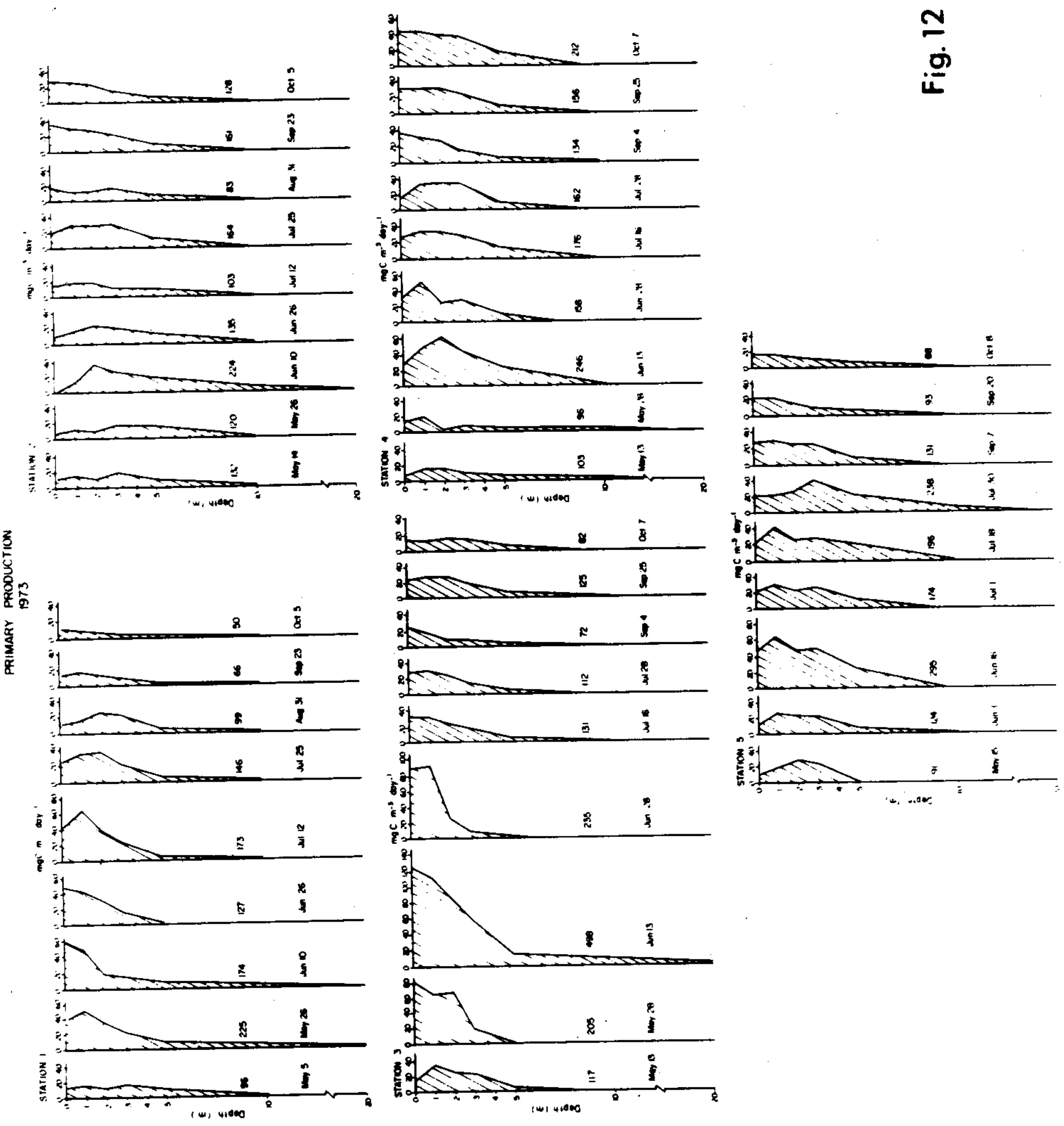

PRIMARY PRODUCTION
1973
STATION 1
STATION 2
STATION 3
STATION 4
STATION 5
mgC m-3 day-1
Depth (m)
May 5
95
May 28
225
Jun 10
174
Jun 26
127
Jul 12
173
Jul 25
146
Aug 31
99
Sep 23
66
Oct 5
50
May 14
132
May 26
120
Jun 10
224
Jun 26
135
Jul 12
103
Jul 25
164
Aug 31
83
Sep 23
161
Oct 5
128
May 13
117
May 28
205
Jun 13
498
Jun 28
235
Jul 16
131
Jul 28
112
Sep 4
72
Sep 25
125
Oct 7
62
May 13
103
May 31
96
Jun 15
246
Jun 31
158
Jul 16
176
Jul 31
162
Sep 4
134
Sep 25
156
Oct 7
212
May 15
91
Jun 1
124
Jun 16
295
Jul 1
174
Jul 18
196
Jul 30
258
Sep 7
131
Sep 20
93
Oct 8
88

Fig. 12

PRIMARY PRODUCTION
1973

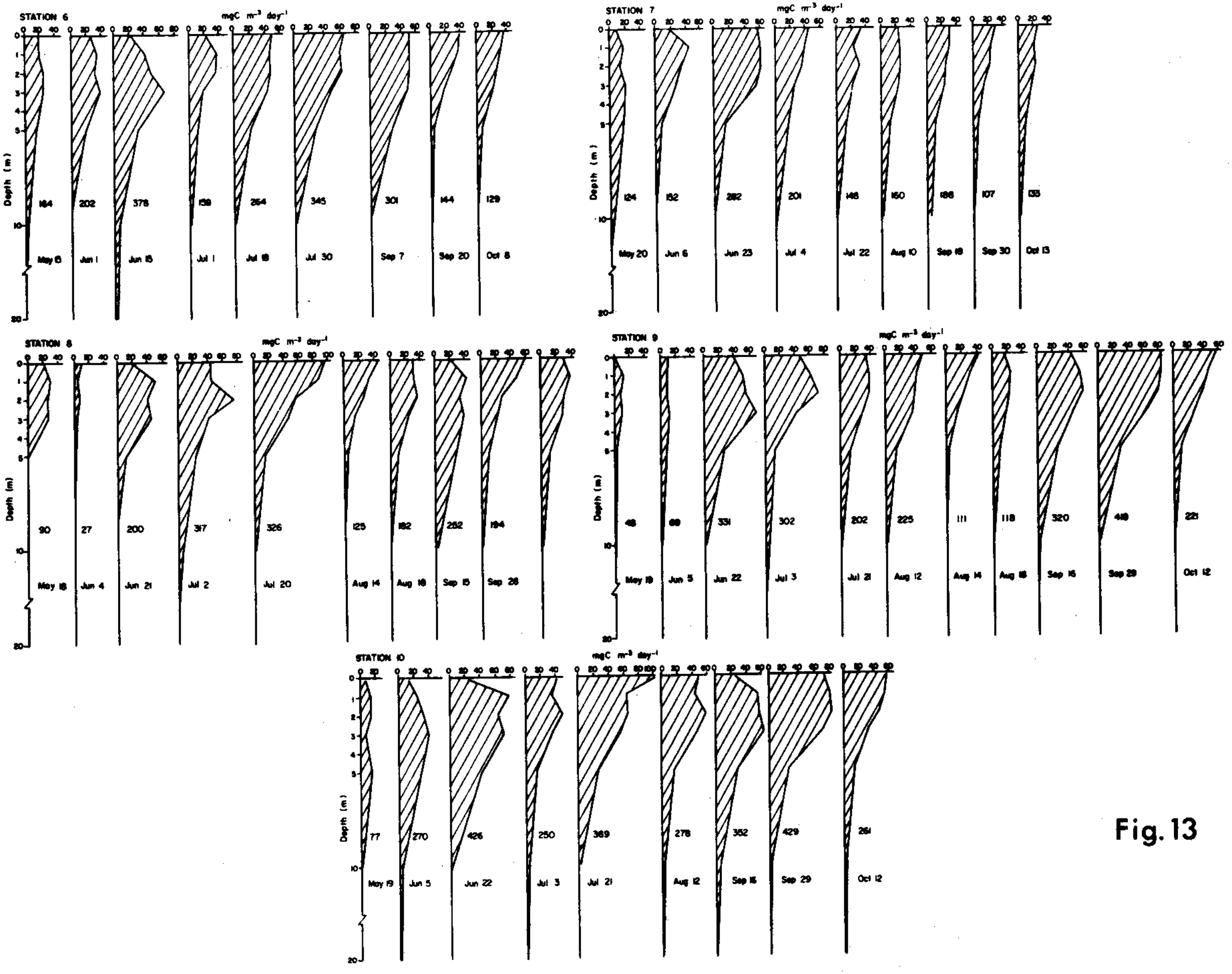


Fig.13

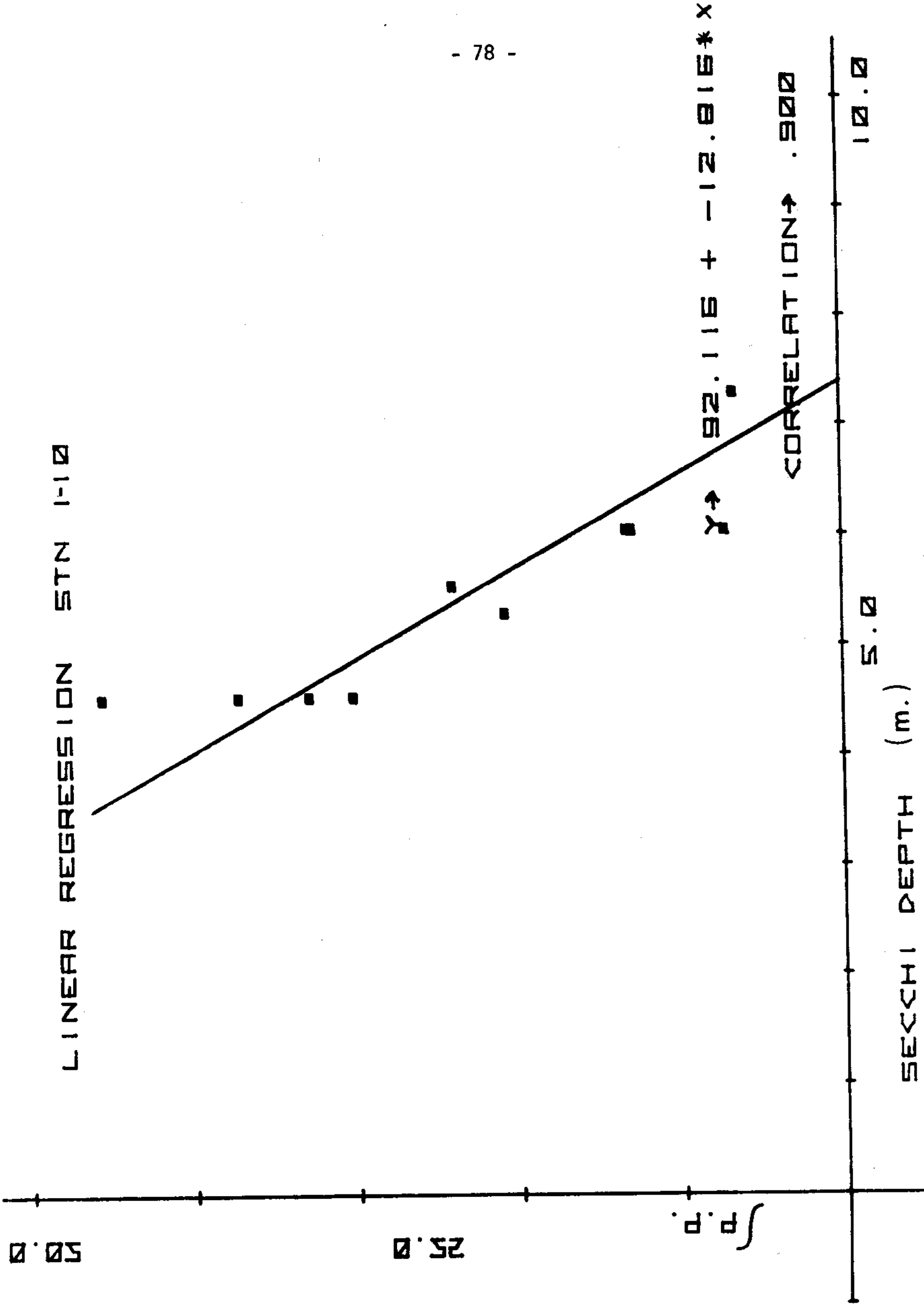

LINEAR REGRESSION STN 1-10
Y→ 92.116 + -12.816*X
<CORRELATION→ .900
10.0
5.0
SECCHI DEPTH (m.)
∫p.p.
25.0
50.0

Fig.14

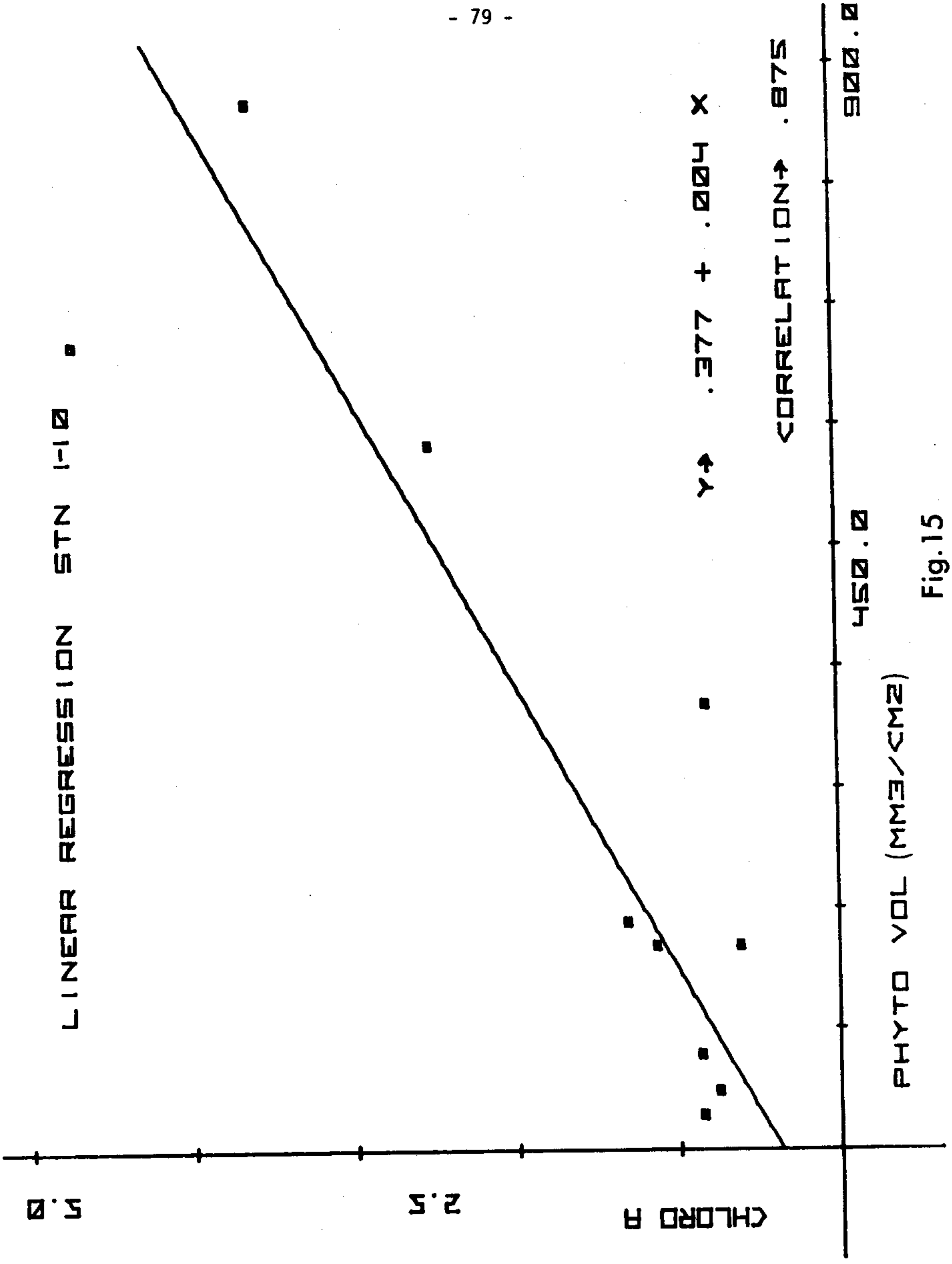

LINEAR REGRESSION STN 1-10
Y→ .377 + .004 X
<CORRELATION→ .875
CHLORO A
5.0
2.5
PHYTO VOL (MM3/CM2)
450.0
900.0

Fig.15

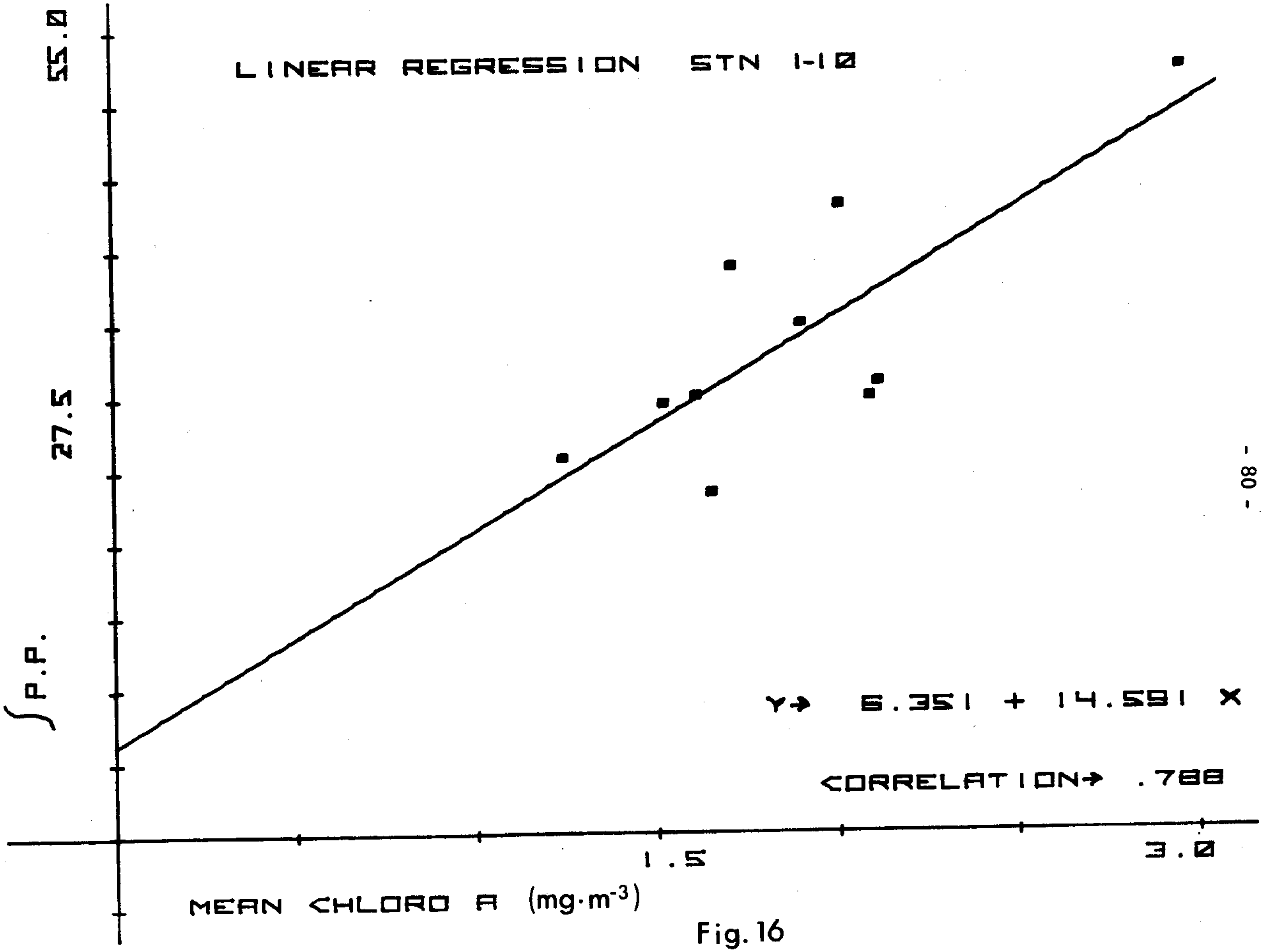

LINEAR REGRESSION STN 1-10
55.0
27.5
∫P.P.
Y→ 6.351 + 14.591 X
<CORRELATION→ .788
1.5
3.0
MEAN <CHLORO A (mg·m^{-3})

Fig. 16

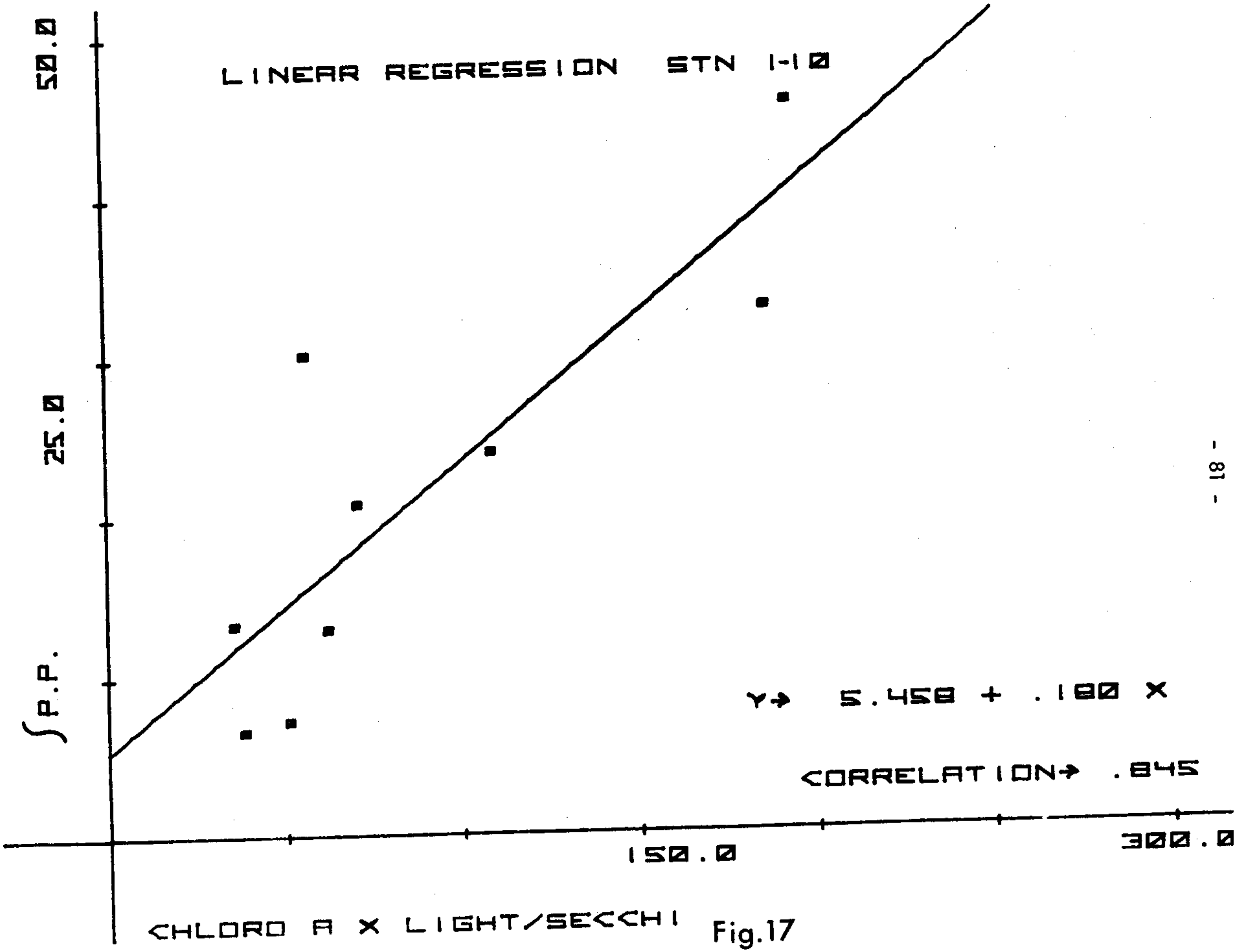

LINEAR REGRESSION STN 1-10
50.0
25.0
∫P.P.
Y→ 5.458 + .180 X
<CORRELATION→ .845
150.0
300.0
<CHLORO A X LIGHT/SECCHI

Fig.17

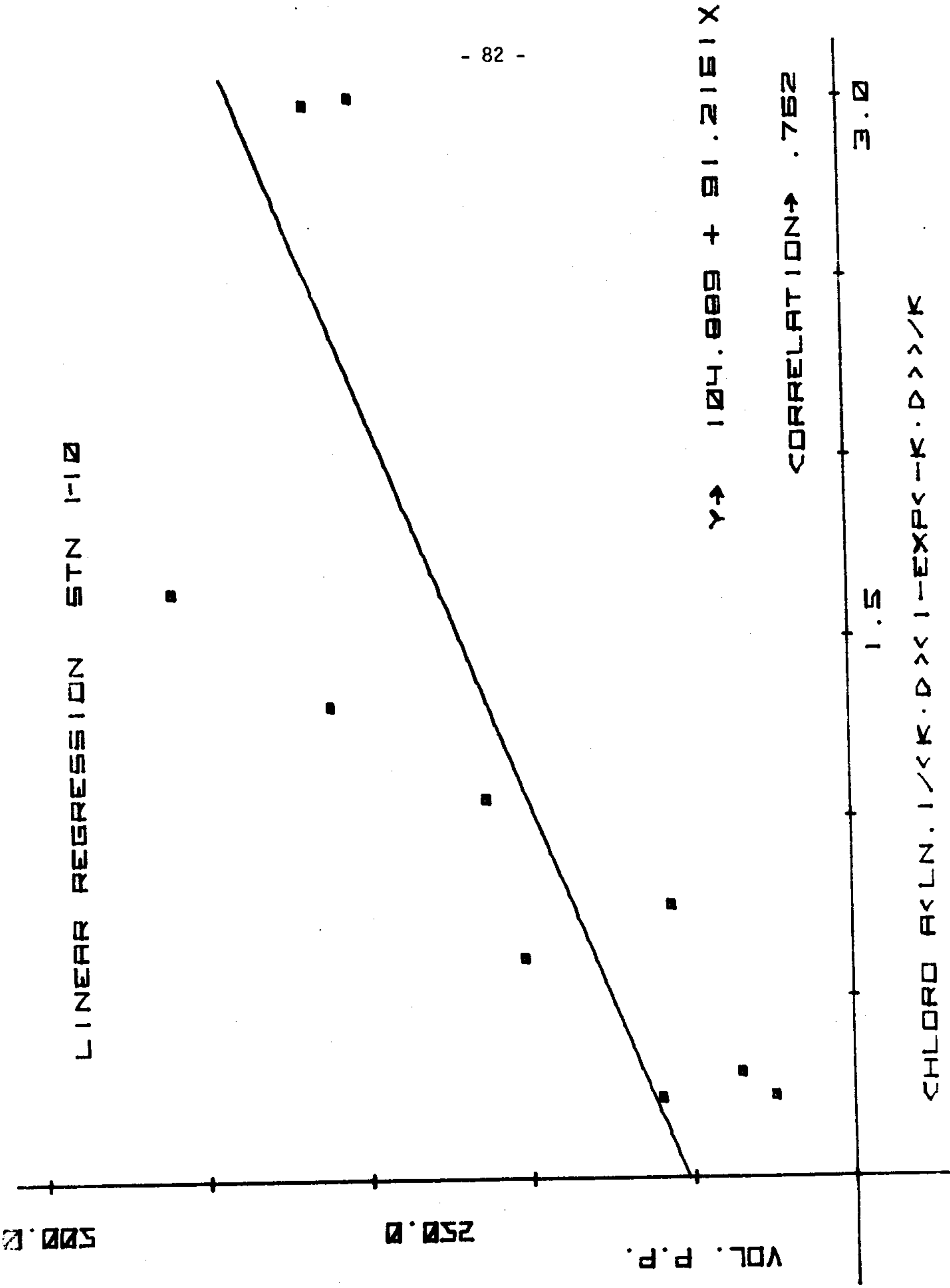

LINEAR REGRESSION STN 1-10
Y→ 104.889 + 91.2161X
<CORRELATION→ .762
<CHLORO A<LN. 1/<K·D><1-EXP<-K·D>>/K
1.5
3.0
VOL. P.P.
250.0
500.0

Fig.18

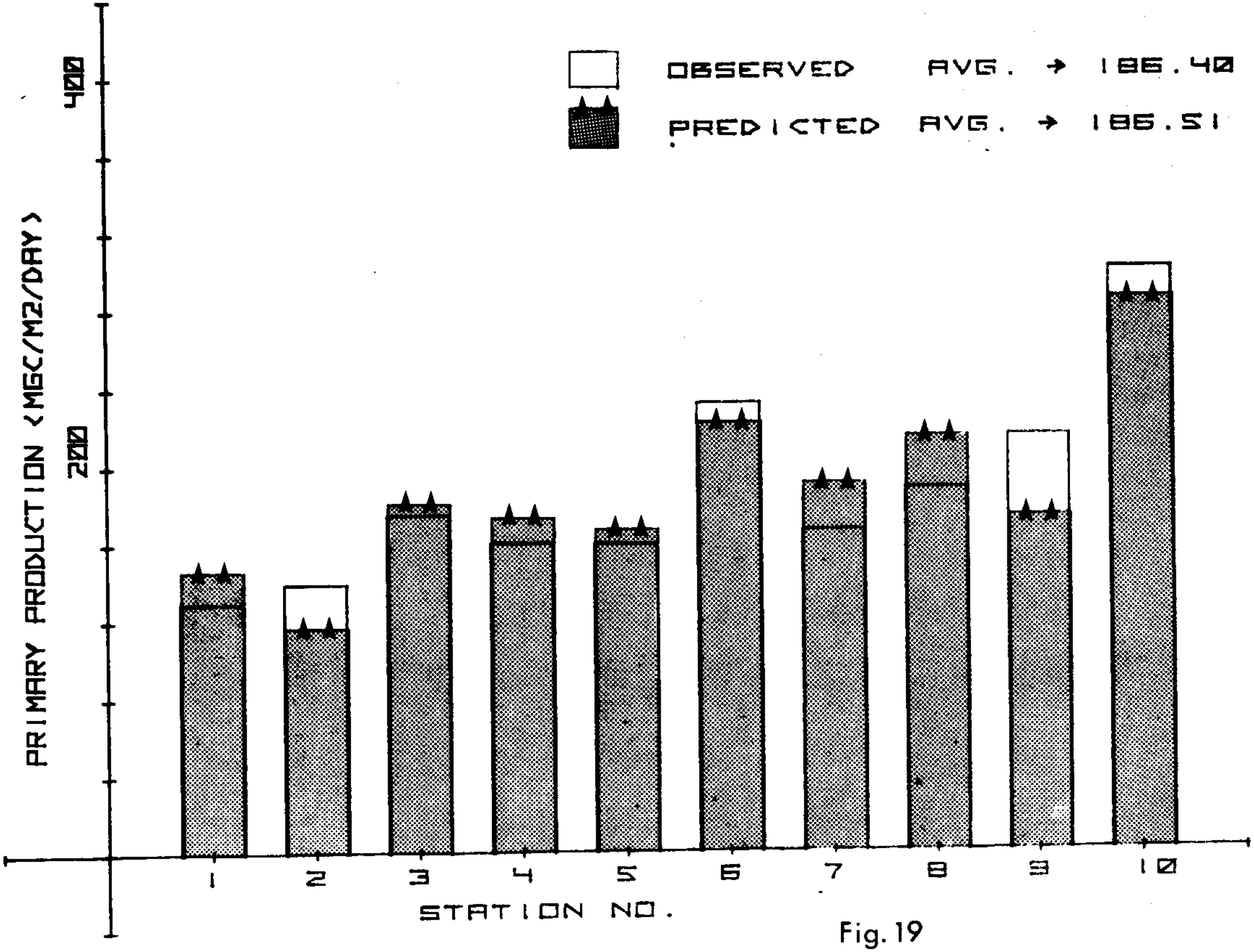

OBSERVED AVG. → 186.40
PREDICTED AVG. → 186.51
PRIMARY PRODUCTION <MGC/M2/DAY>
400
200
1
2
3
4
5
6
7
8
9
10
STATION NO.

Fig. 19

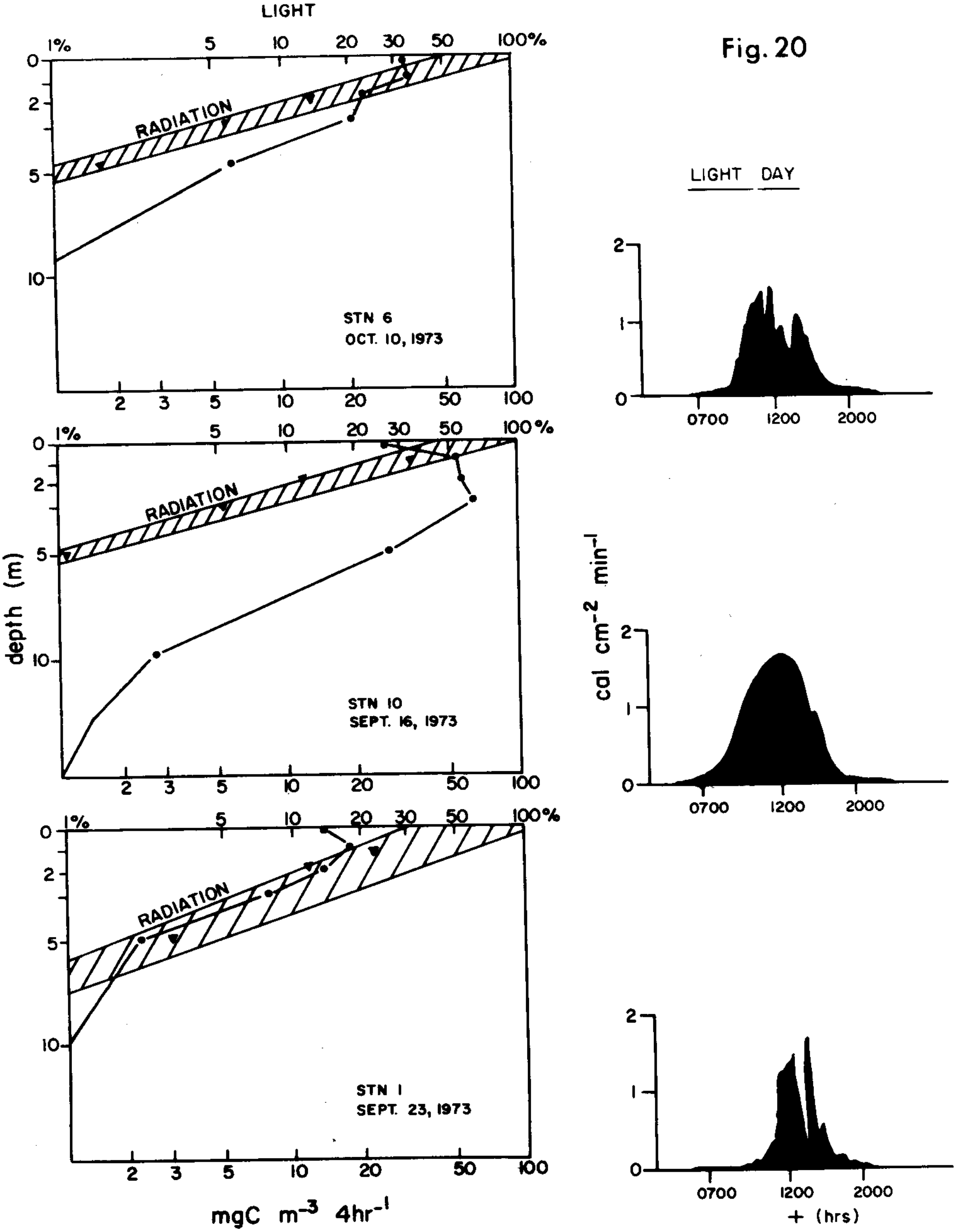
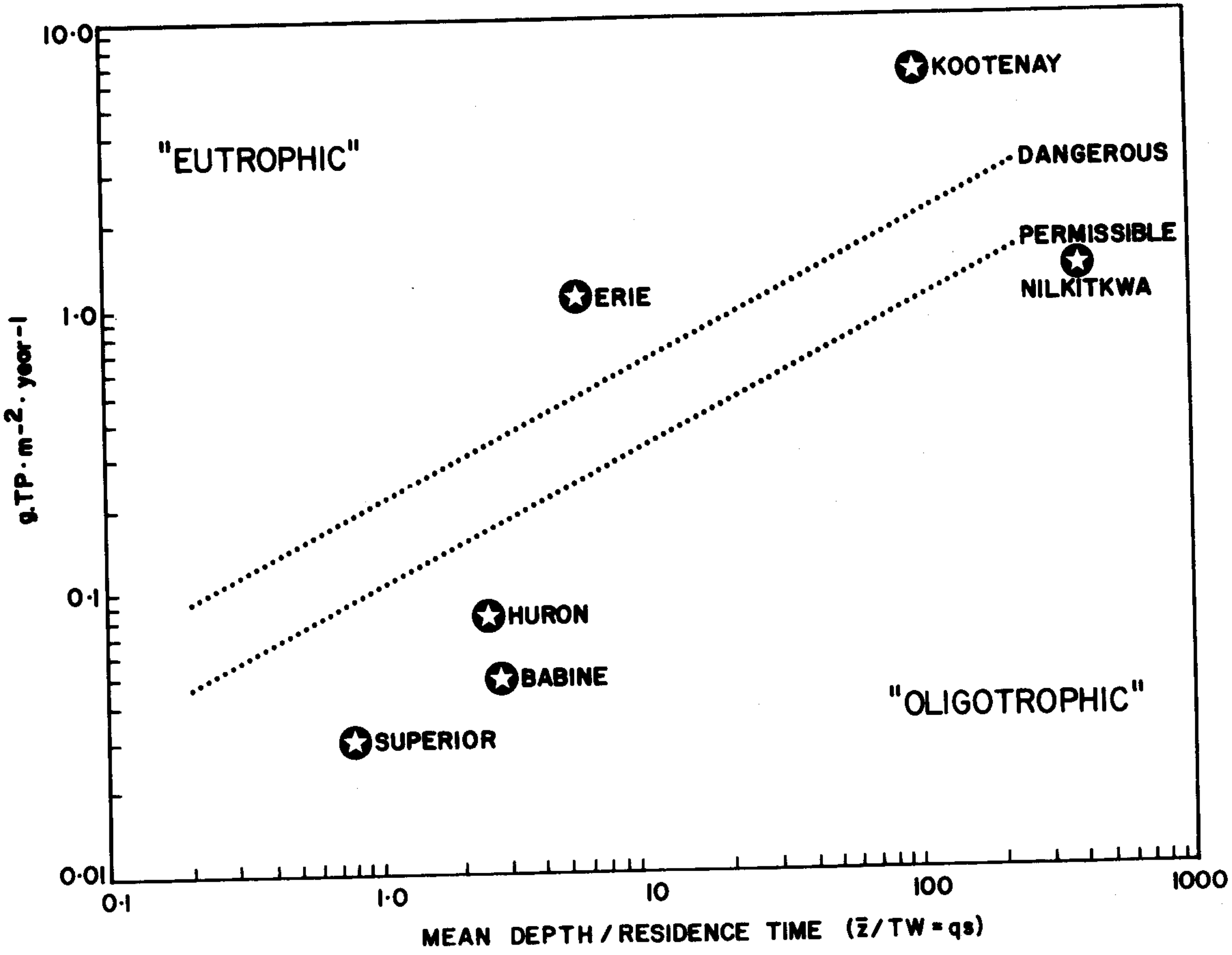

LIGHT
1%
5
10
20
30
50
100%
RADIATION
STN 6
OCT. 10, 1973
STN 10
SEPT. 16, 1973
STN 1
SEPT. 23, 1973
depth (m)
0
2
5
10
2
3
5
10
20
50
100
mgC m-3 4hr-1
LIGHT DAY
cal cm-2 min-1
0
1
2
0700
1200
2000
+ (hrs)

Fig. 20

FIGURE 21.


10·0
1·0
0·1
0·01
g.TP · m-2 · year-1
0·1
1·0
10
100
1000
MEAN DEPTH / RESIDENCE TIME (z̄/TW = qs)
"EUTROPHIC"
"OLIGOTROPHIC"
DANGEROUS
PERMISSIBLE
KOOTENAY
NILKITKWA
ERIE
HURON
BABINE
SUPERIOR

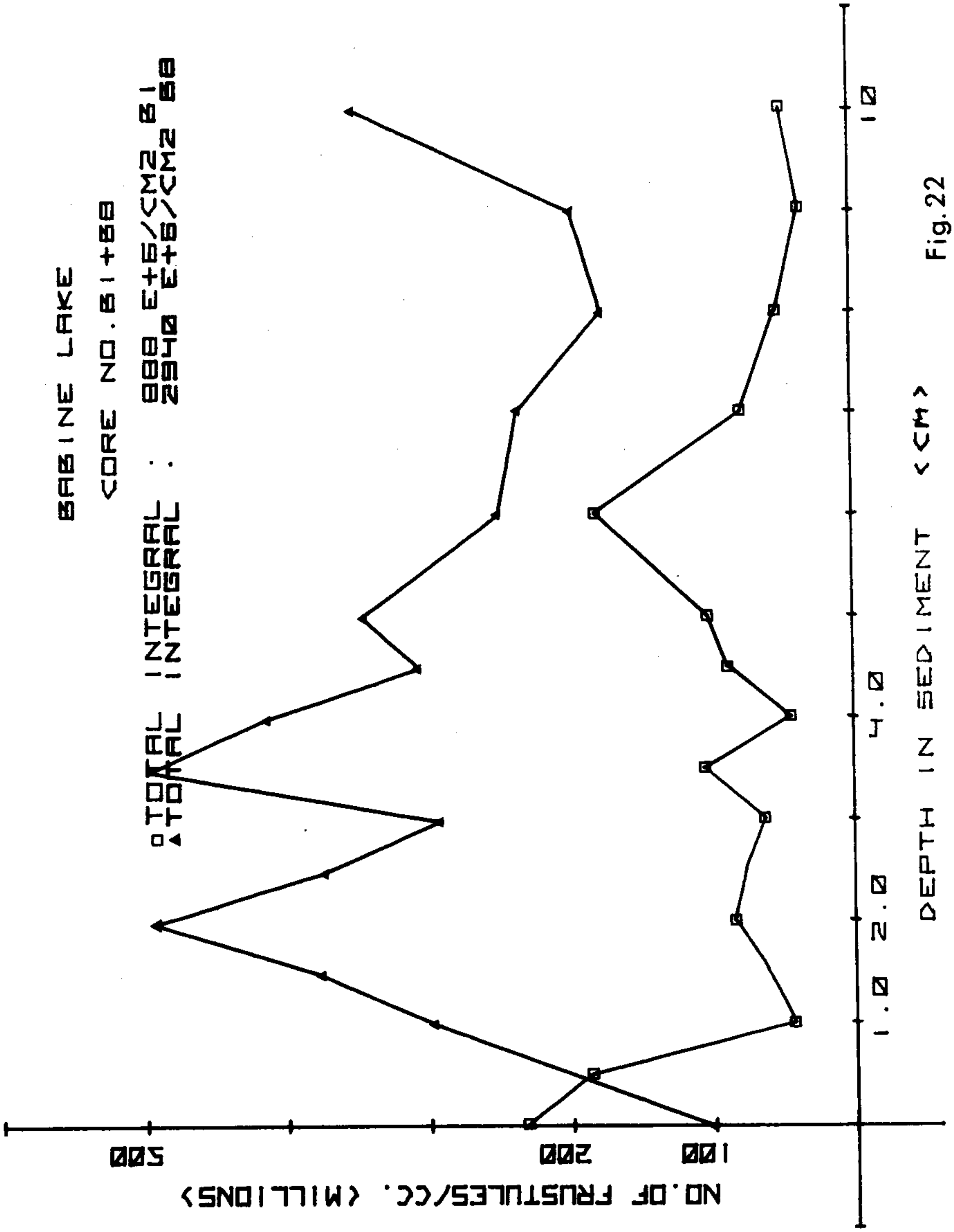

BABINE LAKE
CORE NO.81+88
□TOTAL INTEGRAL : 888 E+6/CM2 81
▲TOTAL INTEGRAL : 2940 E+6/CM2 88
NO.OF FRUSTULES/CC. <MILLIONS>
100
200
500
DEPTH IN SEDIMENT <CM>
1.0
2.0
4.0
10

Fig.22

APPENDIX

Tables 1-10. Summary of light, chlorophyll α, primary production, and assimilation no. for stations 1-10, Babine Lake.

STATION 3

	LIGHT		CHLOROPHYLL α		PRIMARY PRODUCTION		ASSIMILATION NO.
DATE 1973	g.cal cm^{-2}	$\bar{x}$ EXT COEFF.	m^{-3}	m^{-2}	m^{-3}	m^{-2}	Θ
13/5	473.32	-	1.49	11.22	15.57	117.44	10.46
28/5	627.98	-	2.68	25.77	21.34	205.27	7.97
13/6	241.33	-	3.40	35.53	47.64	497.68	14.01
28/6	473.33	-	3.05	26.13	27.37	234.58	8.98
16/7	541.32	-	2.24	19.81	14.80	130.61	6.59
27/7	395.99	-	1.09	9.69	12.58	111.55	11.51
4/9	172.00	-	1.89	16.72	8.12	71.95	4.30
25/9	206.66	.8176	-	-	13.52	124.72	-
29/9	-	-	.80	-	-	-	-
7/10	137.33	.5789	-	-	-	82.48	-
mean		.698	2.08	20.70	20.12	175.33	9.12

STATION 4

DATE 1973	LIGHT g.cal cm^{-2}	$\bar{x}$ EXT. COEFF.	CHLOROPHYLL α m^{-3}	m^{-2}	PRIMARY PRODUCTION m^{-3}	m^{-2}	ASSIMILATION NO. Θ
13/5		-	0.80	9.95	8.36	103.35	10.39
28/5	same as	-	0.38	4.35	8.51	96.30	22.14
13/6	stn. 3	-	2.24	18.14	30.30	245.83	13.55
28/6		-	2.58	18.07	22.46	157.58	8.72
16/7		-	2.60	23.62	19.36	175.65	7.44
28/7		-	1.34	11.28	19.29	162.23	14.38
4/9		-	1.96	19.41	13.55	134.32	6.92
25/9		.6127	-	-	16.77	155.96	-
29/9		-	0.93	-	-	-	-
7/10		.5524	-	-	-	211.62	-
mean		.583	1.60	14.97	17.33	160.32	11.93

STATION 5

	LIGHT		CHLOROPHYLL α		PRIMARY PRODUCTION		ASSIMI-LATION NO.
DATE 1973	g.cal cm^{-2}	$\bar{x}$ EXT. COEFF.	m^{-3}	m^{-2}	m^{-3}	m^{-2}	Θ
15/5	413.32	-	2.10	17.17	11.08	90.74	5.29
1/6	447.99	-	1.08	9.25	14.49	123.60	13.36
15/6	473.32	-	2.93	24.74	35.04	295.47	11.94
1/7	369.32	-	1.31	13.15	17.27	173.86	13.22
18/7	679.98	-	0.75	6.63	22.16	196.01	29.55
30/7	533.32	-	0.73	8.19	21.21	237.65	29.03
7/9	164.00	-	1.28	11.24	14.93	130.77	11.63
20/9	189.33	.5870	1.90	11.83	9.65	93.07	5.09
8/10	137.33	.5996	-	-	-	88.90	-
mean		.593	1.51	12.78	18.23	158.81	14.89

STATION 6

	LIGHT		CHLOROPHYLL α		PRIMARY PRODUCTION		ASSIMILATION NO.
DATE 1973	g.cal cm^{-2}	$\bar{x}$ EXT. COEFF.	m^{-3}	m^{-2}	m^{-3}	m^{-2}	Θ
15/5		-	1.18	13.54	14.31	163.73	12.09
1/6	same as	-	0.85	7.35	23.51	202.47	27.53
15/6	stn. 5	-	2.94	31.27	35.51	378.18	12.09
1/7		-	2.92	26.87	17.23	158.47	5.90
18/7		-	1.26	11.85	28.05	263.60	22.24
30/7		-	1.24	12.33	34.71	345.25	28.00
7/9		-	2.38	22.30	32.20	301.15	13.51
20/9		.5636	2.44	22.77	15.44	143.82	6.32
1/10		-	2.74	-	-	-	-
8/10		.6413	-	-	-	128.72	-
mean		.6024	1.99	18.54	25.12	231.67	15.96

STATION 7

	LIGHT		CHLOROPHYLL α		PRIMARY PRODUCTION		ASSIMILATION NO.
DATE 1973	g.cal cm^{-2}	$\bar{x}$ EXT. COEFF.	m^{-3}	m^{-2}	m^{-3}	m^{-2}	Θ
20/5	386.66	-	0.88	7.62	14.21	123.72	16.23
6/6	241.33	-	0.88	6.68	19.91	151.91	22.73
23/6	291.99	-	5.34	46.36	32.52	282.29	6.09
4/7	386.66	-	3.26	31.78	20.66	201.18	6.33
22/7	498.65	-	0.99	10.01	14.61	148.22	14.81
10/8	575.99	-	0.29	3.05	15.46	160.24	52.60
18/9	283.99	.5413	3.09	34.95	16.65	188.25	5.39
30/9	129.33	-	-	-	11.82	107.13	-
1/10	-	-	4.00	-	-	-	-
13/10	112.00	.6471	-	-	-	132.67	-
mean		.594	2.34	20.06	18.23	166.18	17.74

STATION 8

	LIGHT		CHLOROPHYLL α		PRIMARY PRODUCTION		ASSIMILATION NO.
DATE 1973	g.cal cm^{-2}	$\bar{x}$ EXT. COEFF	m^{-3}	m^{-2}	m^{-3}	m^{-2}	Θ
18/5	378.66	-	0.40	8.50	14.71	89.67	10.53
4/6	214.66	-	0.28	2.58	2.96	27.38	10.60
21/6	258.66	-	5.51	40.90	26.99	200.21	4.90
2/7	309.33	-	1.11	12.78	27.48	317.01	24.81
20/7	318.67	-	0.81	6.99	37.99	326.35	46.67
14/8	258.66	-	1.09	10.44	13.55	124.61	12.41
18/8	344.99	-	0.66	6.27	16.97	161.86	25.82
15/9	318.66	.8104	3.36	31.31	27.03	251.51	8.03
28/9	241.33	-	-	-	20.43	193.72	-
1/10	-	-	4.00	-	-	-	-
1/10	120.00	.8463	-	-	-	187.39	-
mean		.828	1.91	14.92	20.90	187.97	17.97

STATION 9

	LIGHT		CHLOROPHYLL α		PRIMARY PRODUCTION		ASSIMILATION NO.
DATE 1973	g.cal cm^{-2}	$\bar{x}$ EXT. COEFF.	m^{-3}	m^{-2}	m^{-3}	m^{-2}	Θ
19/5	318.66	-	0.84	6.27	6.43	48.02	7.66
5/6	403.99	-	0.74	7.18	7.06	68.60	9.55
22/6	541.32	-	4.71	42.06	37.04	330.83	7.87
3/7	318.66	-	0.78	7.82	30.00	302.45	38.69
21/7	430.66	-	0.85	8.30	20.65	202.02	24.33
12/8	455.99	-	1.30	12.20	23.86	224.66	18.41
14/8	326.66	-	1.12	9.69	12.81	111.09	11.47
18/8	343.99	-	0.60	5.39	13.13	117.99	21.88
16/9	335.99	.8491	2.48	24.22	32.70	319.67	13.20
29/9	241.33	-	-	-	45.48	417.84	-
2/10	-	-	3.59	-	-	-	-
12/10	146.66	.6828	-	-	-	220.64	-
mean		.766	1.70	13.68	22.92	214.89	17.04

STATION 10

DATE 1973	LIGHT g.cal cm^{-2}	$\bar{x}$ EXT. COEFF.	CHLOROPHYLL α m^{-3}	m^{-2}	PRIMARY PRODUCTION m^{-3}	m^{-2}	ASSIMI-LATION NO. Θ
19/5		-	1.36	11.65	9.09	77.75	6.67
5/6	same as	-	1.84	20.65	24.02	270.08	13.08
22/6	stn. 9	-	7.21	63.24	48.57	426.28	6.74
3/7		-	1.23	13.40	22.89	250.20	18.67
21/7		-	.99	9.59	38.23	369.46	38.52
12/8		-	1.31	13.09	27.94	278.50	21.28
16/9		.8217	4.98	46.29	37.98	352.87	7.62
29/9		-	-	-	45.92	492.93	-
2/10		-	4.66	-	-	-	-
12/10		.6153	-	-	-	261.60	-
mean		.719	2.95	25.42	31.83	301.85	16.08

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