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Effects of red tides on oxygen concentration and distribution in the Golfo de Nicoya, Costa Rica

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Abstract: A one year study (April 1978-March 1979) in the inner section of the Golfo de Nicoya (10^{o} N, 85^{o} W), Costa Rica, revealed that red tides in this shallow (< 20 m) region are most common during the dry and at the beginning of the rainy season, but may also occur during the later part of the wet season.The massive occurrence of red tides in distinct patches strongly influences the temporal and spatial concentration of dissolved oxygen, (O_2 saturation values of up to 200 % were observed).Gross primary productivity in the presence of a red tide amounted to 0.64 g C m^{-2} h^{-1}.The productive layer was restricted to the upper 2 m due to massive concentration of the algae near the surface and intensive self-shading.

Key words: red tide, O_2 concentration, primary productivity, Golfo de Nicoya.

Algal blooms are a common feature in many marine areas.A special case of these blooms, the so called red tide, has attracted much attention.The name is due to the reddish discoloration of planktonic algae, which generally belong to the dinoflagellates.In many cases severe toxic effects were observed in the presence of red tides, which may seriously affect a local economy based on the exploitation of marine organisms (Reyer-Vasquez *et al.*1979, Anderson *et al.*1985, Gacutan *et al.* 1985).

Red tides are observed sometimes in temperate regions.From the Western English Channel several toxic blooms were reported in recent years (Boalch 1983).Gillbricht (1983) described the occurrence of a non toxic red tide caused by *Ceratium furca* between July and October in the North Sea.Most red tides, however, occur in tropical and subtropical regions (Margalef 1961, Veintimilla 1982, Martin 1983, Estrada 1986).Dense patches with an extension of more than 100 square miles were observed off Ecuador in 1984 (Jiménez *et al.*1987).

In the Golfo de Nicoya, on the Pacific coast of Costa Rica, red tides are a common feature.Local fishermen indicated that red tides ("mareas rojas") have been observed every year as long as they can remember.Whether these blooms became more frequent and/or more massive during the last decades remains an open question, since the same fishermen do not agree on this point.The algae causing red tides in the Golfo de Nicoya were studied in detail by Hargraves and Víquez (1981, 1985), being mostly dinoflagellates of the species *Cochlodinium catenatum*.

The present paper adds some information on the spatial and temporal distribution of some phenomena related to the occurrence of red tide blooms.The effect of red tides on the oxygen concentration was emphasized.The data were

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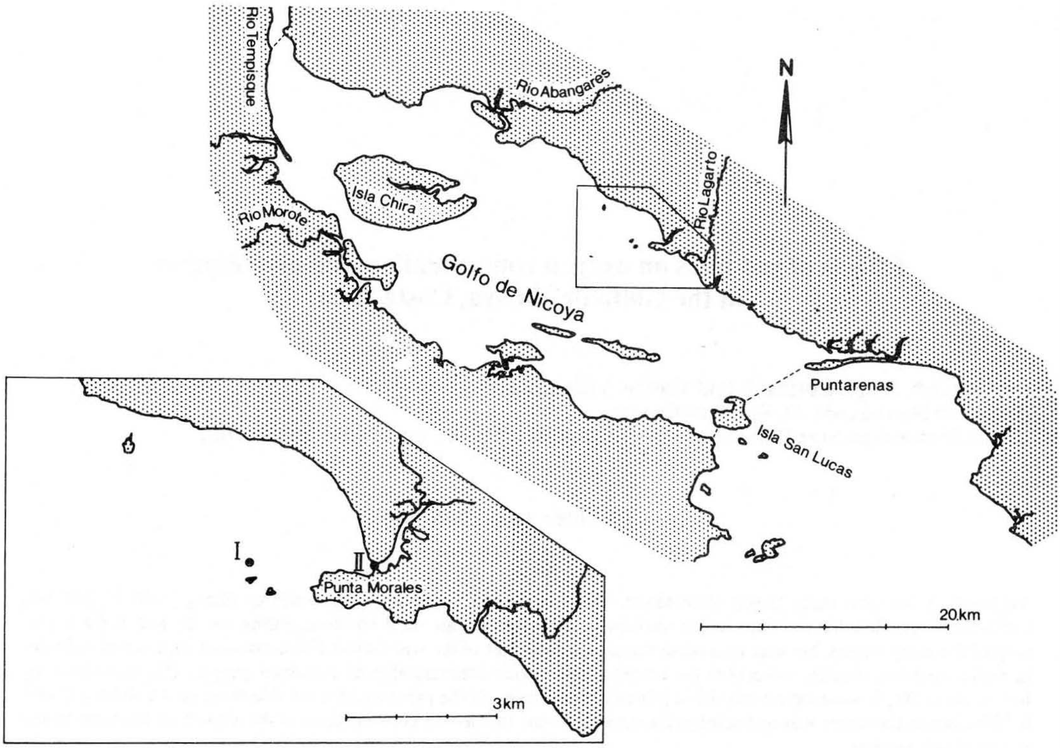

Fig. 1. Location of the study sites near Punta Morales in the Golfo de Nicoya, Pacific coast of Costa Rica.

obtained as a by-product of a one year study in the inner section of the Golfo de Nicoya, during which the primary productivity was measured twice per month.

STUDY AREA

The measurements were performed off Punta Morales on the eastern coast of the inner section of the Golfo de Nicoya (Station 1, Fig.1) and in the main channel of the Estero Morales (Station II, Fig.1), a mangrove swamp with an area of about 327 hectares (10^{0} 5' N and 84^{0} 57'W).The inner section of the Gulf is a funnel shaped region limited to the south by a narrow passage between the Peninsula of Puntarenas and the Island of San Lucas (Fig.1).Much of the shoreline is lined with mangrove swamps and mud flats.The inner Gulf is quite shallow with depths not exceeding 20 m, and especially the area around the study site which is less than 10 m deep.

The tide is semi-diurnal with a mean tidal range of about 2.5 m. Strong tidal currents with rapidly changing velocity and direction are observed especially near and between the islands and in the channels of the mangrove swamps.

The rainy season lasts from April/May to November/December and is followed by a dry season.The region receives fresh water input via the Río Tempisque and several other smaller rivers.

Seasonal salinity variation at the study site was between 28 ^{0}/oo and 33 ^{0}/oo.In the channel of the Estero de Morales the salinity followed the same trend as in the open Gulf.Only very occasionally during the rainy season, and of short duration, was salinity markedly affected by the small creek which enters the mangrove swamp (Gocke *et al.* 1981).At station 1 the temperature varied between 26.4 ^{0}C (November) and 30.1 ^{0}C (May).The measurements were always performed around 8:00 at 1 m depth.

The general hydrographical features of Golfo de Nicoya are described in detail by Peterson (1958) and Voorhis *et al.*(1983).Epifanio *et al.*(1983) add some information about the seasonal changes in nutrient concentrations.According to their observations the Golfo de Nicoya receives appreciable quantities of nutrients from deeper offshore waters, which are driven into the Golfo as a consequence of the positive estuarine character of the system.Additional nutrient input is via untreated sewage from the city of Puntarenas and via river inflow, which carry nutrients from the intensively used agricultural area around the northern and northwestern parts of the Golfo de Nicoya.

MATERIAL AND METHODS

Water samples for oxygen measurements were taken with a 2 l-Niskin bottle.The O_2 concentrations were determined using the Winkler technique.Glass bottles (100 ml nominal size) were cautiously filled in duplicates.The titrations were performed with a micro-burette (0.5 ml total volume divided into steps of 0.2 µl) in the glass bottles themselves.This micro-Winkler method is similar to that proposed by Green and Carrit (1966).It is rapid and yet very precise since it minimizes the errors due to spill of sample and especially due to loss of volatile iodine since it avoids transfer of sample from the sampling bottles to the titration Erlenmeyers (Bryan *et al.*1976).

Secchi depth was measured using a white plastic disc 20 cm in diameter, which was heavily weighted.This was necesary to account for the often very strong water currents.

Primary productivity was measured using the "light and dark bottle method" (Gaarder and Gran 1927).Bottles of 100 ml nominal volume were suspended at the surface and at 1 m, 2 m, 3 m, and 4 m depth.The exposure lasted for 5 hours and was always initiated around 8:30.Oxygen concentration differences were converted into units of organic carbon using a photosynthetic quotient of 1.20 and a respiratory quotient of 0.83 (Fogg 1963, Ryther 1965).

RESULTS AND DISCUSSION

During the period of observation from April 1978 to March 1979 the inner Golfo de Nicoya was never completely covered by the red tides.Sometimes the distinct patches were quite large; however, they normally did not surpass a few hectares in size. Even when a high number of patches were observed, they were always well separated by streaks of "green" water without the presence of red tide algae.The patchy occurence greatly influenced the horizontal and vertical distribution of the dissolved oxygen in the inner Gulf.This is shown in Figs.2 to 4, where the results of an observation performed near the more westerly of the two small islands near Pta.Morales, are presented.The data clearly reveal the small scale inhomogeneities of the O_2 concentration.A dense red tide patch with oxygen saturations near the surface of up to 200 % was partially intersected by a narrow streak of much clearer water undersaturated (75 %) with oxygen (Fig.3).Probably the southward flowing ebb stream caused an upwelling of red tide free bottom water.The near bottom water at the sampling points **a** and **b** was undersaturated with oxygen (Fig.3).The deep water at point **c**, however, was highly supersaturated, probably because here the water turbulence due to the vicinity of the island was so high that a substantial part of the surface water with its high O_2 concentration was mixed with the bottom water.There is an inverse relation between the oxygen concentration and the Secchi depth (Fig.4), the latter being taken as a rough indicator of the concentration of red tide algae.The measurements described above were performed between 11:00 and 12:00, *i.e.*about 5-6 hours after surise.It is obvious that such a massive O_2 supersaturation can be observed only when the algae had sufficient time for intensive photosynthesis.

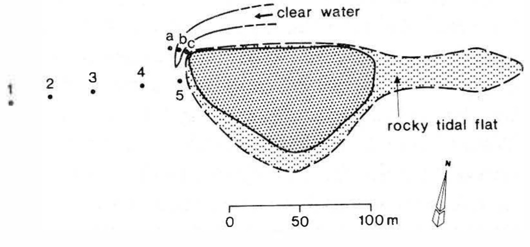

Fig. 2. Location of stations (1-5) and (a-c) within a large red tide patch around a small island off Punta Morales, near Station 1.

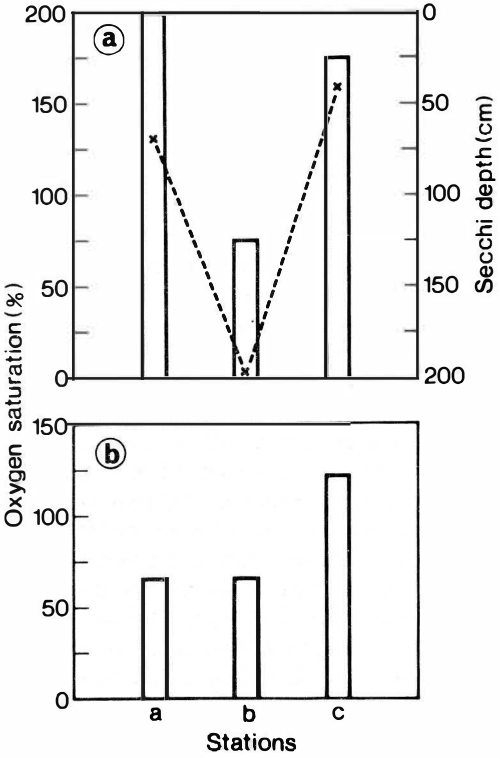

Fig. 3. Oxygen saturation (bars) and Secchi depth (dashed line) in a short transect (for location see Fig. 2). O_2 saturation near surface a and about 1 m above the bottom b.

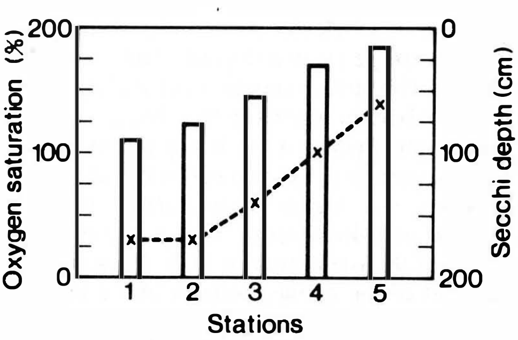

Fig. 4. Oxygen saturation near surface (bars) and Secchi depth (dashed line) in a transect (for location see Fig. 2).

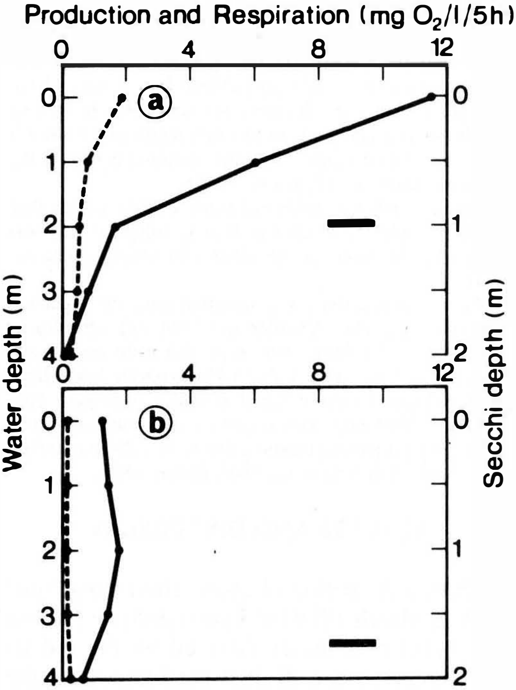

Fig. 5. Gross primary productivity (solid line), respiration (dashed line) and Secchi depth (horizontal bars) measured during the occurrence **a** and in the absence of a red tide **b**. May 15 and July 14, 1984, respectively.

On May 15, 1978, when a very intensive red tide was encountered, primary productivity was measured at station I (Fig. 5).Since temperature (29.5 ^{O}C) and salinity (32.5 $^{O}/_{OO}$) were nearly uniformly distributed within the uppermost 4 m of the water column, the vertical distribution of the respiration is supposed to be proportional to the vertical distribution of the amount of living organisms.The data reveal that the bulk of the organisms was located in the uppermost meter.The high concentration of red tide organisms caused a high primary productivity (0.64 g C m^{-2} h^{-1}) which was almost completely restricted to the upper 2 m due to strong self shading.

Without the red tide, the respiration is nearly uniformly distributed within the upper 4 m and the highest primary productivity rate occurs generally at 2 m depth.As an example for such a case the results obtained on July 14, 1978 are shown in Fig.5.In the absence of a red tide light inhibition of the photosynthesis was always observed near the surface, reaching down to at least 1 m depth.When a strong red tide was present, however, the light inhibition was probably confined only to the uppermost centimeters and therefore not detectable with the method employed, where depth intervals for incubations of 1 m were used.On July 14, 1978, the gross primary productivity amounted to 0.32 g C m^{-2} h^{-1}, which was only half as much as in the presence of the red tide two month before.

It is obvius that the red tide algae are capable of concentrating near the surface in spite of the relative high water turbulence in the inner Golfo de Nicoya.They can thus efficiently utilize the light energy.Hargraves and Víquez (1981) also observed that the density of the algae was much higher at the surface and that at 1 m their number decreased already to about 60 % or less.According to Horstmann (1980) the red tide forming dinoflagellate *Peridinium quinquecorne* moves to near surface layers during intensive solar radiation, but attaches itself to solid surfaces protected from light, when the radiation diminishes.The ability of the organisms for active motility is of special advantage, since it allows the algae to move at night to deeper water layers, where the higher nutrient concentrations can be used, and ascend during the day to the photic layer (Dugdale *et al.*1987, Watanabe *et al.*1988).Yamochi *et al.*(1985) observed that the red tide flagellate *Heterosigma akashiwo* was capable of migrating towards the surface in the morning with a velocity of 1 to 1.3 m per hour.Very high swimming velocities were also reported by Hand *et al.*(1965) for *Gymnodinium* sp.(around 1 m h $^{-1}$), by Hasle (1950) for *Ceratium fusus* (0.5 to 1 m h^{-1}) and by Blasco (1978) for dinoflagellates in the region off Baja California (0.4 to 0.7 m h^{-1}).In the Golfo de Nicoya the red tide algae must also have a very high swimming velocity because they have to compete with the strong turbulence, otherwise, their vertical distribution would be much more uniform.

On April 17, 1978, a 24 hour study was undertaken in order to detect oxygen variations in relation to daytime and presence of red tide patches. Sampling was performed at station I (Fig.1) at 3 h intervals from sunrise (about 6:00) till sunrise of the next day. Between 6:00 and 9:00 in the morning the water was slightly undersaturated with respect to oxygen and the vertical differences were quite small (Fig.6).At noon a strong supersaturation reaching more than 210 % was measured accompanied by a Secchi depth which decreased from 130 cm at 6:00 and 9:00 to only 60 cm. High O_2 concentration and high water turbidity were due to the presence of a very intensive brick-red patch of a red tide which slowly moved to the south with the ebb tide.After 12:00 the rapid decrease in oxygen concentration and the increase in Secchi depth showed that the most massive red tide patches had passed through already.The great difference in O_2 saturation between near surface and near bottom water (total water depth at high tide was about 7 m) reveals that the liberation of O_2 around noon was so fast, that water turbulence at this time was not strong enough to distribute the O_2 more evenly.

A similar experiment was performed at the entrance of the main channel of the mangrove swamp of the Estero de Morales on August 8, 1979 (Station II, Fig. 1).Samples were taken at 1.5 h intervals between 6:00 and 18:00 which coincided roughly with low tides and sunrise and sunset (Fig. 7).From 4.5 mg O_2 l^{-1} (equal to 70 % saturation) the oxygen concentration increased rapidly to 12.3 mg l^{-1} (more than 180 % saturation).A variation of O_2 saturation parallel to the tidal fluctuations was always observed, but only the occurrence of a red tide could cause a supersaturation of such a magnitude.It is most probable that the real increase in O_2 was even higher than the observed one, since a substantial part must have been lost to the atmosphere.

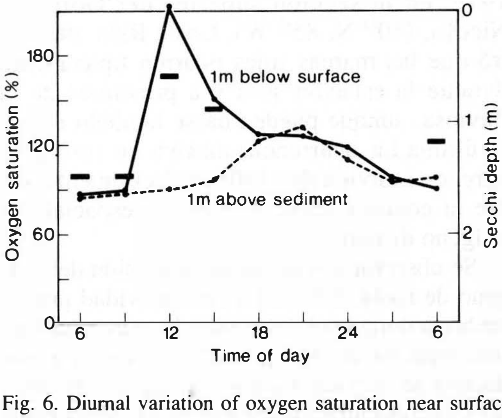

Fig. 6. Diurnal variation of oxygen saturation near surface and about 1 m above the sediment together with Secchi depth (horizontal bars) at Station I.

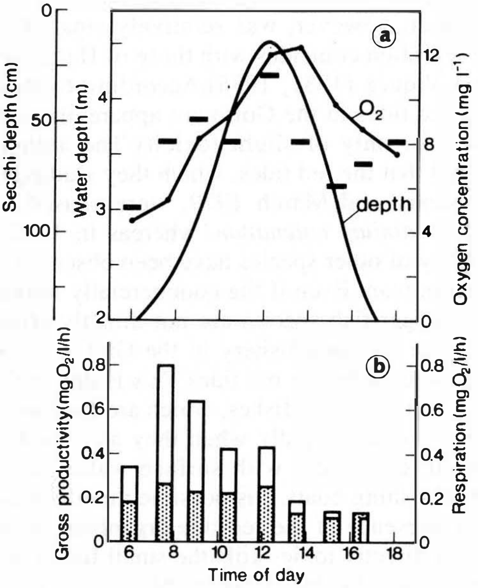

Fig. 7. **a** Oxygen concentration and Secchi depth (bars) in the entrance of the main channel of a mangrove swamp (Station II) in relation to tidal cycle. **b** Temporal variation of gross primary productivity (total length of bars) and respiration (dotted part of bars).

Judging from the actual oxygen curve the primary productivity must have been much higher than deduced from the relatively small increases in the incubation bottles, which were suspended at 1 m depth (Fig 7).Two factors may be responsible for the underestimation of the primary productivity in the presence of a red tide.First, the incubation depth of 1 m was too deep so that light intensity for more intensive photosythesis was insufficient.This reduction in light intensity was probably due to selfshading by the red tide organisms.Second, the effect of enclosure may have been deleterious to the algal population.The latter was believed by Hargraves and Víquez (1981), who observed mass mortality and decay of the red tide algae in the incubation bottles. These authors were therefore unable to detect net primary productivity. This was not the case in our experiments, it is, however, not unlikely, that the enclosure of such a mass of algae in a small glass bottle may have drastically reduced their photosynthetic abilities.

Our observations of the red tides were always accompanied by boat trips to the more distant regions of the inner Golfo de Nicoya. Sometimes dead fishes were observed. Their number, however, was relatively small.This observation coincides with those of Hargraves and Víquez (1981, 1985).According to them the red tides in the Golfo are apparently nontoxic or only of slight toxicity.The authors found that the red tides, which they studied in February and March 1979, were caused by *Cochlodinium catenatum,* whereas in 1982 a variety of other species have been observed to be dominant.Even if the commercially important larger fish species are not directly affected, the artisanal fishery in the Gulf is severely injured by the red tides.This is due to the fact that the small fishes, which are used as living bait, die rapidly when they are maintained in containers with surface water in the small fishing boats.It is possible that the massive presence of the red tide organisms -even if not directly toxic- kills the small fishes due to asphyxia by simply blocking their gills.This may be accelerated by high water temperature and low oxygen concentration, the latter due to respiration of the algae in the darkened containers.

Guzmán *et al.*(1990) encountered massive coral mortality off the Pacific coast of Costa Rica and Panamá when *Cochlodinium catenatum and Gonyaulax monilata* were present in the water at high concentrations.They believed that the mortality was possibly caussed by a combination of factors such as toxic exudates, oxygen depletion, and especially smothering of mucus produced during the red tides.

During the study period between April 1978 and March 1979 red tides were observed in April, May, June (end of the dry and beginning of the wet season), in September (middle of the wet season) and in February and March (dry season).At the southern entrance of the Golfo de Nicoya they were often encountered in December/January (beginning of the dry season).It seems that they are more common in the dry season and at the beginning of the rainy season, when the river input has not yet reached its full effect.The occurrence of a red tide in the middle of the rainy season is not totally uncommon, one was observed in Sept.1978 and another in Aug.1979.The red tides contribute significantly to the primary productivity of the Golfo de Nicoya.Whether the algae are directly used by herbivorous organisms or only after their partial degradation to detritus, *i.e.*via the detrital food chain, remains to be studied.

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RESUMEN

Un estudio hecho de abril-1978 a mayo-1979, en la sección superior del Golfo de Nicoya, (10^{o} N, 85^{o} W), Costa Rica, demostró que las mareas rojas ocurren típicamente durante la estación seca y a principios de la lluviosa, aunque pueden darse también en esta última.La ocurrencia masiva en forma de parches individuales influye fuertemente sobre la concentración temporal y espacial del oxígeno disuelto.

Se observaron valores de saturación del oxígeno de hasta 200 %. La productividad primaria bruta durante el desarrollo de una de las mareas rojas fue de 0.64 g C m^{-2} h^{-1}.La capa productiva se restringió a los 2 m superiores debido a la concentración masiva de las algas cerca de la superficie y debido también al efecto del auto- sombreo.

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