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by

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Correction

Please correct all units in primary production and chlorophyll a concentration on pages 7-9 to be mg $C/m^2/d$ and mg/m^3 respectively.

THE EFFECT OF DUMPING SUSPENDED SOLIDS AT SEA ON CHLOROPHYLL A CONCENTRATIONS AND PRIMARY PRODUCTION VALUES

By PRAWIN LIMPSAICHOL and TEERAYUT POOPETCH[1]

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ABSTRACT

The hydrodynamics of a plume of suspended solids, produced from the offshore dredging operations in Bang Tao region, is related to patterns of tidal flow. This relationship exists up to 5 km downstream of the dumping. The distribution of suspended solids in the water column is stratified into three layers, a high concentration of solids being found in the upper 5 m of water, and in the layer above the substrate, with a lower concentration of solids in the layer between. The presence of suspended solids in the water column reduces the transmittance of light energy at depth. The finer particles absorb light and also cause considerable scattering. Light attenuation occurs at all wavelengths but is critical in the shorter wavelength range (400-550 nm) which containing high energy used by photosynthetic organisms. This effect leads to a reduction in chlorophyll a concentration and hence a decrease in primary production particularly in the light sensitive nanophytoplankton (size < 30 nm) fraction. The macrophytoplankton (size > 30 nm) fraction does note respond as rapidly as nanophytoplankton does.

I. INTRODUCTION

In general, light attenuation in the photosynthetic active wavelengths of 390-710 nm in water varies mainly due to absorption on water molecules, ions (Sverdrup *et al.*, 1942; Neuman and Pierson, 1966), as well as scattering and absorption on suspended fine particles (Vollenweider, 1969; Heath, 1969).

The tailing effluent of offshore dredging consists of very dense coarse and fine particles as muddy plume is continuously discharged into the sea. Such a muddy plume results in an extreme turbid water at the discharge site; the plume being gradually diluted downstream of the discharge through tidal water movements covering an area of approximately 1×5 km^2. A semidiurnal tidal pattern operates in the area here with a 3 m tidal range in spring tides and 1 m in neap tides and probably extends to 8 km offshore (Charoenlarph, 1982). On the next alternating tidal flow this turbid plume is moved away rapidly in almost the opposite direction from the dredge.

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The aim of this investigation was to determine the effects of a flowing turbid water mass on light attenuation with specially centered on the photosynthetic active wavelengths and chlorophyll a pigment concentration of phytoplankton as well as primary production values. A site was selected at Bang Tao Bay (Lat. 08°00′ 30″N, Long. 98°17′ 00″E) on the west coast of Phuket Island, Thailand where tin dredging regularly takes place during the north east monsoon period. The area dredged is generally an alluvial deposit which extends to approximately 25 m water depth, 6 km offshore (Ludwig, 1976).

II. MATERIALS AND METHODS

Description of sampling sites

This study was carried out in two parts; the first part study (2 cruises in 1982) was conducted during the south flowing ebb water of spring tide covering 4 sampling sites in the outer bay whilst there was only one dredge in operation (at outer bay) in the whole region. Site 1 was about 40 m depth and 7 km offshore, sites 2-4 were 0.3-4 km from the tailing effluent with 30 m depth, locating in the downstream plume (Figs. 1 & 2). The second part study (2 cruises in 1983) was conducted during the north dispersing flood water of spring tide covering 3 sampling sites in the inner bay whilst there was only one dredge in operation (at inner bay) in the whole region. Site 5 was about 15 m depth, 1.5 km offshore, sites 6-7 were 0.3-2 km from the tailing effluent with 13 m depth, locating in the dispersing downstream plume (Figs. 1 & 7).

Primary production measurements

The measurements were made only in the outer bay waters. In order to measure relative primary production under different light attenuation conditions, the same population of phytoplankton was used in all experiments. Thus water samples were collected at 5 m depth at site 1 and then transferred to Jena Glass bottles (110 ml capacity) for primary production measurements by the C-14 method (Steemann-Nielsen, 1965). One millilitre of C-14 solution (4 μ curie. Th) International Agency for C-14 Determinatione was added to individual samples and these were placed in light tight black boxes prior to in situ incubation at sites 1-4. Tripicate samples were used at each depth as indicated in Fig. 5. Three dark samples were also incubatedat a 5 m depth at each site to orrect for dark C-14 fixation.

After incubation for 3 hours (1200-1500 hrs), 50 ml of each sample were filtered through membrane filters (Sartorius, 0.2 μm pore size) for total primary production measurements. The rest of each sample was screened through a 30 μm mesh net before menbrane filtration for the estimation of primary production in the nanophytoplankton fraction. All filters were dried in a desiccator and their activities counted in a calibrated Mini Scaler GM Counter.

Chlorophyll a determinations

Samples were taken at 2 m and 7 m depth (as high concentrations of chlorophyll a were recorded during a previous preliminary survey) at each site, then filtered through 0.45 μm membrane filter for total chlorophyll a content. Another portion was screened through a 30 μm mesh net before membrane filtering for nanophytoplankton fraction. All chlorophyll a filters were freeze-dried prior to 90% acetone extraction in laboratory (APHA, 1975).

Water sample measurements

Water samples for suspended solids and transmittance measurements were collected at every 5 m depth interval at each site using nansen bottles. Suspended solids were analysed immediately after collection using glassfibre filter papers (GF/C) filtration method (APHA, 1975). A 50 ml portion of each sample was frozen and brought to the laboratory for % transmittance measurements by a digital readout spectrophotometer (HITACHI, MODEL 100-20). The readings were taken at every 10 nm throughout the wavelengths of 400-720 nm with reference to membrane

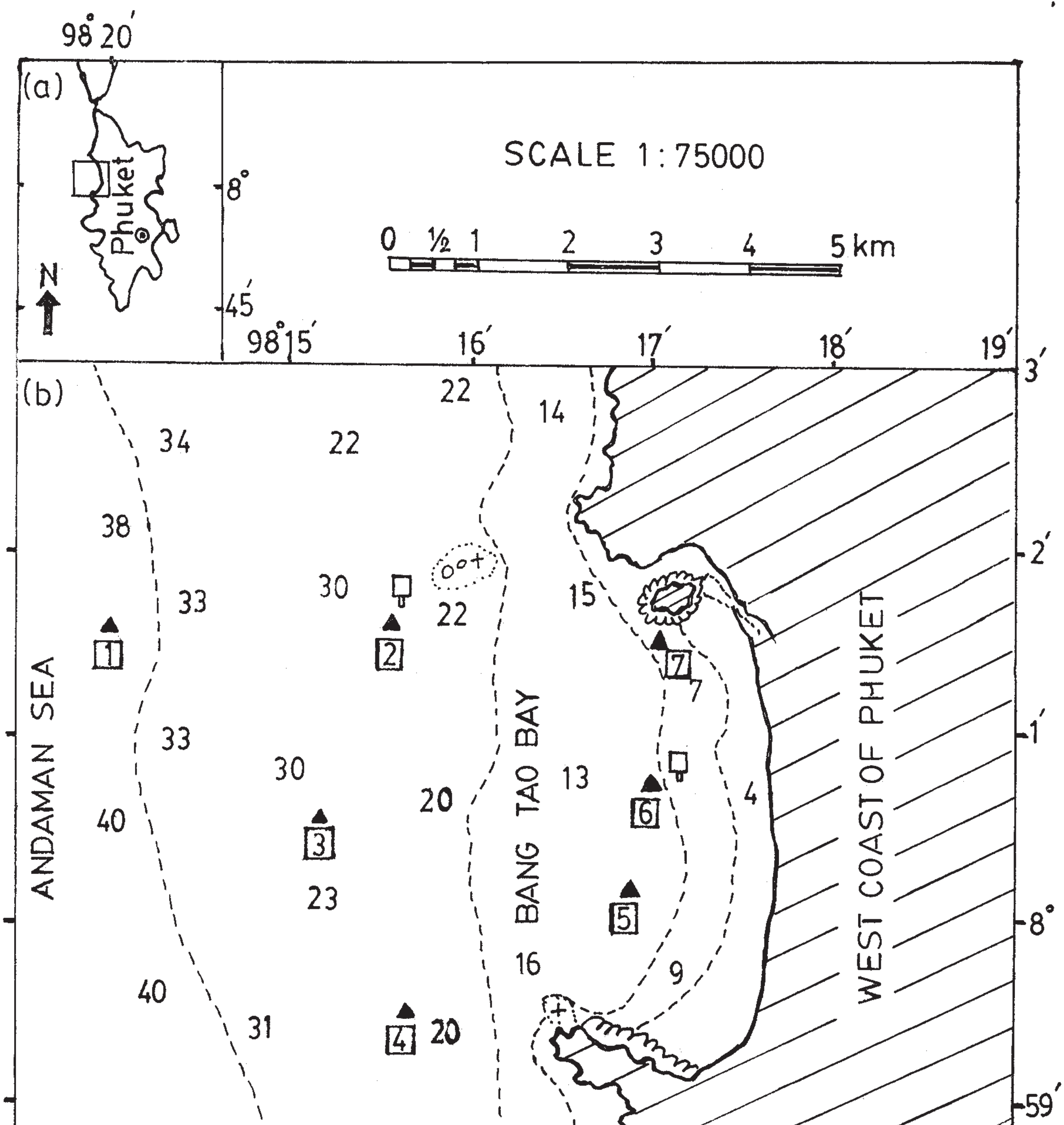
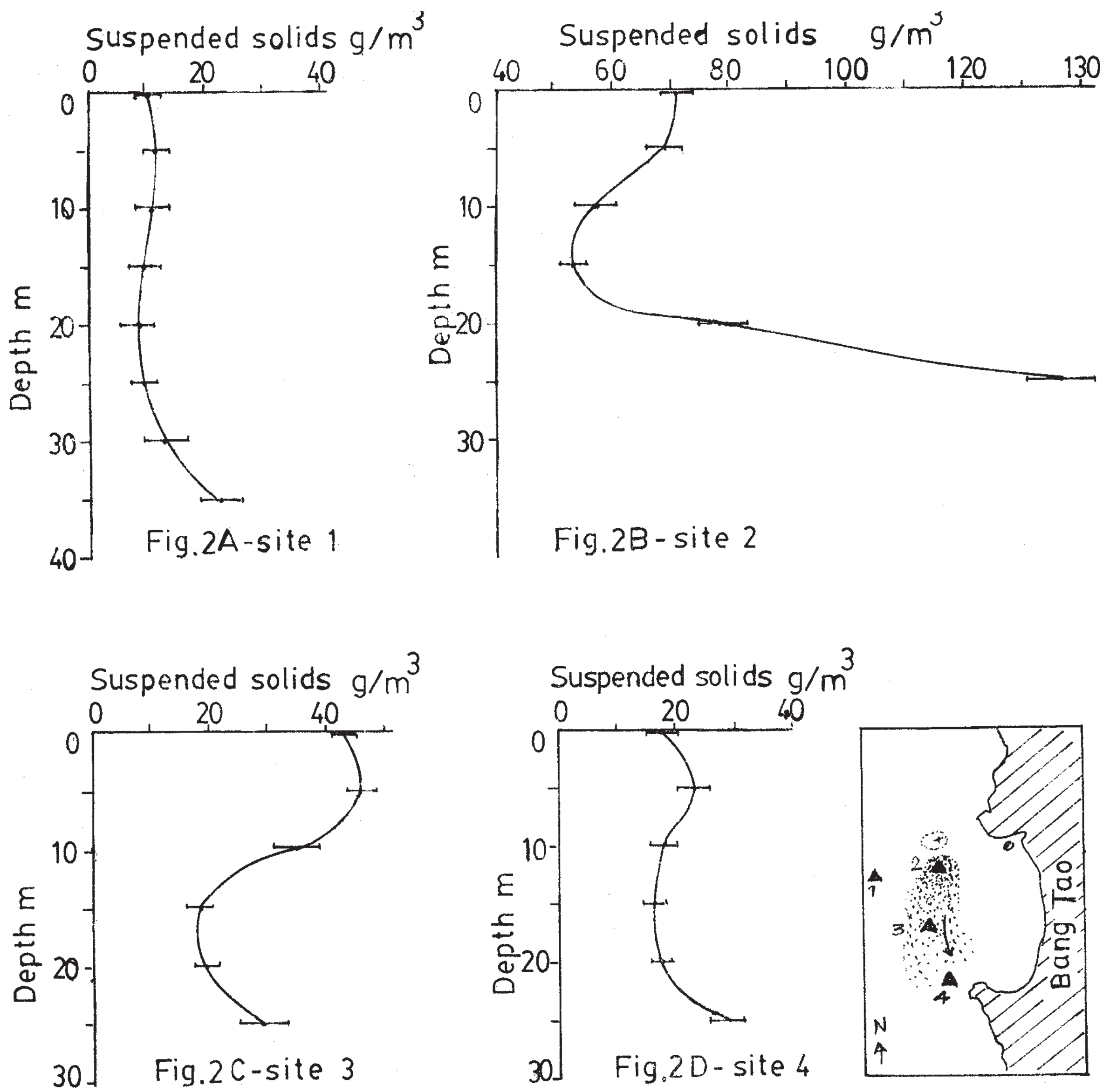


Fig. 1. Map showing Bang Tao Bay west coast of Phuket Island, Thailand.
(a) Phuket Island, box showing sampling locality.
(b) Enlarged map of sampling locality including Bang Tao Bay and offshore Andaman Sea. Numbers indicate water depths in meters. Solid triangles (▲) and number in boxes denote sampling sites and site numbers respectively. The sign [symbol] denotes the discharge site of suspended solids (position of tin dredge), ------ and [symbol] for depth contours and intertidal reefs respectively with [symbol] for rocks.



Figs. 2A-2D. Showing the vertical pattern of discharged suspended solids in the outer bay sites 1-4 (▲). Map showing southward flow of turbid plume during ebb tides.

filtered sea water. During each measurement the samples were stirred vigorously in order to prevent sedimentation in the cuvette. The values were then interpreted by using 95% significant interval to divide the results into 3 subintervals. The mean % transmittance of the upper and lower subintervals were substracted from the overall total mean; the resultant differences in % transmittance represent the critical values of % selective wavelength absorption (% Asw) of light on particles.

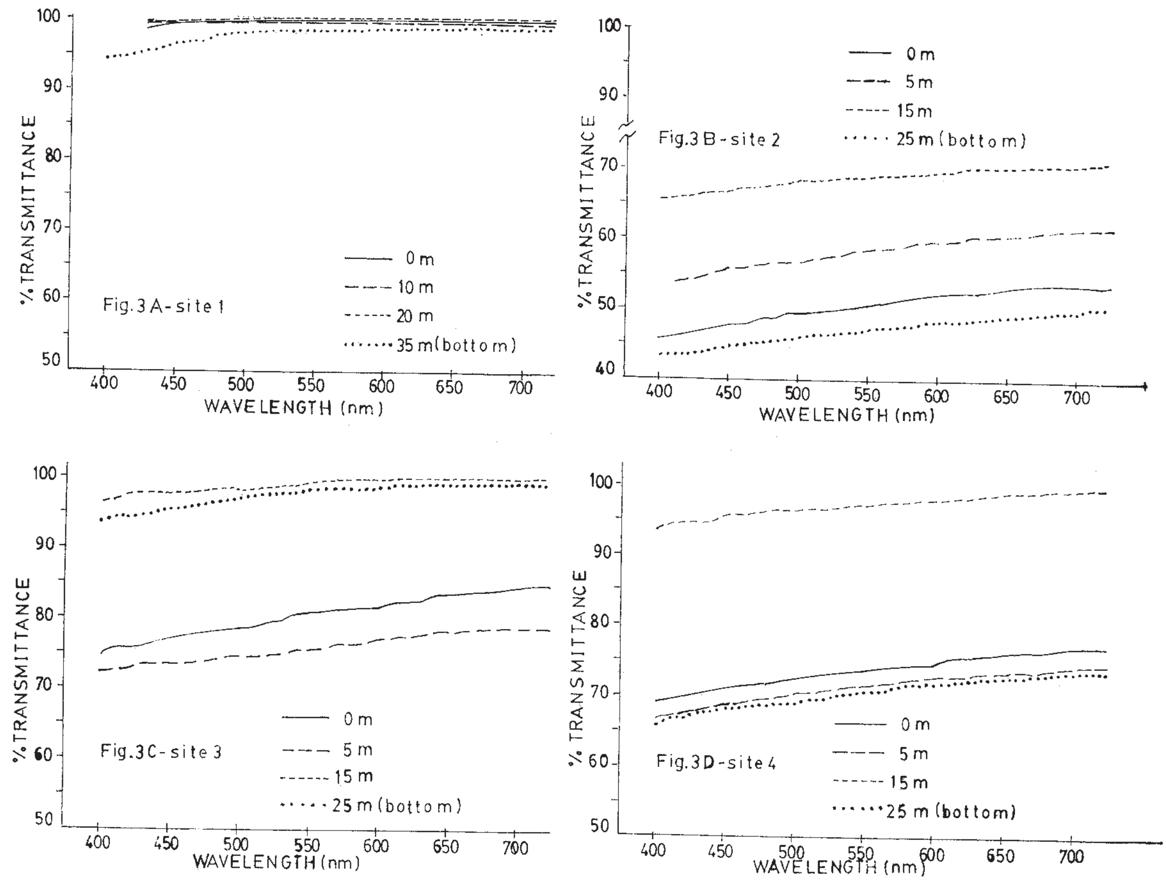
In situ temperatures and salinity were recorded at all depths during 1200-1500 hrs using a reversing thermometer and a calibrated submersible conductivity meter (Electronic Switchgear, Type M.C. 5) respectively. Water transparency was also measured using a 30 cm diameter secchi disc.

III. RESULTS

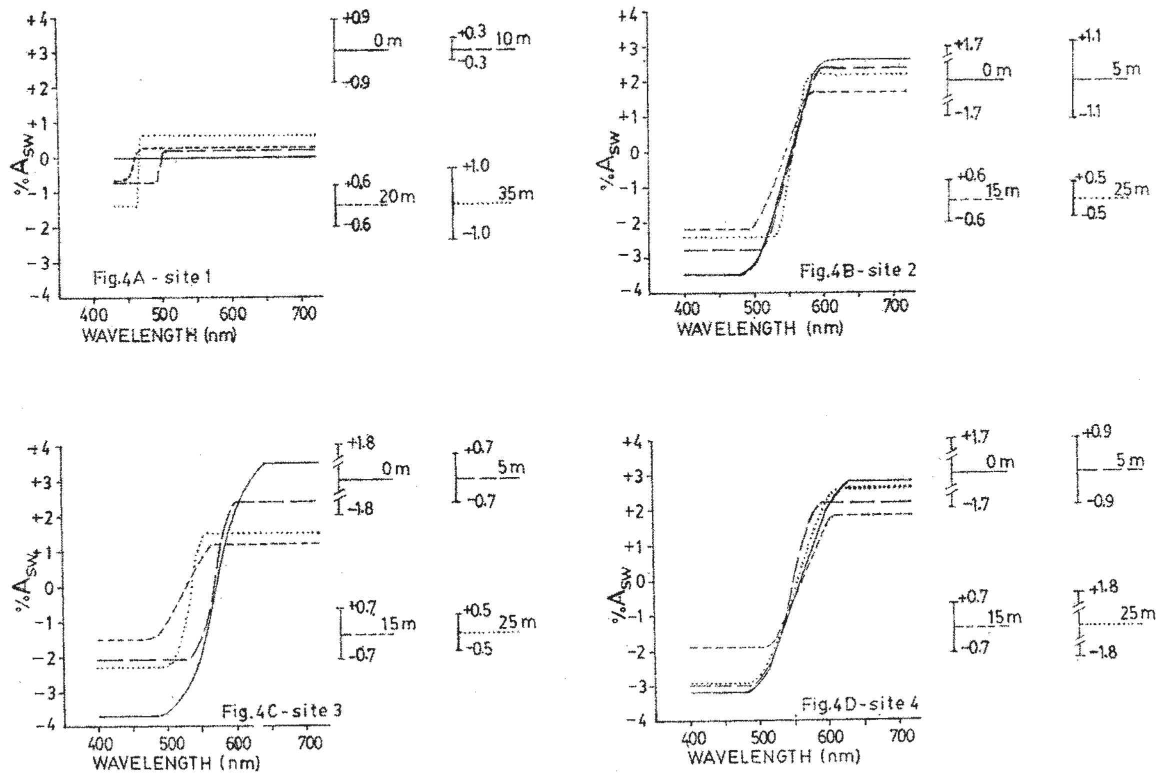
The results of the first part studies are presented in Figs. 2-6, the second part studies in Figs. 7-9 and the average results of all parameters measured through the water column at each study site tabulated in Table 1.

The first part study:

The low concentration of suspended solids of 11.2 g/m^3 was distributed uniformly in the offshore water column (Fig. 2A) resulting in a 23 m transparency value (secchi disc readings, Table 1), and a relatively high concentration value of 24.1 g/m^3 was recorded at the 35 m depth. A very high concentration of 68.4 g/m^3 was recorded at the 5 m surface layer of the dumping site (Fig. 2B) resulting in a very low transparency value of 0.5 m. The rapid settling of coarse particles occurred at 20 m depth with a very high concentration of 136.3 g/m^3, but a large layer of comparatively lower concentration of 53.8 g/m^3 was located in between this and the surface water. The concentrations of 44.4-22.3 g/m^3 were recorded in downstream waters resulting in 5-3 m transparency values with a concentration of 17.5 g/m^3 at 15 m depth (Figs. 2C-2D).



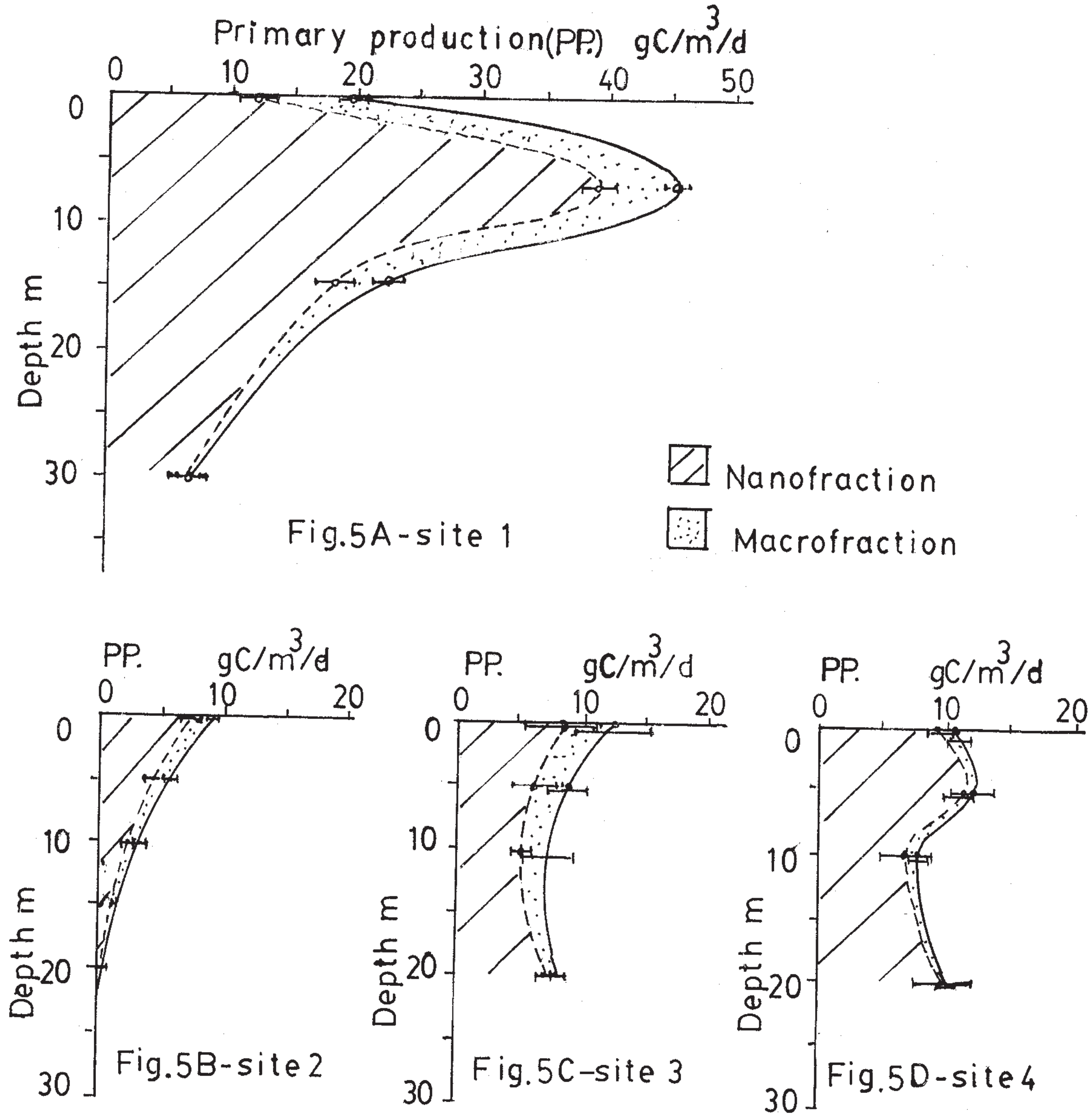
Figs. 3A-3D. Showing % transmittance at various wavelengths and depths in the outer bay sites 1-4. All values are subjected to ± 0.32 % mean standard deviation.



Figs. 4A-4D. Showing the insignificant values of % Asw (selective wavelength absorption of light on particles) at the offshore water (site 1) and high values at the affected turbid waters (sites 2-4).

The transmittance values of almost 100% throughout 400-720 nm were recorded in the offshore water column (Fig. 3A). The marked effect was recorded at the dumping site (Fig. 3B) with a rapid reduction in the shorter wavelength range (400-550 nm). A very low transmittance of 54.9 ± 0.3 % (value of depths average) was recorded with a comparatively high transmittance of 68.7 ± 0.2 % at 15 m depth. Similar patterns but with higher % transmittances (75.2 ± 0.6% - 99.6 ± 0.1%) were recorded at the further downstream sites (Figs. 3C-3D). The absorption of selective waveleghts (% Asw) on particles (Fig. 4A) was insignificant in the offshore water column although it appeared some % Asw over 400-430 nm at 35 m depth. The value of % Asw increased significantly at the affected sites (Figs. 4B-4D). The mean critical Asw values of 6.5% and 4.7% were recorded over 400-550 nm at the surface and at 25 m depth respectively, whilst a value of 3.6% was recorded at the 15 m of relatively clear water.

The chlorophyll a concentrations of 0.851 g/m^3 and 0.163 g/m^3 (Table 1) were recorded in the offshore waters in nano and macrophytoplankton fractions respectively. Under 95% significant comparison between the offshore and affected sites, the former value dropped to about 66% at all the affected sites 2-4 whilst the latter value appeared identical at all sites 1-4. The ratio of chlorophyll a values, between nano and macro fractions, of 5 and 2 were calculated at the offshore and affected sites respectively. The temperature values of offshore water column appeared 0.5°C lower than the values of the



Figs. 5A-5D. Showing primary production in the nano and macrophytoplankton fractions in the outer bay water column of sites 1-4.

affected waters where temperatures were identical. The salinity values remained fairly constant at all sites and depths.

The total primary production of 815.35 g $C/m^2/d$ was recorded in the offshore waters (Table 1). The maximum value of 46.46 g $C/m^3/d$ and a very low value of 7.78 g $C/m/^3d$ were recorded at 7 m and 30 m depth respectively (Fig. 5A). At the affected sites (Figs. 5B-5D), the pattern of primary production changed with the values dropped rapidly to 255.72-86.58 g $C/m^2/d$ (Table 1). The marked low values were recorded at the suspended solids dumping site (Fig. 5B) with a maximum value of only 9.26 g $C/m^3/d$

Table 1. The results of water column average.

Site	Primary Production gC/m²/d	%	N/M	Chlorophyll a g/m³	%	N/M	Suspended solids g/m³	Transparency m	Transmittance % 400-720 nm	Temp. °C	Salinity
1	T 815.35±54.62	100	—	T 1.014 ±0.088	100	—	12.8±2.7	23.5	98.0±0.2	27.3±0.2	32.0±0.5
	N 686.80±57.83	84.2	5.3	N 0.851 ±0.071	83.9	5.2					
	M 128.55± 8.61	15.8	—	M 0.163 ±0.080	16.1						
2	T 86.58±15.77	100	—	T 0.302 ±0.037	100	—	77.1±3.4	0.5	54.9±0.3	27.7±0.2	32.0±0.5
	N 76.33±15.41	88.2	7.4	N 0.187 ±0.026	61.9	1.6					
	M 10.25± 1.87	11.8	—	M 0.115 ±0.032	38.1	—					
3	T 255.72±55.15	100	—	T 0.333 ±0.048	100	—	31.7±2.6	5.0	88.2±0.3	28.0±0.2	32.0±0.5
	N 219.19±30.09	85.7	6.0	N 0.239 ±0.028	71.8	2.5					
	M 36.53 ± 7.88	14.3	—	M 0.094 ±0.038	28.2						
4	T 233.27±53.08	100	—	T 0.335 ±0.044	100	1.9	20.2±2.1	3.0	78.2±0.4	28.2±0.2	32.0±0.5
	N 218.26±23.89	93.5	14.9	N 0.218 ±0.027	65.1						
	M 14.65 ± 6.28	6.5	—	M 0.117 ±0.036	34.9						
5	—	—	—	T 0.726 ±0.052	100	3.0	15.9±2.2	12.0	99.2±0.1	28.7±0.3	32.5±0.5
				N 0.544 ±0.039	74.9						
				M 0.182 ±0.046	25.1						
6	—	—	—	T 0.531 ±0.031	100	1.8	21.0±2.4	0.8	94.6±0.2	28.7±0.3	32.5±0.5
				N 0.342 ±0.025	64.4						
				M 0.189 ±0.028	35.6						
7	—	—	—	T 0.582 ±0.015	100	2.0	17.3±1.9	3	97.9±0.2	28.7±0.3	32.5±0.5
				N 0.390 ±0.019	67.0						
				M 0.192 ±0.017	33.0						

T = Total M = Macro fraction N = Nano fraction g/m³ = mg/litre

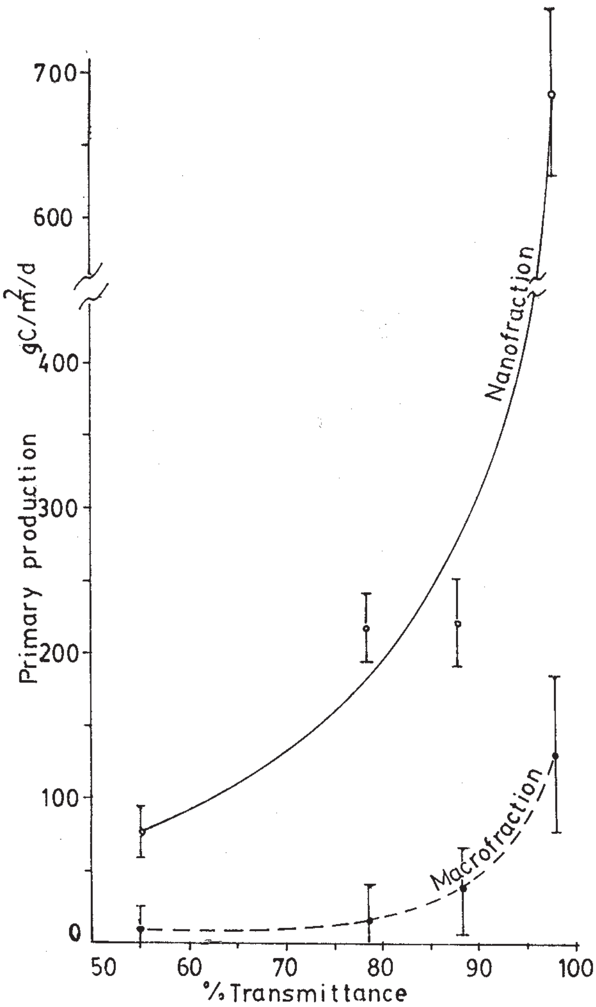


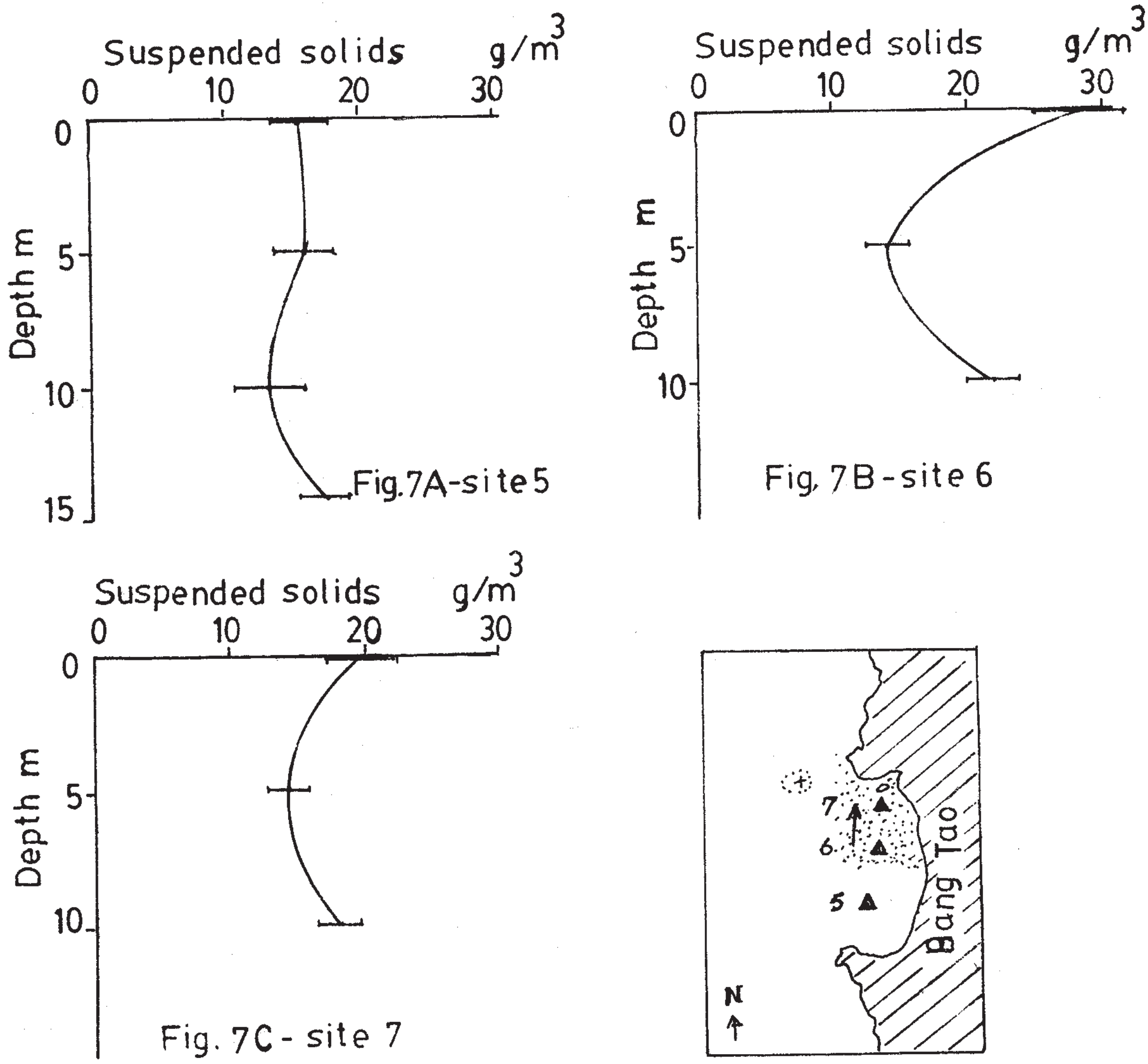
Fig. 6. Showing the rate of primary production per unit sea surface area (m2) in the nano and macrophytoplankton fractions under various illuminations (% transmittance) in the outer bay sites 1-4.

located at the surface and a very low value of 1.58 g $C/m^3/d$ at 20 m depth. The major fraction of primary production was nanophytoplanktons with 83.9% for offshore site and 61.9-71.8% for affected sites (Table 1).

The primary production was also affected by limited illuminations as transmittance value increased 44%, the rate of primary production increased 600 g $C/m^2/d$ by nanofraction and 118 $C/m^2/d$ by macrofraction (Fig. 6).

The second part study:

The low concentration of suspended solids of 15.1 g/m^3 was distributed uniformly in the least affected 10 m water column (Fig. 7A) resulting in a 12 m transparency value (Table 1). A comparatively high concentration of 27.7 g/m^3 and a low value of 13.9 g/m^3 were recorded at the surface and 5 m depth respectively at the dumping site (Fig. 7B) resulting in a 0.8 m transparency value (Table 1). A high concentration value was

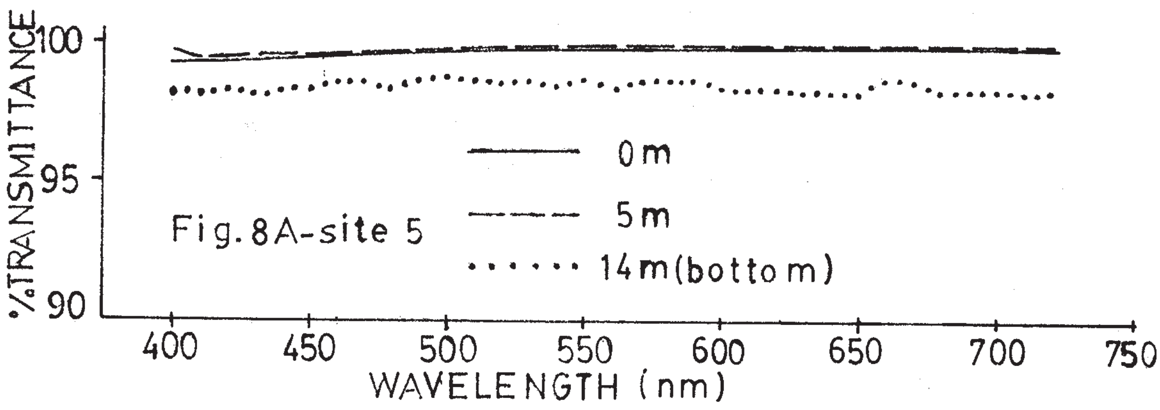


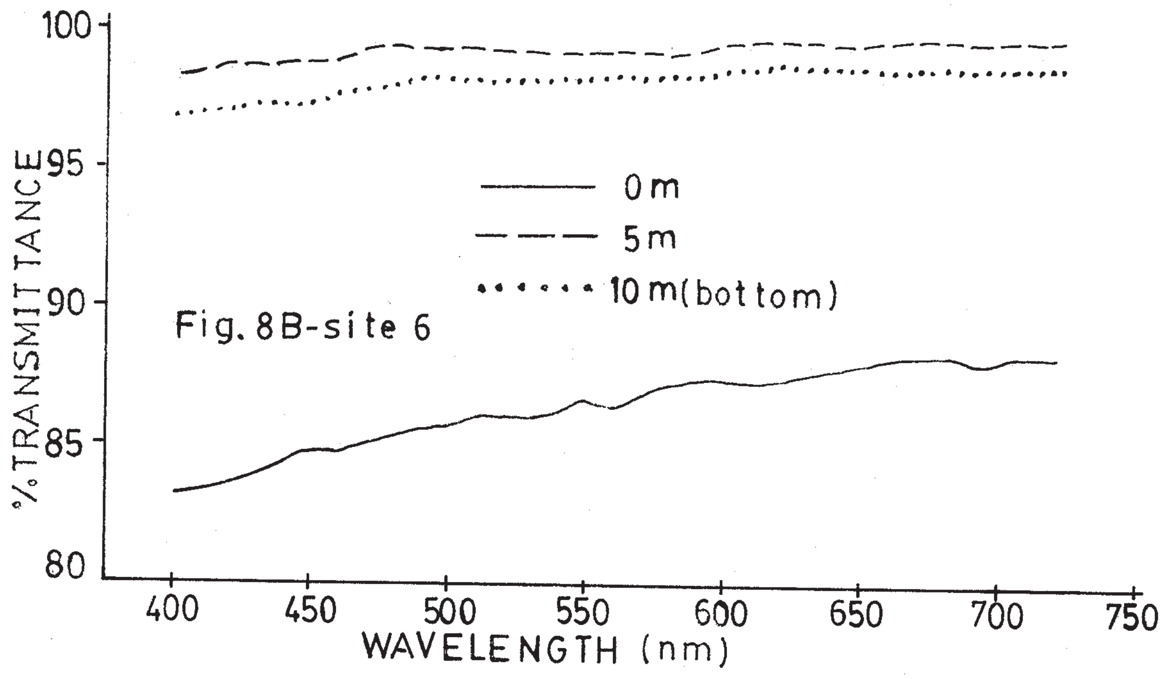
Figs. 7A-7C. Showing the vertical pattern of discharged suspended solids in the inner bay sites 5-7 (▲). Map showing the tubid plume dispersing northwards in the whole downstream area of the bay during flood tides.

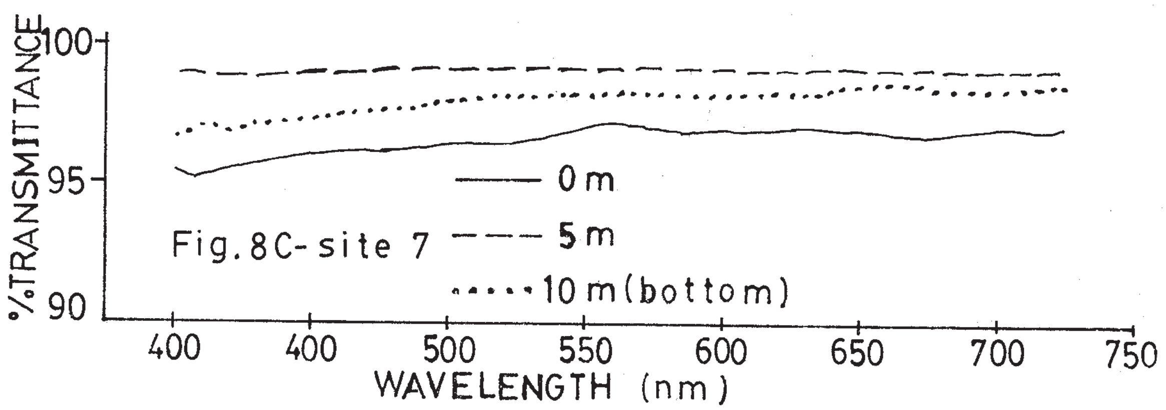
also recorded at the 10 m depth. Similarly, in the downstream dispersing plume (Fig. 7C), the concentration of 18.8 g/m^3 was recorded at the surface and 10 m depth with a value of 14.5 g/m^3 in between resulting in a 3 m transparency value.

The transmittance values of almost 100% throughout 400-720 nm were recorded in the least affected water column (Fig. 8A). The marked effect was observed at the dumping site (Fig. 8B) where a relatively low transmittance of 86.1 ± 0.2 % was recorded at the surface water with a high transmittance of 98.6 ± 0.2 % at depths. Similar patterns but with higher % transmittances (96.3 ± 0.2 % - 99.2 ± 0.5 %) were recorded at the downstream waters (Fig. 8C).

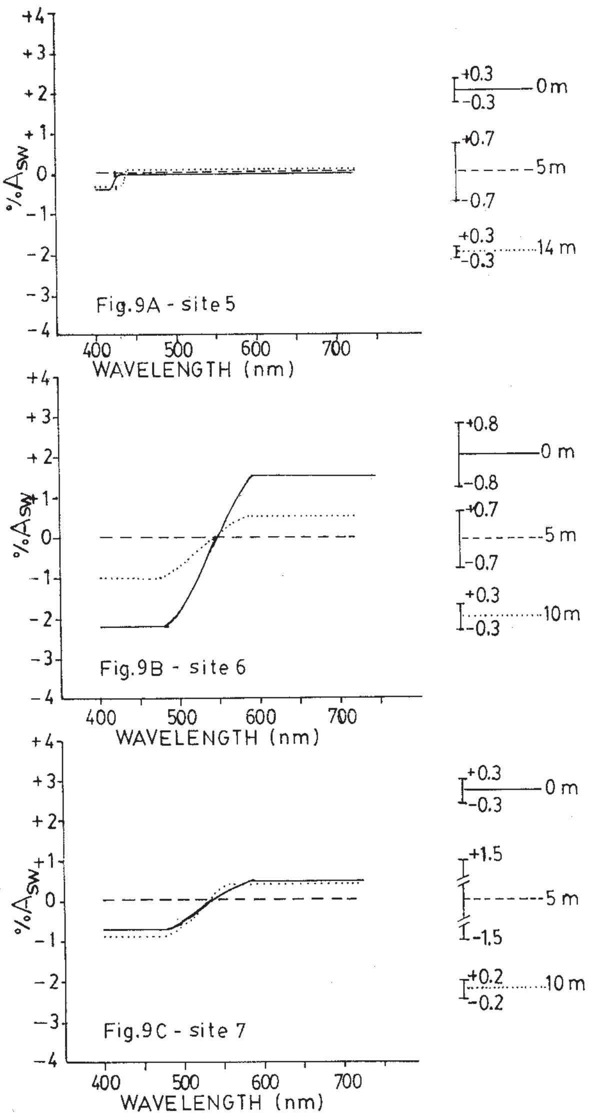
The value of % Asw was insignificant in the least affected water column (Fig. 9A) with some values over the wavelength range of 400-430 nm







Figs. 8A-8C. Showing % transmittance at various wavelengths and depths in the inner bay sites 5-7. All values are subjected to ± 0.26 % mean standard deviation.



Figs. 9A-9C. Showing the insignificant values of % Asw (selective wavelength absorption of light on particles) at the least affected inner bay site (5) and high values at the affected downstream area (sites 6-7).

at 10 m depth. The value of % Asw increased significantly at the affected sites (Figs. 9B-9C) where the mean critical Asw values of 2.6 % and 1.5 % were recorded over 400-550 nm at the surface and 10 m depth respectively. In the layer between these depths, however, the % Asw values were insignificantly different.

IV. DISCUSSION

The values of environmental parameters of the offshore Bang Tao Bay waters correspond to the values of the normal unpolluted Phuket west coast waters (Chareonlarph, 1982). The dense particles at the upper layer and seafloor waters of the dumping area indicate the settling of primary plume and fine particles suspending in the form of a turbidity plume (Barnard, 1978). The downstream concentration of suspended solids as secondary plume, can be explained by Barnard's experiments (1978) that the plume is formed by the tidal dispersion of upper layer suspending fine particles from the primary plume and stratified with the resuspension of seafloor sediments indicating the horizontal mixing is much greater than the vertical mixing. The patterns of suspended solids are also similar to those at the Narragansett Bay, Rhode Island where the low concentration layer with high % light transmission exists in the mid depth of water column (Collins, 1976). However, the concentration of suspended solids at the 15 m comparatively clear water of most affected sites appeared to be identical to the value obtained in the offshore water. The low concentration layer could be regarded exclusively as a least affected layer of the water column. The concentration of supended solids in the offshore water obtained during a later cruise appeared lower than those obtained during the previous one (Poopetch *et al.*, 1982; Limpsaichol, 1982). Similar variations of suspended solids were also obtained by Hylleberg *et al.* (1983) at a nearby area. Such variations were probably due to the seasonal effects.

The importance of light attenuation is the absorption and scattering of light intensities throughout the wavelength range of 400-700 nm on particles (Kamen, 1963). The critical absorption of Asw is in the low wavelength region of 400-550 nm which includes the highly photosynthetic active wavelengths (Rabinowitch and Govindjee, 1969). Neuman and Pierson (1966) showed these lower wavelengths contain more energy than those higher ones. Heath (1969) concluded the previous experimental results of the effect of different chlorophyll concentrations on photosynthesis that chlorophyll is the most important factor at severely limiting light intensities as much more extralight energy is absorbed although the concentration of chlorophyll/cell decreases. Riley and Chester (1971) also showed that under low light intensity, chlorophyll a remains very active and when the light intensity increases (unsaturatedly) the photosynthesis increased rapidly. The chlorophyll a concentration as well as the primary production value in nanophytoplankton fraction taken at the offshore water (84%) is comparable to the value of 91% of total nanophytoplankton standing crop in the Andaman Sea (Wium-Andersen, 1979). Thus the major chlorophyll a content is in the scattering of dense nanophytoplankton fraction leading to rapid respond to light intensities and hence is so primary production.

A further laboratory study made by Limpsaichol and Janekarn (1984) on the effect of light on chlorophyll showed that after 30 minutes exposure to different lighting conditions ranging from 10,000 Lux to 50 Lux, the concentration of chlorophyll a of *Chlorella* sp. and others at the limited lights dropped significantly. Kamen (1963) studied the etiolated *Euglena* and showed that chlorophyll formation ceased abruptly when lighting ceased and resumed when illumination increased. Heath (1969) showed that the function of chlorophyll a was affected even after a few minutes of exposure to reduced light intensity. Riley and Chester (1971) and Rabinowitch and Govindjee (1969) also demonstrated that under low light intensities, some phytoplankton species can adapt quite rapidly as a result of high density of chromatophores and a greater proportion of active carotenoids or other pigments. All the evidences suggest that the covering of secondary plume created an important effect on light attenuation in water critically in the shorter wavelengths, leading to reduction in chlorophyll a concentration particularly in the nanophytoplankton fraction and as a result the primary production values were affected.

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