

## THE GULF OF PARIA (VENEZUELA): EFFECT OF ORINOCO RIVER DISCHARGE ON WATER TRANSPARENCY AND CHLOROPHYLL *a* DISTRIBUTION.

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**ABSTRACT:** Chlorophyll *a* and dissolved/suspended material effects on Secchi depth (Ds) were studied in the Gulf of Paria (Venezuela), during periods of low (June 1984 and May 1985) and high (October 1984) Orinoco river discharge (dry and rainy season, respectively). Correlations between *k<sub>c</sub>* (attenuation due to dissolved chlorophyll *a*), *k<sub>r</sub>* (attenuation due to suspended and dissolved material) and Ds were negative and statistically significant, except the *k<sub>r</sub>* to Ds correlation in October. This suggests that such relations prevail during periods of low river discharge, but they are disrupted during high river input. In June, light in the upper 20 m decreased from Dragon's Mouth to the west and to the south inside the gulf. A similar pattern was observed in October 1984, but light decreased even faster in the vertical. In May, the light penetration keeps former spatial pattern but it was more uniform and maximum light penetration was lowest. Even though the Orinoco river discharge produces a considerable decrease in water transparency in the Gulf of Paria -basically due to input of dissolved/suspended material during all seasons-, light supply is high enough to keep large phytoplankton populations, as suggested by chlorophyll *a* data. Key words: light, Secchi depth, chlorophyll, Gulf of Paria, Venezuela.

**RESUMEN:** Se estudió el efecto de la clorofila *a* y la materia disuelta/suspendida sobre la profundidad Secchi (Ds) en el Golfo de Paria (Venezuela), durante los períodos de baja (junio 1984 y mayo 1985) y alta descarga (octubre 1984) del río Orinoco (estación seca y estación lluviosa, respectivamente). Las correlaciones entre *k<sub>c</sub>* (atenuación debida a la clorofila *a* disuelta), *k<sub>r</sub>* (atenuación debida a la materia suspendida y disuelta) y Ds fueron negativas y estadísticamente significativas, a excepción de la correlación entre *k<sub>r</sub>* y Ds en octubre. Esto sugiere que tales relaciones prevalecen durante los períodos de baja descarga, pero desaparecen al aumentar el aporte del río. En junio, la luz disminuyó en aguas someras (0-20 m) desde Boca de Dragón hacia el oeste y el sur dentro del golfo. Un patrón de distribución espacial similar se observó en octubre de 1984, pero la luz disminuyó aún más rápido en sentido vertical. En mayo, la distribución espacial de la luz dentro del golfo se mantiene, pero fue más uniforme y los porcentajes de penetración fueron los más bajos registrados. Aun cuando la descarga del río Orinoco causa un descenso considerable en la transparencia del agua (debido básicamente a los aportes de material disuelto/suspendido durante todas las estaciones), el suministro de luz es lo suficientemente alto para sostener grandes poblaciones de fitoplancton, tal como lo sugieren los datos de clorofila. Palabras claves: luz, Secchi, clorofila, Golfo de Paria, Venezuela.

### INTRODUCTION

The Venezuelan oil industry has shown great interest on natural gas deposits located in the northern Gulf of Paria. A project named "CRISTÓBAL COLÓN" aims at extracting and transporting this resource, but environmental information about the area is rather scarce to assess any impacts of this project. The Gulf is an important ground for artesian shrimp and finfish fisheries, and is also a nursery area for some commercially valuable fishes -e.g. *Macrondon aencylodon*, *Macropogonias furnieri*, *Lutjanus synagris*, *Trachurus lepturus*, etc.- (MARCANO *et al.* 1995).

The influence of the hydrography on plankton

communities in the Gulf of Paria has received some attention (SÁNCHEZ-SUÁREZ, 1985; TRONCONE-OSORIO, 1987; BIDIGARE *et al.*, 1993; SÁNCHEZ-SUÁREZ & TRONCONE-OSORIO, 1994; SÁNCHEZ-SUÁREZ *et al.*, 1995), but remains unclear. Some studies have focused on oceanographic conditions and primary productivity (VAN ANDEL & POSTMA, 1954; GADE, 1961; FUKUOKA, 1964; OKUDA, 1974; BONILLA, 1977; MOIGIS & BONILLA, 1985; MOIGIS & BONILLA, 1988; MOIGIS, 1989; HEILEMAN & RAMSAROOP, 1990; BONILLA *et al.*, 1993; FARMER *et al.*, 1993 and BLOUGH & ZAFIRIOU, 1993).

Here we focus on the effect of chlorophyll *a*, dissolved and suspended material on light penetration in the Gulf of

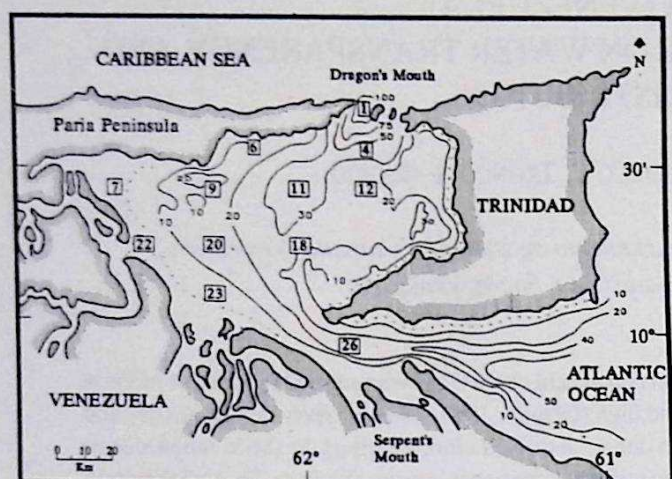


Fig. 1. Map of the study area showing sampling stations and bathymetry (meters).

Paria, where great quantity of seston and large diatoms are found (SÁNCHEZ-SUÁREZ *et al.*, 1995).

## MATERIALS AND METHODS

### Collection of Samples.

The Gulf of Paria is located off northeastern Venezuela. It is connected to Caribbean Sea and Atlantic Ocean through Dragon's and Serpent's mouths, respectively. The Orinoco river delta is located to the south of the gulf (fig. 1). Samples were collected on periods of low (June 1984 and May 1985) and high (October 1984) Orinoco river discharge (dry and rainy season, respectively). The data used in this paper were obtained during a campaign carried out by the Instituto Oceanográfico de Venezuela (Universidad de Oriente, Cumaná) aboard R.V. "Guaiquerí II".

### Light Attenuation.

Water transparency was measured with a Secchi disk (TYLER, 1968) while chlorophyll *a* concentration was determined according to STRICKLAND & PARSONS (1972). Average chlorophyll *a* concentration (Chl) was computed between the surface and Secchi depth (Ds) (Babenerd & Krey, 1974). The diffuse attenuation coefficient of light (Kt) and its components were calculated using the Lambert-Beer equation (MOIGIS, 1989; PARSONS *et al.*, 1977):

$$K_t = k_w + k_c + k_r = k_w + (F_c \cdot \text{Chl}) + k_r$$

where:

$K_t$  = the diffuse attenuation coefficient of light, roughly calculated from Secchi depth (Ds) as  $K_t = 1.7/D_s$ .

$k_w$  = diffuse attenuation coefficient for pure water, set to 0.0384 (LORENZEN, 1972).

Tabla 1.- Data from the Gulf of Paria for June 1984, October 1984 and May 1985. Secchi depth (Ds) is in meters; average Chlorophyll *a* concentration from surface to Ds (Chl) in  $\text{mg m}^{-3}$

Station	Date	Ds	Chl
1	06/84	9	0.721
4	06/84	8	0.665
6	06/84	5	1.842
7	06/84	0.9	1.602
9	06/84	6	1.842
11	06/84	9	0.881
12	06/84	7	0.669
18	06/84	9	1.148
20	06/84	5	1.121
23	06/84	1	1.602
26	06/84	1.7	2.323
1	10/84	2	0.903
4	10/84	6	4.004
6	10/84	5	1.281
7	10/84	1	4.484
9	10/84	3	6.354
11	10/84	5	2.616
12	10/84	5.5	3.100
18	10/84	3	1.709
20	10/84	3	2.563
22	10/84	0.5	2.562
23	10/84	2	2.242
4	05/85	3	0.841
18	05/85	2.5	1.308
20	05/85	3	0.970
22	05/85	1	2.240
23	05/85	2	0.747

$kc = Fc \cdot Chl =$  diffuse attenuation coefficient of light due to chlorophyll *a*.

$Fc =$  attenuation coefficient of light due to 1 mg of chlorophyll *a*,  $0.016 \text{ m}^2 (\text{mg chl})^{-1}$  (SMITH & BAKER, 1978).

$Chl =$  average chlorophyll *a* concentration, as described above.

$kr =$  attenuation coefficient of light due to suspended and dissolved organic materials, total suspended minerals and scattering of light. Here, it was obtained as  $kr = Kt - (kc + kw)$ .

$Kt$  values were used to determine the amount of light at specific depth as follows:

$$I_d = I_0 \cdot e^{-Kt \cdot d}$$

where  $I_0 =$  incoming light intensity at the surface  
 $I_d =$  light intensity at depth *d*  
 $Kt =$  light attenuation coefficient (in  $\text{m}^{-1}$ )

$I_d$  was defined as percentage of incoming light intensity replacing the factor  $I_0$  by 100 (PARSONS *et al.*, 1977).

Relationships between  $Chl$ ,  $kr$ ,  $kc$  and  $Ds$  were evaluated using the Pearson product-moment correlation (SOKAL & ROHLF, 1979).

### RESULTS

Secchi depth ( $Ds$ ) and Chlorophyll *a* ( $Chl$ ) data are shown in table I. Maximum  $Ds$  (9 m) and minimum  $Chl$  ( $0.665 \text{ mg m}^{-3}$ ) were detected in June while minimum  $Ds$  (0.5 m) and maximum  $Chl$  ( $6.354 \text{ mg m}^{-3}$ ) were found in October (table 1).

Average chlorophyll *a* and respective Secchi depth values only showed a statistically significant negative relationship in June 1984 (fig. 2). In general, contribution of the detritus component ( $kr$ ) dominated  $Kt$ , particularly near Orinoco river delta (stations 7, 22, 23 and 26; table 2, fig. 3). In contrast, contributions of  $kc$  and  $kw$  to  $Kt$  were quite negligible;  $kc$  was lightly greater in October 1984 than in June 1984 and May 1985, while  $kw$  was constant (fig. 3).

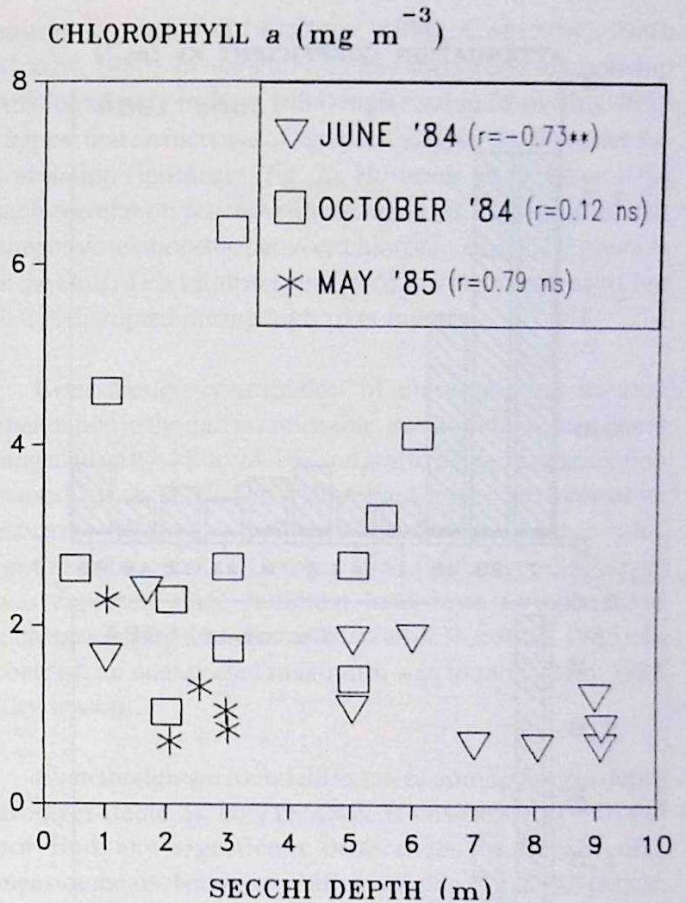


Fig. 2.- Relationships between Secchi depth and chlorophyll *a* in the Gulf of Paria in June and October 1984 and May 1985. ns = no significant; \* = significant at  $p < 0.01$  (99.9%).

Correlations between  $kr$  and  $Ds$  were negative and statistically significant in all cases, but correlations in May were higher than those from June and October. Correlations between  $kc$  and  $Ds$  were negative and statistically significant only in June and May (fig. 4). Correlations  $kr$ - $Ds$  were higher and more significant than correlations  $kc$ - $Ds$ . In

Table 2. Average of all stations for each season of Secchi depth ( $Ds$ ), Chlorophyll *a* ( $Chl$ ), total attenuation coefficient due to chlorophyll *a* ( $kc$ ) and to the "rest" ( $kr + kw$ ).  $Ds$  in m;  $Chl$  in  $\text{mg m}^{-3}$ ;  $Kt$ ,  $kc$  and "rest" in  $\text{m}^{-1}$ .

	June 84		October 84		May 85	
$Ds$	5.6		3.3		2.3	
$Chl$	1.310		2.892		1.221	
$Kt$	0.581		0.888		0.873	
$kc$	0.021	(3.6%)	0.046	(5.2%)	0.020	(2.3%)
rest	0.521	(89.7%)	0.804	(90.5%)	0.815	(93.4%)

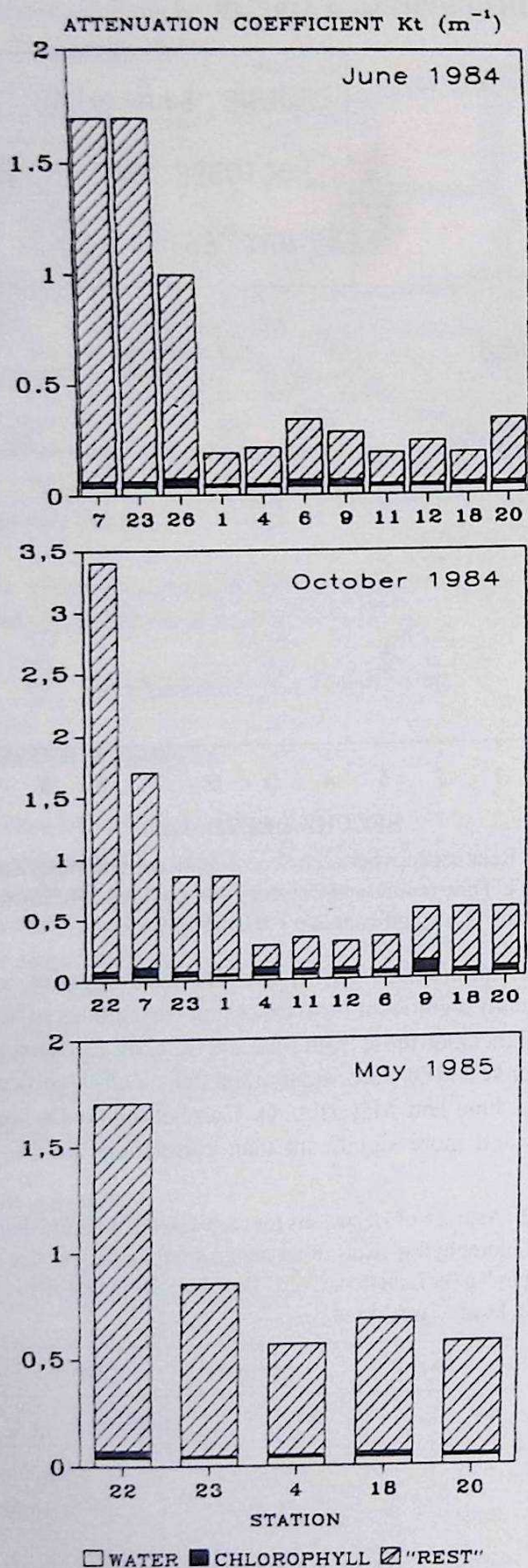


Fig. 3.- Absolute variation of the coefficient of total attenuation and its components in the Gulf of Paria.

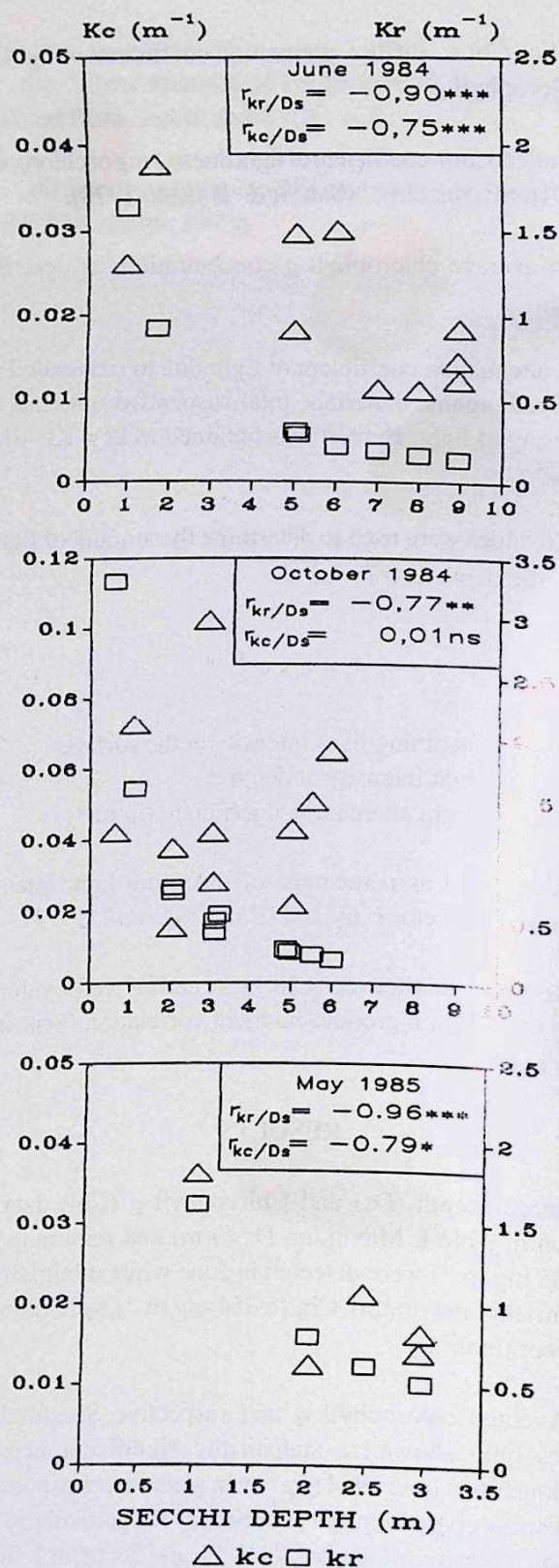


Fig. 4.- Relationship between Secchi depth and the components of the total attenuation coefficient due to chlorophyll *a* (*k<sub>c</sub>*) and the "rest" (*k<sub>r</sub>*) in the study area. ns = no significant; \* = significant at  $p < 0.05$  (99.5%). \*\* = significant at  $p < 0.01$  (99.9%). \*\*\* = significant at  $p < 0.001$  (99.99%).

short, when chlorophyll *a* increased *D<sub>s</sub>* decreased; when suspended and dissolved material increased, *D<sub>s</sub>* decreased as well (except in October).

In June 1984 (beginning of the rainy season), illumination within the gulf decreased from Dragon's mouth to the west and to the south, particularly in shallow waters (0 - 20 m); percentage of incoming light at 1 m depth varied from 40% to 80%, increasing toward the deep channel of Serpent's mouth (fig. 5). A similar pattern of light distribution occurred in October 1984 (rainy season), but percentage of incoming light at 1 m depth was lower (20 - 70%) (fig. 5). In May 1985 (dry season), light penetration pattern seemed to be more uniform over the gulf, but light values at 1 m depth were even lower than in June and October (20% - 50%), decreasing to the west as well (fig. 5).

In June 1984, chlorophyll *a* was distributed inversely with respect to light (fig. 5). But in October 1984, chlorophyll *a* was distributed quite differently; there was an increase in pigment concentration -from the north, west and south- to the gulf center; from this core, its concentration increased toward the deep channel in Serpent's mouth (fig. 5). In May 1985, a core of chlorophyll *a* was found in the central gulf area, pigment values increased to the west and southeast (fig. 5).

A more tridimensional view of chlorophyll *a* distribution, using vertical and horizontal and two vertical planes sections of the Gulf of Paria -a first section from station 7 to 12 and a second one from 12 to 1-, is depicted in figure 6. This representation of the data has been used by other researchers (e.g. BLASCO *et al.*, 1980, SÁNCHEZ-SUÁREZ and TRONCONE-OSORIO, 1994). In June 1984, chlorophyll *a* values increased from deep to shallow waters, and decreased from north to central area of the gulf (fig. 6). In October 1984, two shallow cores of high pigment concentration were found, one to the north -close Dragon's mouth-, and the other to the west; chlorophyll *a* concentration decreased from bottom to surface, a sharp gradient change occurred at ten (10) meters. In May 1985, a shallow core of low pigment concentration was found to the east, and chlorophyll *a* concentration decreased from shallow to deep water, and from channels of the Orinoco river delta toward to this core (Fig. 6).

## DISCUSSION

An inverse relationship between chlorophyll *a* concentration and Secchi depth has been observed in

eutrophic waters (LORENZEN, 1980; CARLSON, 1980; MOIGIS, 1986). In our study, a clear and strong relationship was found only in June 1984; high *r* value from May 1985 suggest that an increase of samples number would make the correlation significant (fig. 2). However, in October 1984 such correlation was not significant. This may indicate that a negative relationship between chlorophyll *a* and *D<sub>s</sub>* prevails in the Gulf of Paria during periods of low river discharge, but that is disrupted during high river input.

Even though contribution of chlorophyll *a* to total attenuation in the gulf is noticeable, the dominant component ranged from 87.4% to 93.4%, and is also related to attenuation caused by suspended and dissolved materials, typical of estuaries (EISMA *et al.*, 1978). Nevertheless, a higher value for this component in October 1984 (high river discharge) was expected since sediment load from Orinoco river increases during that season (MOIGIS & BONILLA, 1985). In contrast, an unexpected maximum was found in May 1985 (dry season).

Even though we found differences among Secchi depth averages (table 2). HEILEMAN & RAMSAROOP (1990) did not find any significant differences in Secchi disk measurements between seasons during 1978-80 period. They reported a high degree of vertical mixing of shallow water (0 - 20 m), which affected the eastern side of the gulf in the dry season (wind speed around 12 km h<sup>-1</sup>). They suggest that wind-induced vertical mixing reintroduces some of the sediment into the water column, thus reducing any seasonally difference in the water transparency. Tides and waves also resuspend sediments, particularly in dry season, and may accentuate this effects (VAN ANDEL & POSTMA, 1954). It is evident that a definitive conclusion will require a year-round study with a sampling transect from eastern Trinidad to the northern Orinoco river delta.

A decrease of *D<sub>s</sub>* caused by high *K<sub>r</sub>*, as described before, is the reason for low light penetration values found in May 1985 (fig. 5). The reduction varied between 30 - 40% of incoming light at 1 m depth, and this value may be significant.

Even though the Orinoco river discharge produces a considerable decrease in water transparency in the Gulf of Paria -basically due to input of dissolved/suspended material during all seasons-, light supply is high enough to keep large phytoplankton populations, as suggested by chlorophyll *a* data. A detailed work about those populations features supports it, at least for dry season (SÁNCHEZ-SUÁREZ &

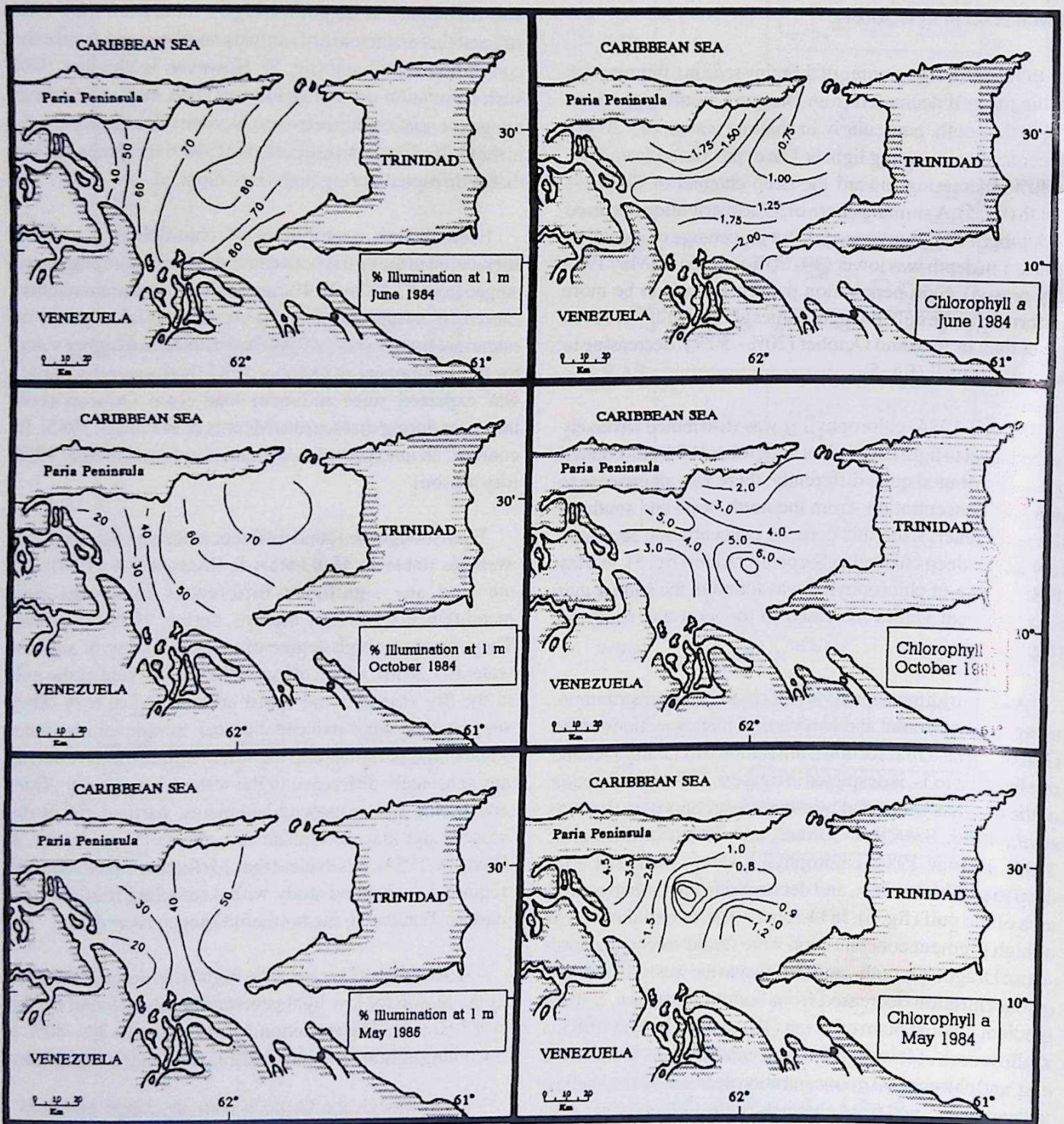


Fig. 5.- Distribution of illumination (%) and chlorophyll *a* at 1 m depth on Gulf of Paria. Chlorophyll *a* in  $\text{mg m}^{-3}$ .

TRONCONE-OSORIO, 1994; SÁNCHEZ-SUÁREZ *et al.*, 1995). The effect of the Orinoco river on transparency in the rainy season will be studied in a paper under preparation. However, a one-year study involving an increase of sampling size (spatially and temporally) and measurements of light using radiometers should be the strategy of future research.

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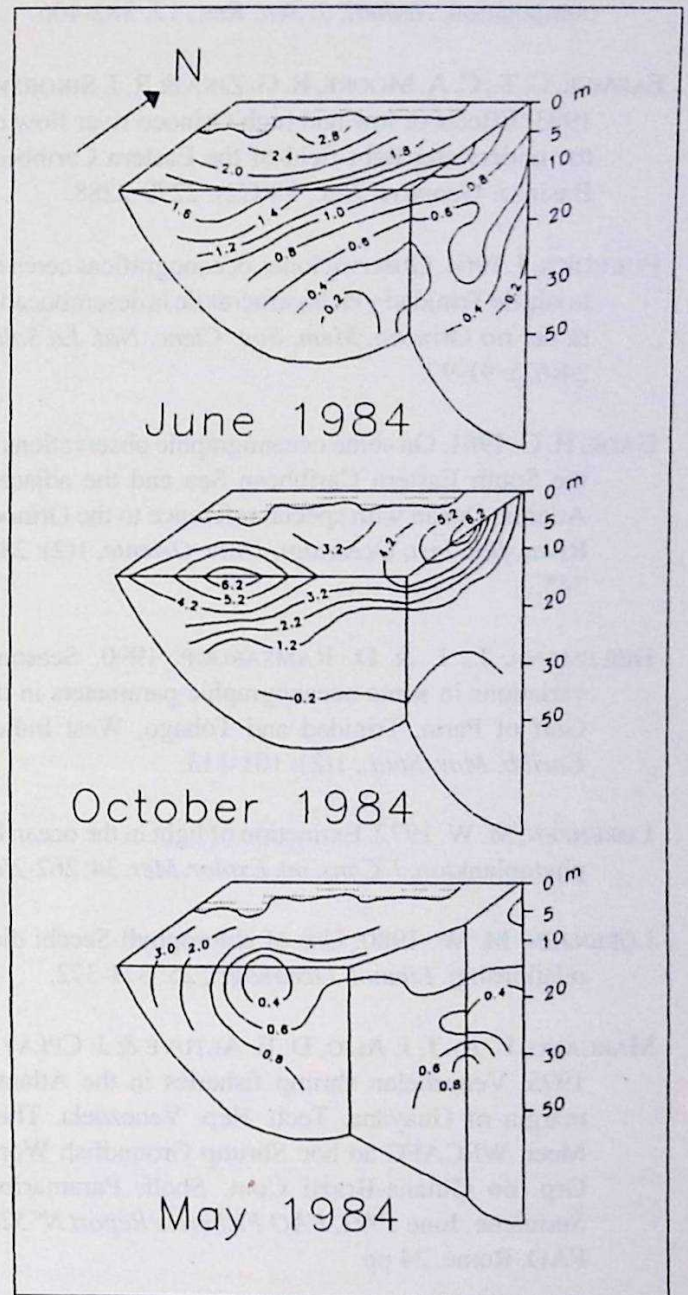


Fig. 6.- Tridimensional distribution of chlorophyll *a* in the Gulf of Paria. Chlorophyll *a* in  $\text{mg m}^{-3}$ .

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