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# PHYTOPLANKTON STANDING STOCK LEVELS AND BIVALVE CULTURE POTENTIAL IN AITUTAKI AND RAROTONGA LAGOONS, COOK ISLANDS

By

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## ABSTRACT

Basic physical and biological water quality parameters were investigated in Aitutaki lagoon and Avana Stream estuary complex on Rarotonga (Cook Islands). Maximum potential of net primary production was used to estimate a potential bivalve production of 0.4 kg $m^{-2}$ for Aitutaki lagoon. Avana Stream estuary is unsuitable for any such aquaculture activity.

# 1 - INTRODUCTION

## 1.1. The Problem

The potential for commercial mariculture of filter-feeding bivalves in the Pacific islands is highly dependent on the primary productivity of the waters, which in turn is controlled largely by the adjacent land areas, freshwater run-off, and lagoon water retention patterns. The oligotrophic oceanic waters and small size of islands in Polynesia therefore impose significant constraints on development of such activities. On some Polynesian islands, aquaculture development projects have involved construction of large-scale, capital-intensive pond systems in attempts to overcome the natural limitations of lagoon and estuary circulation and productivity patterns. These projects have met with variable success (see Uwate, et al., 1984, for a comprehensive review of Pacific Island aquaculture activities).

In the Cook Islands, interest has been expressed in the commercial cultivation of mullet (Villaluz, 1972), oysters (Glude, 1971 and 1972) and a variety of other edible finfish and shellfish in the estuaries and lagoons of the Southern Group islands. These developments were proposed both to provide local protein supplements, and as export-oriented industries (Uwate, et al., 1984), but took little account of the condition of the waters in which such developments were to take place. A recent attempt to introduce the green mussel (***Perna viridis***) to Avana Stream estuary on Rarotonga failed (Sims, 1985). The rapid demise of these mussels was attributed to salinity and temperature fluctuations, combined with the stresses of starvation of the mussels.

## 1.2. The Islands

The study investigated the basic physical and biological water quality parameters in Aitutaki lagoon and in the Avana Stream estuary complex on Rarotonga. Aitutaki (18 50'S, 149 50'W ; Fig. 1) has a small volcanic remnant and an exceptionally shallow lagoon approximately 50 square km in area (Summerhayes, 1971 ; and Stoddart, 1975) Rarotonga (21 15'S, 159 45'W ; Fig. 2) is a mountainous high island with a surrounding moat (popularly called a lagoon, but not actually such) up to 800 m wide on the southern perimeter, narrowing to a bench reef on the northern coast (see Lewis, et al., 1980). The Avana Stream estuary complex is located on the eastern side of the island, where both the Avana and Turangi Streams flow into the moat adjacent to Ngatangiia Passage, a deep pass open to the sea which drains most of the "lagoon" water from the southern and eastern reaches of the moat.

The northern, protected reaches of Aitutaki lagoon, and the Avana Stream estuary complex represent the most apparently productive areas of marine or estuarine environment in the Cook Islands. For this reason, these areas have been repeatedly suggested as suitable sites for introduction trials of the various possible mariculture species.

### 1.3. The Aims

The study intended to examine these waters using rapid, simple sampling techniques, which could be readily employed by Pacific island fisheries researchers (with the support of a co-operating laboratory for sample analysis), and yet could still provide useful indicators of the potential for mariculture development. The experiences in the Cook Islands, and throughout the Pacific islands, underline the importance of supportive research in planning and implementing Pacific island aquaculture developments. A greater understanding of lagoon water quality and primary productivity would thereby enable more enlightened decision-making on the viability and optimal location of future mariculture developments in the Southern Group lagoons.

## 2 - MATERIALS AND METHODS

Measures of primary productivity in the water column provide the best indicators of potential production outputs for edible filter-feeding bivalve culture. However, the very nature of fisheries research work in the more isolated Pacific islands imposes significant constraints on available time, equipment reliability and applicability, and the level of expertise of field workers, and more appropriate methods are required. The methods employed here estimated the standing stock of phytoplankton in the water column by obtaining measures of the concentrations of the two principal phytopigments. Simple filtration techniques are used in the field, and laboratory analyses can be performed later.

A total of twenty-two sites were sampled on Aitutaki and seven on Rarotonga, in December 1985. The Aitutaki sites included standing lagoon back-waters close to a mud-flat inlet (Stn 20), semi-enclosed lagoon reaches (Stns 1, 2, 3 and 4), open lagoon areas, Arutanga passage and its mouth (Stns 17 and 18, respectively), and oceanic waters (Stn 19) ; (see Fig. 1). Temperature and salinity measurements, using a YEO-KAL T/S meter and probe were taken at each meter through the water column, except at Stns 18 and 19. These were sampled every 2 m and 5 m, respectively, to 20 m depth. A Niskin 1.7 litre water bottle was used to collect surface and bottom water samples for dissolved oxygen determinations and for filtration to allow later analysis of chlorophyll-a and phaeophytin levels by fluorometry (Yentsch and Menzel, 1963).

The Rarotongan stations traversed the Avana Stream estuary (see Fig. 2). Only surface water measurements and samples were taken at Stns 1-6 because of the shallowness of the water. At Stns 7, in the passage, temperature and salinity samples were taken each metre throughout the water column, and dissolved oxygen, chlorophyll-a, and phaeophytin determinations were made from surface samples only.

## 3 - **RESULTS**

### 3.1. Aitutaki

The Aitutaki data are displayed in Table 1. Dissolved oxygen concentrations are given as percentage saturation levels at the specific temperature and salinity. Percentages of chlorophyll-a relative to the summed chlorophyll-a and phaeophytin determinations are also given.

The most significant aspect is the extreme values for all parameters recorded at Stn 20, at the opening of the Vaipeka mudflat into the upper reaches of the northern lagoon arm. The summed phytopigment levels were more than three times that recorded elsewhere, and more than twenty times that of the oceanic waters of Stns 18 and 19.

Temperature profiles for six stations, selected on the basis of their representative characteristics, are given in Figure 3. These profiles all display the expected higher surface water temperatures, except for Stn 17 in the Arutanga channel, which is subject to vigorous tidal mixing. Stn 3 exhibits particularly high temperatures, which along with high salinities, are typical for the lagoon's northern arm and reach their extremes at Stn 20. Stn 5 also exhibits these characteristics, though with greater fetch from the southeast trade winds this station is subject to more wind-mixing and has less notable heating of surface water. Stns 13 and 15 show the increasing influence of oceanic water with greater proximity to the reef perimeter. The Stn 19 temperature profile of the relatively colder oceanic waters shows a slight warming trend towards the surface but no significant surface water stratification.

Chlorophyll concentration patterns exhibit highest levels of between 0.5 mg $m^{-3}$ and 1.0 mg $m^{-3}$ in the inner lagoon waters. Lower phytoplankton pigment levels are found towards the southern and eastern sectors of the lagoon, where oceanic influences are greater (Figure 4).

Although the sum of pigment determinations (chlorophyll-a plus phaeophytin) does not represent the total pigment concentration, it can still be taken as an approximation of phytoplankton standing stock levels. These summed pigment levels were plotted against the percentage saturation of dissolved oxygen in the sample (Figure 5). There is again an evident trend from oceanic to lagoon water, although decreases in dissolved oxygen concentrations are found at the higher phytoplankton levels.

The oxygen concentration of the oceanic water at Stns 18 and 19 lies just below saturation (100 %), with correspondingly low pigment levels. With increasing lagoon water retention time increases occur in both oxygen levels and pigment concentrations. This is reflected in the initial trend towards the upper right-hand corner of Figure 5 (Stns 13-16 : Mid-lagoon or mixed water). With even greater increases in pigment levels, however, there is, as indicated **by the arrow in Figure 5, a decrease in oxygen concentration,** with surface and bottom water for Stn 6 having only 81 % of oxygen saturation. Only Stns 20 and 22 have pigment concentrations much greater than 1.0 mg $m^{-3}$ and oxygen levels well above 100 % saturation.

3.2. Rarotonga

The physical and pigment characteristics through the Avana passage are detailed in Table 2. Although only one sample was taken at each station, there was an obvious thermo-haline stratification in Avana Stream, with a cold freshwater surface layer of 10-20 mm thickness and with water becoming warmer and more saline with increasing depth. In the passage mouth, colder oceanic water is found below 2 m depth.

As the Avana sampling represents a continuum through the estuary, the physical and pigment characteristics can be plotted against the station location, as in Figure 6. The distinction between the estuarine stations (Stns 1-3) and the lagoon stations (Stns 4-7) is here clearly evident. The higher salinity colder water at depth at Stn 7 represents the oceanic "wedge", with the warmer less saline lagoon water running out at the surface.

In periods of heavy rainfall, the entire stream is flushed with freshwater, which spreads throughout the lagoon. However, no rainfall had been recorded for the week prior to the survey, and only a minimal input of fresh-water was evident. Below the surface run-off layer in the stream, the more saline water was standing, subject only to tidal influence across the bar at the stream mouth.

The high pigment concentration in the stream (reaching, at Stn 3, a level almost double that of the maximum recorded at Aitutaki in the Vaipeka Swamp mouth) corresponds with a relatively low dissolved oxygen level. At the lagoon stations, however, the converse holds true, with a dissolved oxygen concentration level of 156 % saturation at Stn 4, and a combined pigment concentration of only 0.69 mg $m^{-3}$.

## 4 - DISCUSSION

### 4.1. Water quality distribution patterns

#### a) *Aitutaki*

Under the influence of the prevailing south-easterly winds and swell, there is a gradual movement of water across the Aitutaki lagoon from the south-east towards the western passage at Arutanga. All of the southern reaches of the lagoon are subject to some oceanic influences from continual interchange by tidal and wave action across the reef. Those stations closest to the reef (Stns 11, 12, 14 and 15) exhibit the greatest oceanic attributes, particularly in respect of their pigment concentrations (Fig. 5). Stations 13, 14 and 15 do exhibit warmer water than other stations in the southern reaches, probably due to their proximity to the shallow sandflats in the lee of the islets, where oceanic water entering over the reef quickly becomes heated.

The stations in the northern arm of the lagoon almost all exhibit characteristics typical of waters which have been resident in the lagoon for some time. Water here is generally warmer (Fig. 3, Stns 3 and 5) and with greater pigment concentrations (Fig. 4 and 5). At these stations, and at the old lagoon water stations of the center and west of the lagoon (Stns 7, 8, 9 and 10), there is however, a decrease in oxygen levels to around, and in some cases below, that recorded for oceanic waters.

It may be hypothesized from Figures 4 and 5 that as oceanic water enters the lagoon, increased nutrient input from terrestrial run-off and benthic processes stimulates phytoplankton growth, resulting in increased oxygen levels. As phytoplankton growth continues with greater residence time, the higher standing crop stimulates an increase in growth of zooplanktonic grazers. The resultant increase in respiratory activity produces a net decrease in oxygen levels in the water column of the old lagoon water. The increased biomass of phytoplankton would also result in increased activity by heterotrophic decomposers and an even greater rate of oxygen utilization.

At Stn 20 a film of epibenthic algal slime was obvious. Immediately below the surface of the fine silt substratum a sulfide aroma indicated that anaerobic bacteria were active. These observations suggest that benthic and planktonic photosynthesis support the high oxygen concentrations found there, and the anaerobic bacteria might displace the aerobic decomposers active at other lagoon stations. This may explain the exceptionally high levels of both pigment and oxygen concentrations at this station.

(b) ***Rarotonga***

The Avana estuary-lagoon complex displays a more diverse range of physical and biological attributes than Aitutaki lagoon. The salinity and temperature gradients are typical of an estuarine situation, with progressive mixing of warmer fresher water with the colder more saline oceanic water.

The parameters of productivity are far more extreme than those found in Aitutaki. Only the values for Stations 2 and 7 fall within the range of oxygen concentrations and pigment levels displayed in Figure 5. Stations with the greatest fresh-water influence (Stns 1, 3) display very high pigment concentrations, with only moderate percentage oxygen saturations. It may be inferred that the nutrient input from terrestrial run-off stimulates rapid phytoplankton growth. As much of this water is standing, trapped within the salt-water lens created by the bar at the stream mouth, it has an extended residence time and ample opportunity to build up a high standing crop of phytoplankton. As with the old lagoon water of Aitutaki, the oxygen production by such photosynthetic activity is balanced by the respiratory activity of bacterial decomposers and other heterotrophs. Within the stream, these decomposers are supported not only by plankton outfall, but also by the large amounts of terrestrial detritus littering the substratum. The nutrient release from the breakdown of this terrestrial plant matter is probably a significant factor in stimulating the phytoplankton bloom found in the stream.

The stations of increasing oceanic influence within the lagoon (Stns 4, 7) have very high levels of dissolved oxygen, but with pigment values only slightly above that of the oceanic stations at Aitutaki (cf. Fig. 5 and 7). The Avana values are most proximal to those recorded for stations 21, 22 and 3 (surface) in Aitutaki which were similarly located in the shallow moat behind the reef. As these waters are subject to tidal and wave action flushing there is not the necessary residence time for phytoplankton levels to increase greatly. In these stations of oceanic influence and low phytoplankton standing stocks the high oxygen levels probably result from benthic primary production as water moves across the reef and lagoon shallows.

### 4.2. Extrapolation of pigment levels to potential bivalve yields

The relationships between pigment levels, rates of primary productivity, and potential production of filter-feeding bivalves are both complex and variable, in time and location.

As the Avana Stream estuary is subject to considerable variation in environmental influences, the single data set obtained in this study is of limited applicability. Some stations within the estuary indicated high phytoplankton levels, with implications of localized high net productivity. However, the seasonal variation in the physical and biotic environment and the small-scale of distribution of such highly productive areas precludes any temporal or geographical extrapolation of these results. Estimates of primary productivity and thereby potential bivalve yield were then not attempted for the Avana Stream estuary.

The larger lagoon of Aitutaki is a more stable environmental system, and it was assumed that the data obtained during this study could be accepted as indicative of the normal conditions within the lagoon. The discussion below details the calculations and assumptions made in applying the best available information to this pigment concentration data in order to obtain indicative estimates of potential filter-feeding bivalve production.

(i) ***Gross phytoplankton production***

The areas of Aitutaki lagoon encompassed by those stations with "old lagoon water" (Fig. 5) with relatively high concentrations of chlorophyll-a and high standing stocks of phytoplankton represent the sites most likely to support intensive culture operations for filter-feeding bivalves. Chlorophyll concentrations average 0.67 mg $m^{-3}$, over these areas. The site with greatest phytoplankton standing stocks, Stn 20, had a chlorophyll concentration of 3.3 mg $m^{-3}$.

From these measurements, approximation of phytoplankton production (chlorophyll only) can then be estimated using the production to chlorophyll ratio given by Charpy and Charpy-Roubaud (1990) for Tikehau lagoon surface waters (0 - 5 m) in French Polynesia of 17 mg C $mg^{-1}$ Chla $hr^{-1}$. Assuming, say, 10 hours illumination per day, gross production from chlorophyll is then 0.14 g C $m^{-3}$ $day^{-1}$ for the "old lagoon water" areas, and 0.56 g C $m^{-3}$ $day^{-1}$ for Stn 20.

(ii) ***Net phytoplankton production***

Net production will be considerably lower. Estimates can be made using a ratio of gross photosynthesis to respiration (P/R), although the lack of data on respiratory activity in the water column makes estimation of a P/R ratio for phytoplankton difficult (Kinsey, 1983). The P/R ratio given by Yentsch (1962) of 2.5 : 1 may be the best approximation for determining optimum potential yields. This gives estimates of net production of 0.06 g C $m^{-3}$ $day^{-1}$, and 0.22 g C $m^{-3}$ $day^{-1}$, for "old lagoon water" and Stn 20, respectively. Assuming a ratio of dry weight to carbon weight of 3 : 1 (Margalef and Vives, 1967), dry weight production is 0.2 g C $m^{-3}$ $day^{-1}$, and 0.7 g C $m^{-3}$ $day^{-1}$, respectively, for "old lagoon water" and Stn 20.

(iii) ***Potential bivalve yields***

These estimations of maximum potential net primary production in the water column for these optimum areas of Aitutaki lagoon can be used to provide indicative estimates of potential bivalve production by further extrapolation. Assumptions of a 10 % rate of transfer of organic carbon weight to the filter-feeding bivalves, and a ratio of bivalve fresh weight to dry weight of 9.4 (Trancart, 1978) can be accepted as best estimates. The maximum annual production of bivalves then, under optimal conditions, would be 0.07 kg $m^{-3}$ for the "old lagoon water" areas, and up to 0.24 kg $m^{-3}$ for Stn 20. With average depth in the "old lagoon water" areas of around 5 m, production in terms of water surface area is optimally around 0.35 kg $m^{-2}$. This potential production from both the "old lagoon water" and from Stn 20 (of negligible depth) is very low compared with French or Spanish bivalve culture areas where annual production attains 30 kg $m^{-3}$ $year^{-1}$ (Firth, 1969 and Bardach et al., 1972).

### (iv) *Limitations and qualifications*

This estimation of potential bivalve yield must be accepted as indicative only. The extrapolations and assumptions involved above mean that the figure is probably only useful as an estimate of the order of magnitude of potential bivalve production. Nevertheless, even if actual yields were ten times that predicted here, intensive bivalve culture is hardly likely to prove commercially viable.

The method employed in this study, however, are appropriate as a means for Pacific island fisheries researchers to identify optimum sites for bivalve culture trials. Further strengthening of the above assumptions and extrapolations would also allow the method to become a far more robust predicative tool. Measurement of phytoplankton concentrations could be used as a simple, standardized method of determining the ecological and commercial viability for filter-feeding bivalve introduction programs.

A number of questions need to be resolved before pigment concentrations can be widely and confidently used in planning and implementing bivalve culture trials. Nutrient concentrations will be the principal parameter relating pigment concentrations to production rates. The relationship between pigment and production would need to be determined over a range of lagoon types, of varying adjacent landmass and runoff characteristics, and lagoon water retention patterns. Further, the above estimates are based solely on chlorophyll-a production and assimilation rates. Phytoplankton utilizing pigments other than chlorophyll-a are likely to be equally or more significant to net production. The relative importance of each phytoplankton pigment type, and of other particulate organic matter (POM) in filter-feeding bivalve nutrition also needs to be determined. Most simply, POM levels could be typified for each lagoon type, as proposed above for nutrient levels. However, as POM probably plays a major part in bivalve nutrition, however, methods of measuring POM which were similarly simple and equally appropriate to use in isolated island situations would best be devised.

## 5 - CONCLUSION

Actual bivalve yields could vary considerably from the estimates obtained above. Nevertheless, these methods do provide useful comparative measures of available phytoplankton, and thereby allow identification of optimum sites for bivalve culture trials.

Further study of the parameters influencing primary productivity and bivalve production rates in tropical lagoon ecosystems is necessary before these methods can be confidently used in the more significant role of assessment of the viability of intensive bivalve culture operations. Baseline data on pigment concentrations, productivity and bivalve yields should be obtained from other areas where tropical bivalves are already introduced or under culture. Substantiation and refinement of this method will eventually permit accurate assessment of potential bivalve production capacities in natural lagoon systems, and assist greatly in planning and implementation of aquaculture development programs throughout the Pacific.

The observed levels of phytoplankton pigment concentrations demonstrate the relative poverty of Aitutaki lagoon waters. Estimates of potential yields for filter-feeding bivalves, even in the most productive areas of Aitutaki lagoon, do not compare well with those cited from other intensive bivalve culture areas. Avana Stream estuary is unsuitable for any such aquaculture activity, despite localized areas of high primary productivity.

The natural lagoon environments of Aitutaki and Rarotonga are unlikely to be able to support intensive culture of filter-feeding bivalves. The construction of aquaculture pond systems appears to be the only possibility for commercial filter-feeding bivalve culture in these lagoons. However, the history of such capital-intensive development in the Pacific Islands (Uwate et al., 1984) is hardly encouraging.

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Table 1 : Physical caracteristics and pigments concentrations in Aitutaki lagoon (Cook Islands) in December 1985. % sat : percent of 02 saturation, Chl.a = chlorophylle-a, Pheo.a = Pheophytin-a, % Chl.a = 100 Chl-a. (Chl.a + Pheo-a).

| Station | Depth (m) | Temp. (°C) | Salin. ‰ | 02 mg.1-1 | % sat. | Chl.a mg.m-3 | Pheo. mg.m-3 | % chl.a |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 30.7 | 35.8 | 5.7 | 91 | .64 | .65 | 50 |
| | 1 | 30.7 | 35.8 | – | – | – | – | – |
| 2 | 0 | 31.3 | 36.1 | 6.3 | 100 | .68 | .46 | 60 |
| | 1 | 31.3 | 36.1 | – | – | – | – | – |
| 3 | 0 | 32.5 | 35.8 | 7.4 | 118 | .42 | .33 | 56 |
| | 1 | 30.5 | 35.8 | – | – | – | – | – |
| | 2 | 30.5 | 35.8 | – | – | – | – | – |
| | 3 | 29.8 | 35.8 | – | – | – | – | – |
| | 4 | 29.7 | 35.9 | 5.8 | 92 | .85 | .81 | 51 |
| 4 | 0 | 31.4 | 35.8 | 6.7 | 107 | .58 | .44 | 57 |
| 5 | 0 | 30.6 | 35.7 | 6.9 | 110 | .44 | .40 | 52 |
| | 1 | 30.5 | 35.6 | – | – | – | – | – |
| | 2 | 30.0 | 35.7 | – | – | – | – | – |
| | 3 | 29.9 | 35.7 | – | – | – | – | – |
| | 4 | 29.7 | 35.7 | – | – | – | – | – |
| | 5 | 29.7 | 35.8 | 7.0 | 111 | .56 | .46 | 55 |
| 6 | 0 | 29.8 | 35.7 | 5.1 | 81 | .22 | 1.13 | 16 |
| | 1 | 29.7 | 35.7 | – | – | – | – | – |
| | 2 | 29.7 | 35.8 | – | – | – | – | – |
| | 3 | 29.7 | 35.8 | 5.1 | 81 | .60 | .45 | 57 |
| 7 | 0 | 29.3 | 35.4 | 6.2 | 99 | .46 | .35 | 57 |
| | 1 | 29.3 | 35.4 | – | – | – | – | – |
| | 2 | 29.2 | 35.4 | – | – | – | – | – |
| | 3 | 29.2 | 35.5 | – | – | – | – | – |
| | 4 | 29.2 | 35.5 | 6.2 | 99 | .34 | .83 | 29 |
| 8 | 0 | 29.2 | 35.5 | 5.8 | 92 | .42 | .33 | 56 |
| | 1 | 29.2 | 35.5 | – | – | – | – | – |
| | 2 | 28.7 | 35.3 | – | – | – | – | – |
| | 3 | 28.7 | 35.3 | – | – | – | – | – |
| | 4 | 28.7 | 35.3 | – | – | – | – | – |
| | 5 | 28.6 | 35.3 | 6.2 | 99 | .74 | .48 | 61 |
| 9 | 0 | 28.7 | 35.2 | 6.3 | 100 | .66 | .45 | 59 |
| | 1 | 28.6 | 35.2 | – | – | – | – | – |
| | 2 | 28.5 | 35.2 | – | – | – | – | – |
| | 3 | 28.4 | 35.2 | – | – | – | – | – |
| | 4 | 28.3 | 35.3 | – | – | – | – | – |
| | 5 | 28.3 | 35.3 | – | – | – | – | – |
| | 6 | 28.2 | 35.3 | – | – | – | – | – |
| | 7 | 28.1 | 35.3 | 6.5 | 103 | 1.008 | .65 | 61 |

| Station | Depth (m) | Temp. (°C) | Salin. ‰ | 02 mg.1-1 | % sat. | Chl.a mg.m-3 | Pheo. mg.m-3 | % chl.a |
|---|---|---|---|---|---|---|---|---|
| 10 | 0 | 28.8 | 35.3 | 6.3 | 100 | .82 | .79 | 29 |
| | 1 | 28.8 | 35.3 | - | - | - | - | - |
| | 2 | 28.7 | 35.3 | - | - | - | - | - |
| | 3 | 28.6 | 35.2 | - | - | - | - | - |
| | 4 | 28.6 | 35.2 | - | - | - | - | - |
| | 5 | 28.6 | 35.2 | - | - | - | - | - |
| | 6 | 28.5 | 35.2 | 6.3 | 100 | .32 | .79 | 29 |
| 11 | 0 | 29.0 | 35.4 | 6.2 | 99 | .22 | .14 | 61 |
| | 1 | 28.8 | 35.3 | - | - | - | - | - |
| | 2 | 28.0 | 35.5 | - | - | - | - | - |
| | 3 | 27.8 | 35.5 | 6.0 | 95 | .20 | .22 | 48 |
| 12 | 0 | 28.8 | 35.3 | 6.4 | 102 | .10 | .11 | 47 |
| | 1 | 28.5 | 35.4 | - | - | - | - | - |
| | 2 | 28.0 | 35.4 | - | - | - | - | - |
| | 3 | 27.6 | 35.4 | - | - | - | - | - |
| | 4 | 27.5 | 35.5 | 6.3 | 100 | .06 | .09 | 39 |
| 13 | 0 | 30.5 | 35.6 | 6.2 | 99 | .52 | .29 | 64 |
| | 1 | 30.2 | 35.6 | - | - | - | - | - |
| | 2 | 29.8 | 35.6 | - | - | - | - | - |
| | 3 | 29.8 | 35.6 | 6.6 | 105 | .36 | .48 | 43 |
| 14 | 0 | 30.2 | 35.5 | 6.4 | 102 | .30 | .24 | 56 |
| | 1 | 30.3 | 35.5 | - | - | - | - | - |
| | 2 | 29.6 | 35.5 | - | - | - | - | - |
| | 3 | 29.5 | 35.6 | 6.5 | 103 | .30 | .21 | 59 |
| 15 | 0 | 30.4 | 35.5 | 6.8 | 108 | .30 | .27 | 53 |
| | 1 | 29.6 | 36.0 | - | - | - | - | - |
| | 2 | 29.1 | 35.6 | - | - | - | - | - |
| | 3 | 29.0 | 35.6 | - | - | - | - | - |
| | 4 | 28.9 | 35.6 | 6.5 | 103 | .51 | .27 | 65 |
| 16 | 0 | 29.0 | 35.3 | 6.7 | 107 | .54 | .45 | 55 |
| | 1 | 29.0 | 35.3 | - | - | - | - | - |
| | 2 | 29.0 | 35.2 | 6.7 | 107 | .44 | .37 | 54 |
| 17 | 0 | 29.0 | 35.2 | 6.9 | 110 | .63 | .42 | 60 |
| | 1 | 29.0 | 35.2 | - | - | - | - | - |
| | 2 | 29.0 | 35.2 | 6.8 | 108 | .44 | .34 | 56 |
| 18 | 0 | 27.6 | 35.4 | 6.1 | 97 | | .17 | .21 |
| | 2 | 27.4 | 35.3 | - | - | - | - | - |
| | 4 | 27.2 | 35.3 | - | - | - | - | - |
| | 6 | 27.1 | 35.3 | - | - | - | - | - |
| | 8 | 27.0 | 35.3 | - | - | - | - | - |
| | 10 | 26.9 | 35.4 | 6.0 | 95 | .11 | .11 | 52 |
| | 12 | 26.8 | 35.4 | - | - | - | - | - |
| | 14 | 26.9 | 35.4 | - | - | - | - | - |
| | 16 | 26.9 | 35.4 | - | - | - | - | - |
| | 18 | 26.9 | 35.4 | - | - | - | - | - |
| | 20 | 26.9 | 35.4 | - | - | - | - | - |

| Station | Depth (m) | Temp. (°C) | Salin. ‰ | 02 mg.1-1 | % sat. | Chl.a mg.m-3 | Pheo. mg.m-3 | % chl.a |
|---|---|---|---|---|---|---|---|---|
| 19 | 0 | 27.6 | 35.3 | 6.1 | 97 | .12 | .11 | 53 |
| | 5 | 26.9 | 35.2 | – | – | – | – | – |
| | 10 | 26.8 | 35.3 | 6.2 | 99 | .10 | .13 | 44 |
| | 15 | 26.8 | 35.3 | – | – | – | – | – |
| | 20 | 26.6 | 35.3 | 6.3 | 100 | .11 | .10 | 54 |
| 20 | 0 | >35.0 | 38.4 | 8.1 | 130 | 3.13 | 2.13 | 60 |
| 21 | 0 | 29.6 | 35.4 | 7.5 | 119 | .26 | .28 | 48 |
| 22 | 0 | 28.9 | 35.3 | 7.2 | 115 | .64 | .86 | 43 |

Table 2 : Physical caracteristics and pigments concentrations in Avana Stream estuary in Rarotonga (Cook Islands) in December 1985. % sat. = percent of 02 saturation, Chl.a = Chlorophyll-a, Pheo.a = Pheophytine-a, % Chl.a = 100 Chl-a (Chl-a + Pheo).

| Station | Depth (m) | Temp. (°C) | Salin. ‰ | 02 mg.l-1 | % sat. | Chl.a mg.m-3 | Pheo. mg.m-3 | % chl.a |
|---|---|---|---|---|---|---|---|---|
| 1 | .2 | 30.0 | 31.5 | 6.9 | 110 | 2.15 | 1.95 | 52 |
| 2 | .3 | 29.9 | 33.2 | 6.7 | 107 | .91 | .75 | 55 |
| 3 | 1 | 28.5 | 34.3 | 5.9 | 94 | 6.00 | 3.38 | 64 |
| 4 | 1 | 29.6 | 34.7 | 9.8 | 156 | .30 | .39 | 43 |
| 5 | 1 | 29.2 | 34.9 | 8.9 | 142 | .22 | .20 | 52 |
| 6 | 1 | 28.5 | 34.2 | 9.0 | 143 | .20 | .40 | 33 |
| 7 | 0 | 28.7 | 34.7 | 7.8 | 124 | .28 | .29 | 49 |
| | 1 | 28.6 | 34.8 | - | - | - | - | - |
| | 2 | 26.2 | 35.1 | - | - | - | - | - |
| | 3 | 25.9 | 35.1 | - | - | - | - | - |
| | 4 | 25.7 | 35.2 | - | - | - | - | - |
| | 5 | 25.7 | 35.2 | - | - | - | - | - |

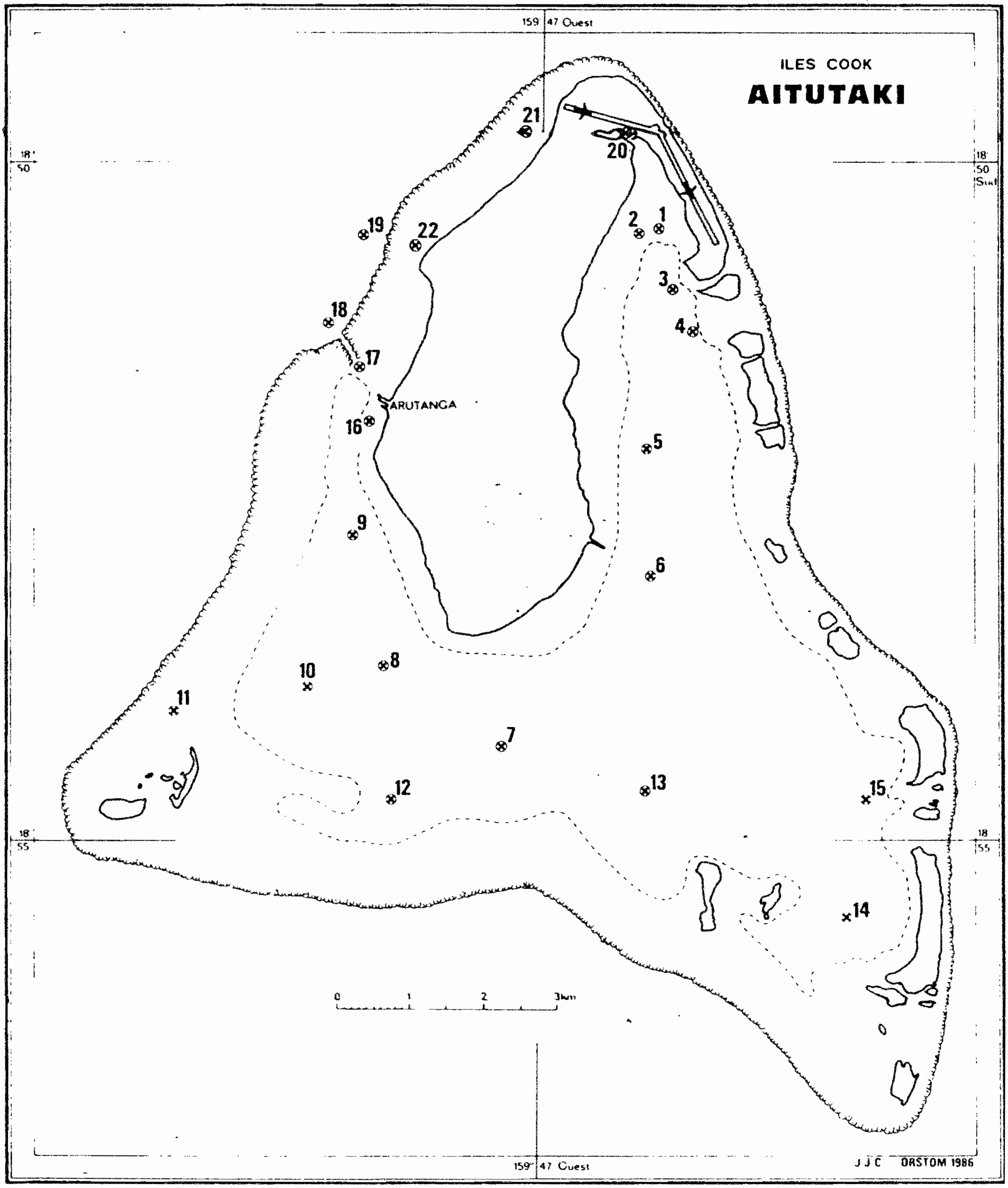


Figure 1 : Aitutaki Atoll : Station locations.

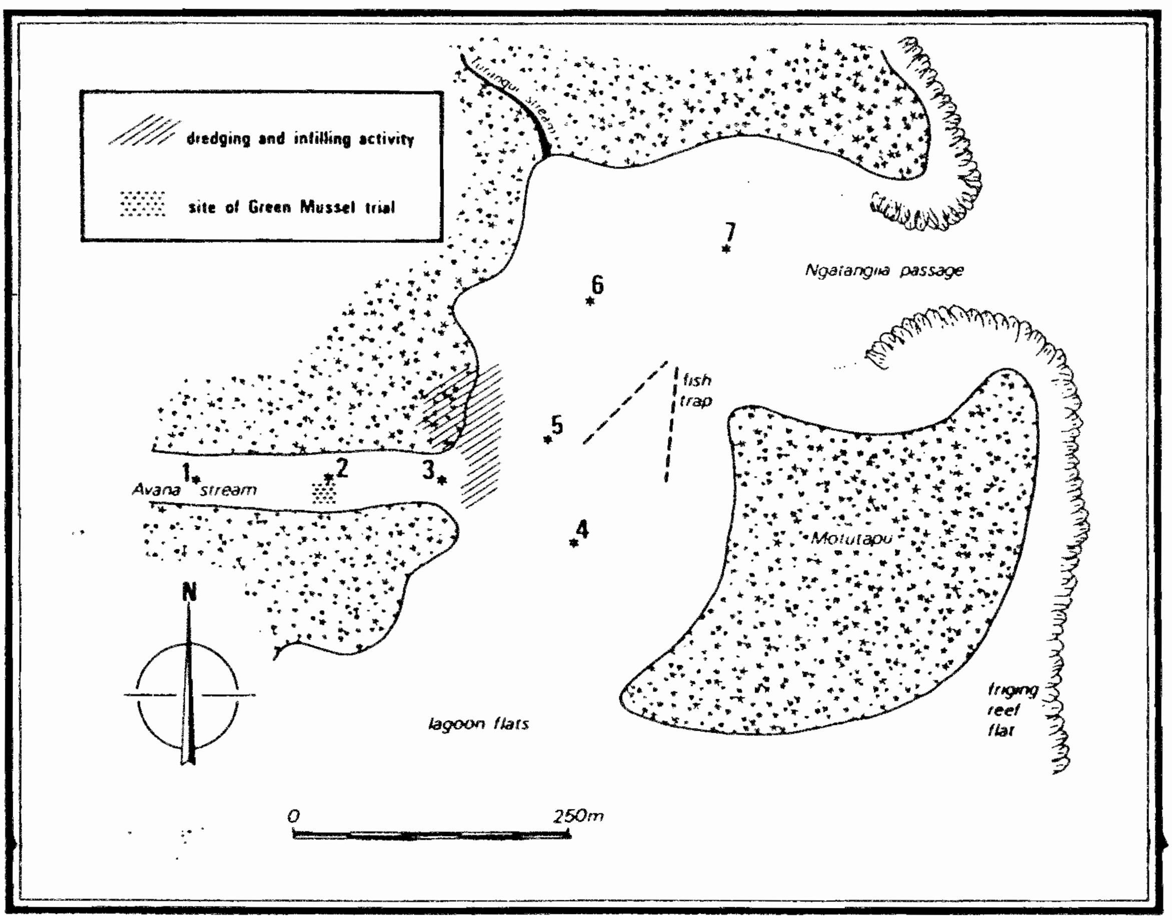


**Figure 2** : Avana Stream estuary : Station locations.

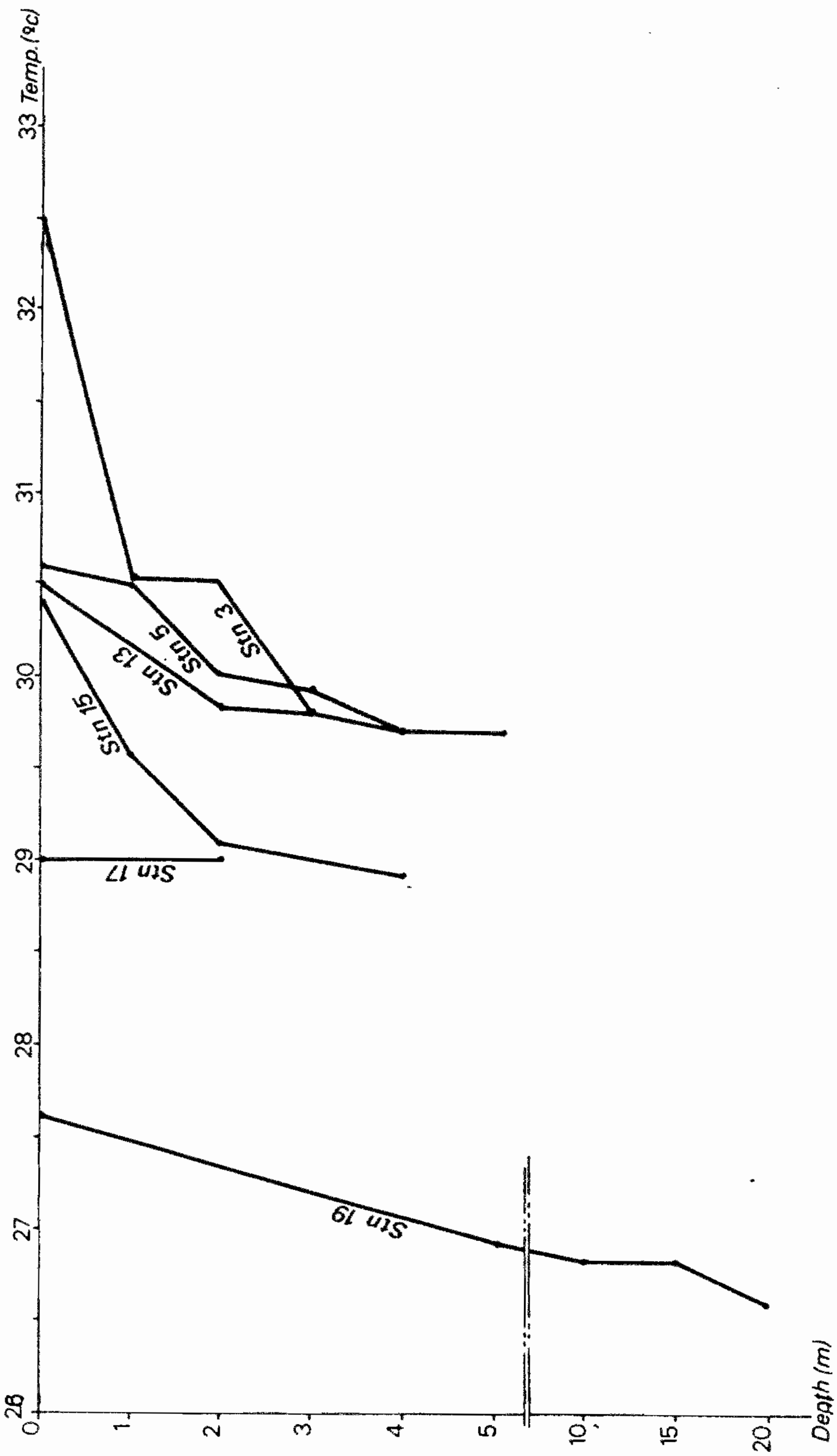


Figure 3 : Temperature profiles for six selected stations at Aitutaki.

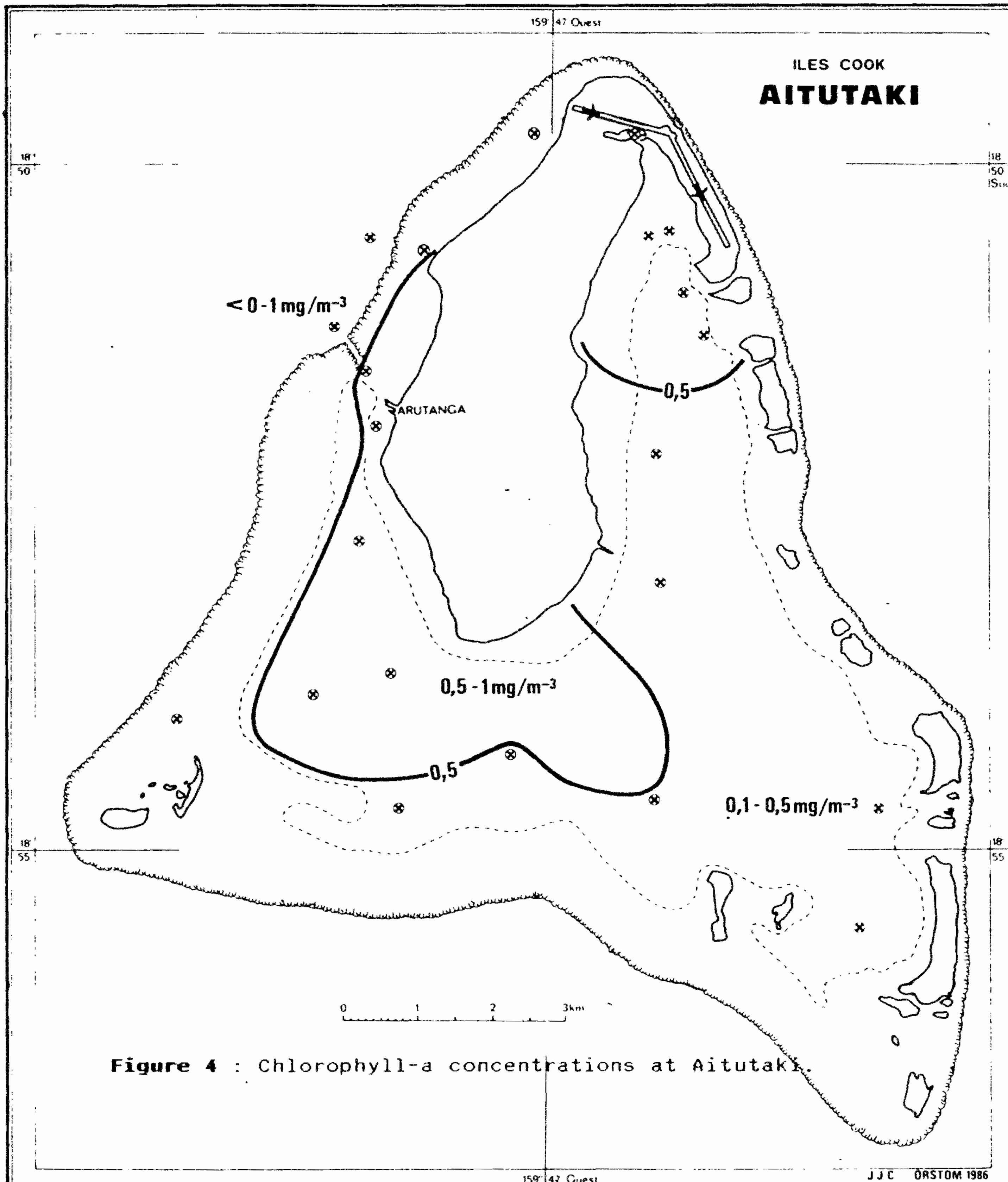


**Figure 4** : Chlorophyll-a concentrations at Aitutaki.

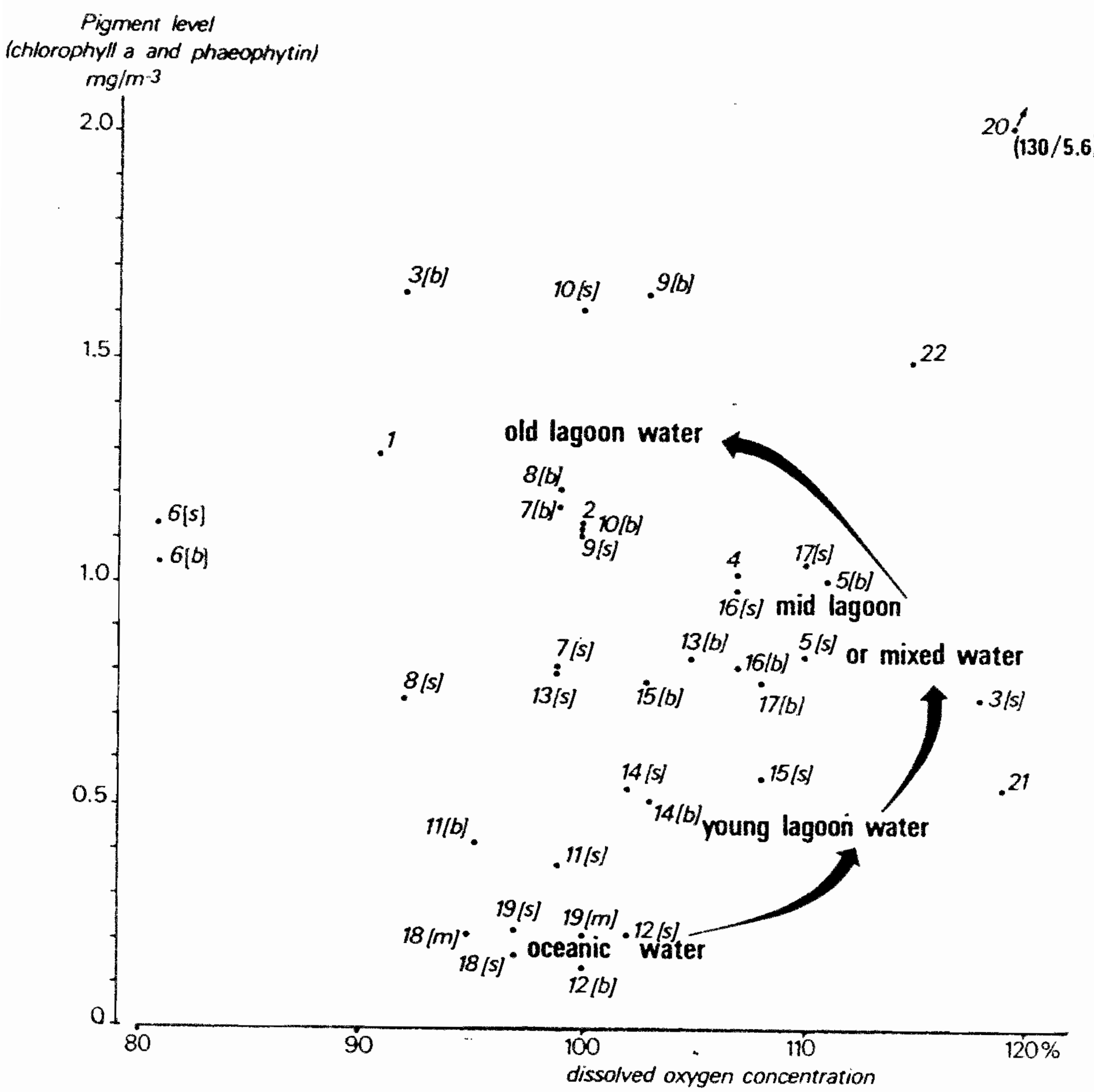


**Figure 5** : Parameters of Primary Production at Aitutaki. Pigment levels increase with increasing lagoon water retention time. Increased phytoplankton growth initially produces super oxygenated water. Eventually, increasing heterotrophic biomass results in a decrease in oxygen levels in older lagoon water, while pigment concentrations increase still further.

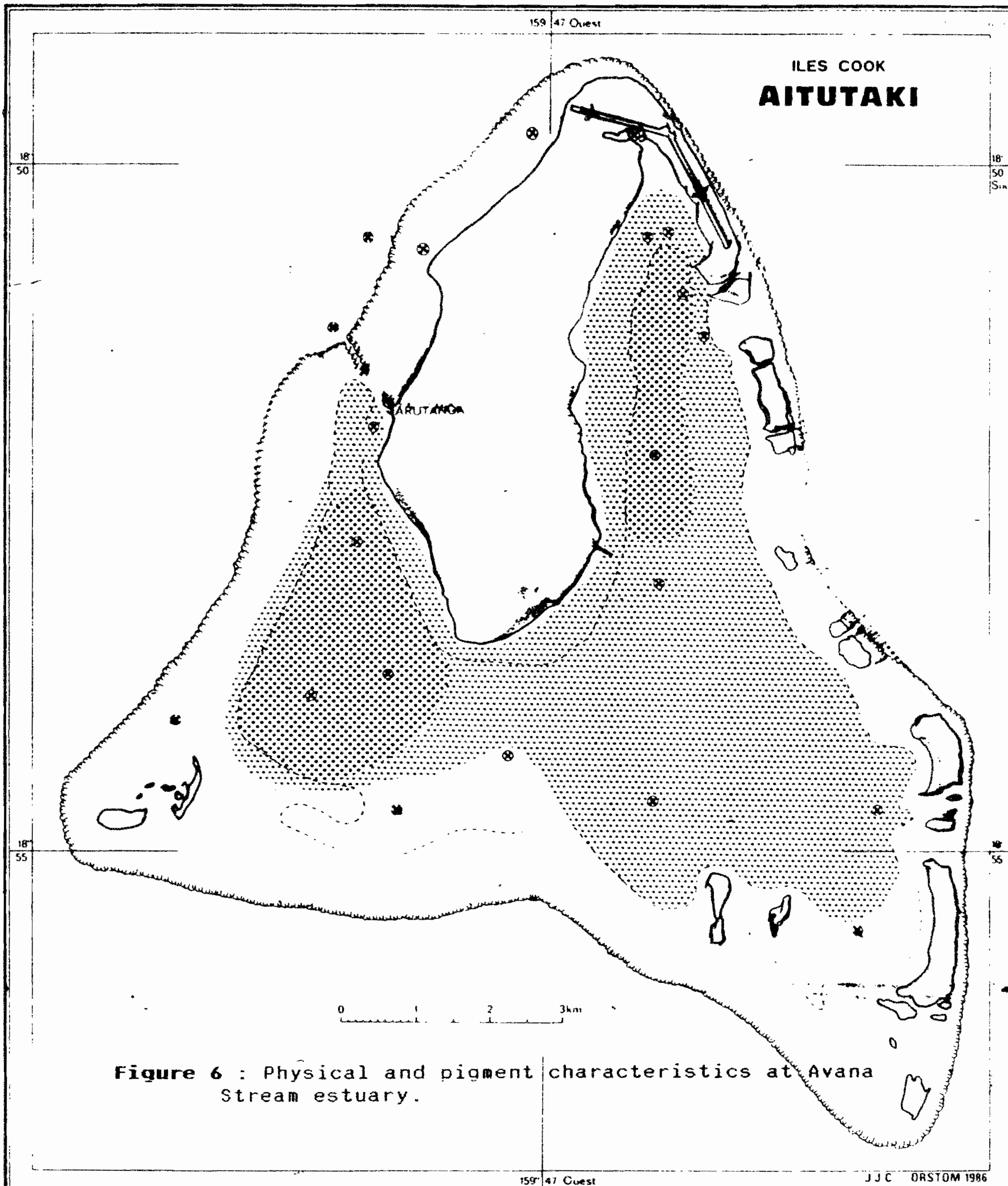


**Figure 6** : Physical and pigment characteristics at Avana Stream estuary.

$> 2 mg/m^{-2}$ | $1 < 2 mg/m^{-2}$ | $< 1 mg/m^{-2}$

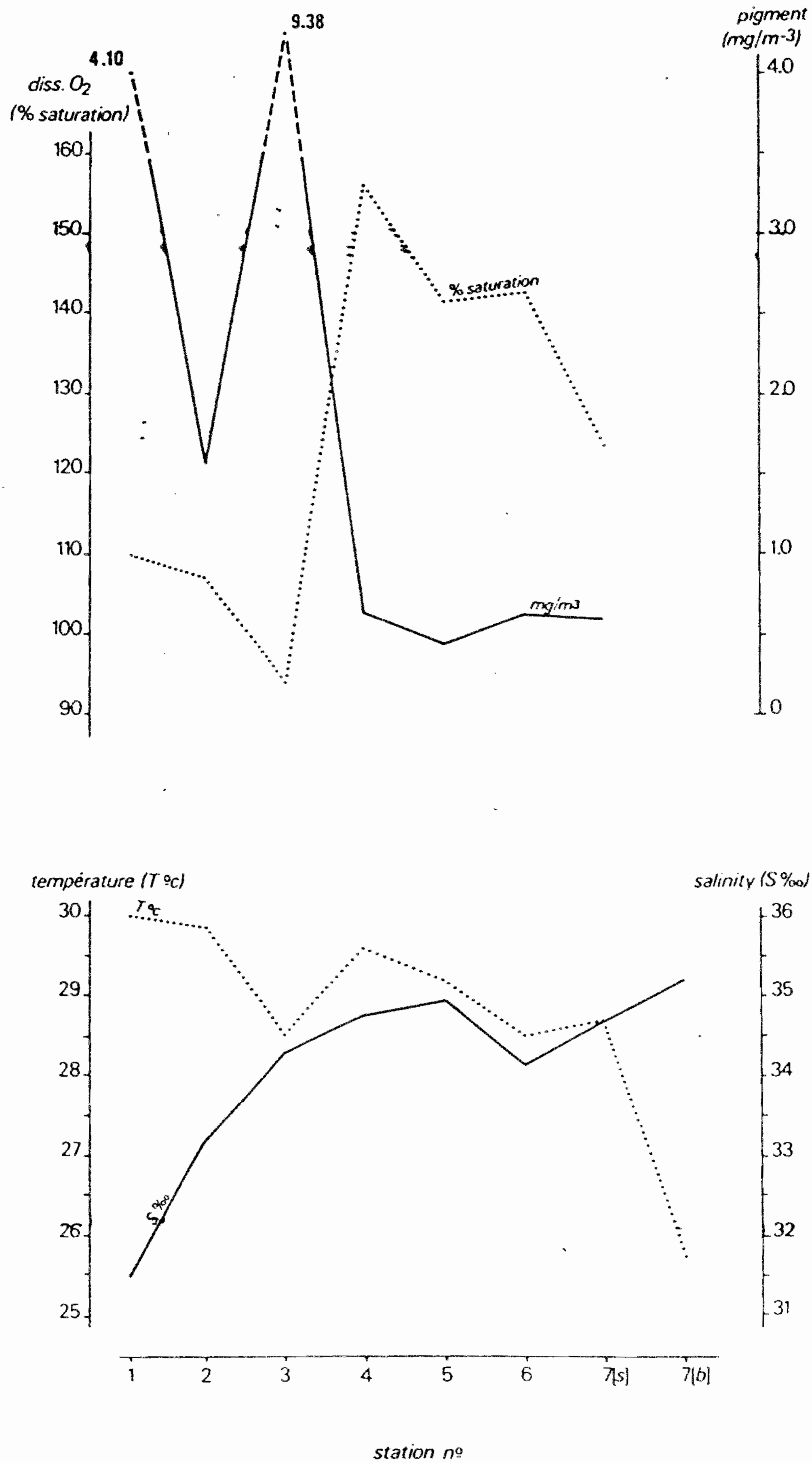


Figure 7 : Percentage of $O_2$ saturation, pigment concentration, temperature and salinity at Avana estuary-lagoon complex.