Phytoplankton productivity in the Barra de Navidad coastal Lagoon on the Pacific coast of Mexico

Laila C. SANDOVAL ROJO (1),
Francisco J. FLORES VERDUGO (2)
Ubaldo ZARAGOZA ARAUJO (3), John W. DAY, Jr. (4),
Antonio ESTRADA MERCADO (1)

ABSTRACT

Aquatic primary productivity was measured in the Barra de Navidad Lagoon, Jalisco, Mexico from October 1983 to September 1984. The net daytime productivity was 772 g O_2 $m^{-2}yr^{-1}$ and a gross productivity of 1034 g O_2 $m^{-2}yr^{-1}$. Temporal heterogeneity in the rate of production was high, influenced by well defined seasonal changes in water transparency, temperature, salinity and riverflow. Temporally, higher productivity values occurred during the rainy season (from June to October). Spatially, the highest values occurred in the central lagoon and decreased towards the ocean and the river inlet. In general, the highest productivity values were a consequence of higher nutrient concentrations and better light conditions in the mid part of the lagoon. During the dry season productivity levels decreased as river flow diminished. Productivity decreased, however, during the time of highest river flow because of extreme turbidity.

KEY WORDS : Coastal lagoons — Tropical environment — Primary production — Phytoplankton — Seasonal variations — River discharge.

RÉSUMÉ

PRODUCTIVITÉ DU PHYTOPLANCTON DANS BARRA DE NAVIDAD, LAGUNE CÔTIÈRE DE LA CÔTE PACIFIQUE DU MEXIQUE

La production du phytoplancton a été mesurée dans la lagune Barra de Navidad, Jalisco, Mexique d'octobre 1983 à septembre 1984. La production nette au cours de la journée était de 772 g O_2 $m^{-2}an^{-1}$ et la production brute 1036 g O_2 $m^{-2}an^{-1}$. Dans le temps, la productivité a varié en fonction de variations saisonnières bien marquées de la transparence, de la température, de la salinité et des apports par les rivières. Les plus fortes productivités ont été observées en saison des pluies (juin à octobre). Dans l'espace, les plus fortes valeurs ont eu lieu dans la zone centrale, avec une diminution vers l'embouchure de la rivière et la communication avec l'océan. D'une façon générale, les productivités élevées résultent de concentrations en nutriments et de transparence plus favorables dans la zone centrale.

(1) *Laboratorio de Ciencias Marinas, Universidad Autónoma de Guadalajara, Apdo. Postal 3, Barra de Navidad, Jalisco, México.*
(2) *Instituto de Ciencias del Mar y Limnología, Estación Mazatlán, Apdo. Postal 811, Mazatlan, Sinaloa, Mexico.*
(3) *Escuela de Biología, Universidad Autónoma de Guadalajara, Apdo. Postal 1-440, Guadalajara, Jalisco, Mexico.*
(4) *Coastal Ecology Institute, Louisiana State University, Baton Rouge, LA 70803, USA.*

La productivité diminue avec la diminution des apports continentaux durant la saison sèche, mais également avec la forte turbidité liée à la crue de la rivière.

MOTS-CLÉS : Lagunes côtières — Environnement tropical — Production primaire — Phytoplancton — Variations saisonnières — Crues fluviales.

RESUMEN

PRODUCTIVIDAD DEL FITOPLANCTON EN LA LAGUNA COSTERA DE BARRA DE NAVIDAD EN LA COSTA DEL PACIFICO MÉXICANO

Se estimó la productividad primaria acuática de la laguna costera de Barra de Navidad, Jalisco, México; a partir de octubre de 1983 a septiembre de 1984. La productividad bruta fué de 1034 g O_2 $m^{-2}año^{-1}$ y una productividad neta de 772 g O_2 $m^{-2}año$. Las tasas de producción presentaron una alta heterogeneidad temporal, debido a cambios estacionales bien definidos en la transparencia, temperatura, salinidad y flujo del rio. Los valores más altos de productividad se presentaron durante la época de lluvias (de junio a octubre). Los valores también fueron más elevados cerca de la desembocadura del rio disminuyendo hacia la boca de la laguna. En general, los valores más altos de productividad fueron consecuencia de la alta concentración de los nutrientes del agua proveniente del rio. Durante la época de sequia la productividad disminuyó así como el flujo del rio. Sin embargo, ocasionalmente, la productividad llega a disminuir durante la afluencia del rio como consecuencia de un aumento en la turbidez.

PALABRAS CLAVES : Lagunas costeras — Ambiente tropical — Productividad primaria — Fitoplancton — Variaciones estacionarias — Crecidas fluviales.

INTRODUCTION

Coastal lagoons and estuaries are important natural and economic resources. A high proportion of coastal fisheries are dependent on organisms which spend at least part of their life cycle in these ecosystems (MCHUGH, 1976) and this is especially true for Mexico (YÁÑEZ-ARANCIBIA, 1978). An important reason for the high fisheries productivity in coastal lagoons is high primary productivity which has been documented by a number of authors (SUBBA RAO 1978, MEE 1977, BARNES 1979, DAY and YÁÑEZ-ARANCIBIA 1981). WHITTAKER and LIKENS (1975) identified coastal lagoons and estuaries as among the most productive of the world's aquatic ecosystems and production by phytoplankon is a very important component of this production. Estuarine and coastal lagoon phytoplankton production has been related to such factors as the shallow depth of these areas, inputs of nutrient from terrestrial and riverine runoff, and rapid internal recycling (NIXON 1981, 1982, BOYNTON *et al.* 1983).

Coastal lagoons are a common feature of the Mexican coast : LANKFORD (1977) identified 125 coastal lagoons in Mexico which occupy approximately one third of the coastline. These lagoons are important in the life cycles of many commercially important fishery species. For this reason, a large amount of work has been carried out in order to understand and manage these areas. Aquatic primary productivity has been measured in a number of coastal lagoons on the Pacific and Gulf coasts of Mexico (MEE 1978, EDWARDS 1978, GILMARTIN and REVELANTE 1978, DAY *et al.* 1982, 1987, and FLORES-VERDUGO 1985).

The objectives of this study were to measure aquatic primary productivity in the Barra de Navidad Lagoon in relation to physical and chemical factors, and attempt to draw some generalizations about the factors controlling phytoplankton productivity in tropical coastal lagoons.

AREA DESCRIPTION

Barra de Navidad is a small coastal lagoon located on the Pacific coast of Mexico (fig. 1). The area of the lagoon is about 5.0 km^2 and depth averages 1.5 m. The lagoon is connected to the ocean by a single permanent inlet 80-90 m wide. The climate corresponds to the driest of the warm subhumids (GARCÍA 1981). Water temperature ranges from 24 °C to 32 °C. Annual rainfall ranges from 500 to 1000 mm and is strongly seasonal with a pronounced dry season from November through May (fig. 2). The shores of the lagoon are bordered almost completely by four species of mangrove : *Rhizophora mangle* L., *Laguncularia racemosa* Gaertn., *Avicennia germinans* (I.) L. and *Conocarpus erectus* L. The system is

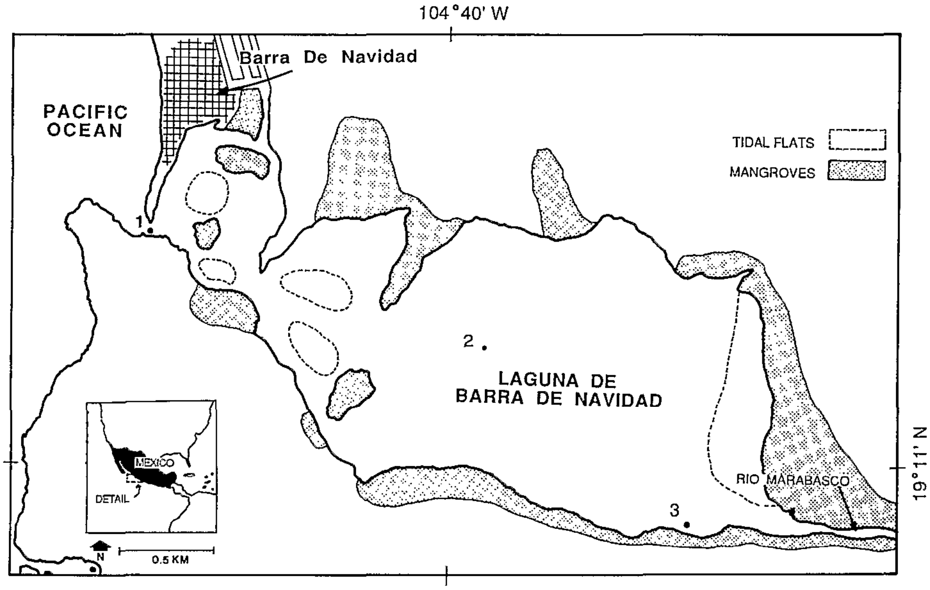

FIG. 1. — Map of Laguna de Barra de Navidad showing locations of the three sampling stations.
Situation et carte de la lagune Barra de Navidad. Position des 3 stations de mesure

influenced by semidiurnal tides with a maximum range of 1.3 m. The Marabasco river discharges into the southeastern part of the lagoon (fig. 1), but there is river flow only during the wet season. The average salinity in the lagoon ranges from 35‰ during the dry season to less than 5‰ during the wet season.

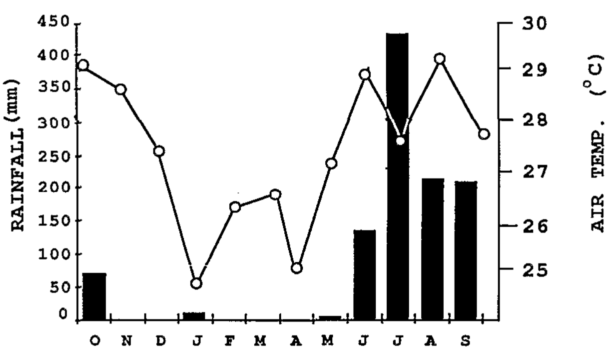

FIG. 2. — Seasonal rainfall in mm per mouth (bars) and air temperature (solid line) during 1983-1884. Source : Laboratorio de Ciencias Marinas, Universidad Nacional Autónoma de Guadalajara, Barra de Navidad, Jalisco, Mexico)
Évolution des précipitations et de la température de l'air en 1983-84 (d'après : Laboratorio de Ciencias Marinas)

Methods

Plankton productivity was measured monthly from October 1983 to September 1984 using the light/dark bottle oxygen method described by STRICKLAND and PARSONS (1972). Three hour duplicate incubations of light and dark bottles were carried out around local noon at half Secchi depth which corresponds to 0.5 incident radiation (I_o). Oxygen concentrations were determined using Winkler titrations (STRICKLAND and PARSONS 1972). During each productivity measurement Secchi depth, water temperature and salinity were measured. Hourly net production was multiplied by a 8.6 to estimate daily net production. This factor, which corrects for lower light during early morning and late afternoon, was calculated by FLORES-VERDUGO (1986) with an irradiometer in a nearby coastal lagoon. It is very similar to the value used by RANDALL and DAY (1987) to make similar corrections for a coastal bay in Louisiana, USA. Hourly respiration rates were converted to daytime respiration and total respiration by multiplying by the hours of daylight and 24, respectively. The daily rate of gross production per m^3 equalled the daily rate of net daytime production plus the daily rate of daytime respiration (RANDALL and DAY 1987). Productivity values for the whole water column were calculated on a m^2 basis by integrating the productivities calculated at several depths according to the equation :

$P_z = [2 (I_z/I_{pmax}) / [1 + (I_z/I_{pmax}) ½]] P_{max}$ MEE (1977)
Where : P_z = the productivity at depth Z
I_z = the light intensity at depth Z
P_{max} = the productivity at the depth of maximum productivity
This equation is derived from the VOLLENWEIDER equation (1974), and is used when the water depth is lower than the depth of the euphotic zone. The extinction coefficient (K) was related to the Secchi depth (S) by the equation $K = 1.42/S$, based on results from several coastal lagoons along the Pacific coast of Mexico (FLORES-VERDUGO 1985, FLORES-VERDUGO *et al.* 1986). The P/R ratio was calculated by dividing daily gross oxygen production per m^2 by total oxygen respiration per m^2. O_2 metabolism values were converted to carbon values using factors of 0.313 g C/g O_2 for production and 0.375 g C/g O_2 for respiration (STRICKLAND and PARSONS 1972).

RESULTS AND DISCUSSION

The results show that Barra de Navidad Lagoon is a productive aquatic system and that there is a temporal and spatial variability in aquatic primary productivity. These patterns reflect changes in the main parameters which affect aquatic metabolism of this lagoon including riverflow, turbidity, salinity, organic matter input, and nutrient levels.

Riverflow strongly influenced seasonal patterns of both respiration and net production at the station nearest the river mouth, but the effect was progressively less at the mid-lagoon and inlet stations (fig. 3, table I). Peak values for net production occurred in June, during the rainy season, at the mid-lagoon (3.74 g $O_2\,m^{-2}d^{-1}$) and riverine (2.84 g $O_2\,m^{-2}d^{-1}$) sites. The lowest values generally occurred during the dry season. Mininum values for net production occurred in April in the mid-lagoon (0.66 g $O_2\,m^{-2}d^{-1}$) as in the riverine site (0.34 g $O_2\,m^{-2}d^{-1}$). A number of authors have reported a strong correlation of aquatic production with nutrient input from rivers in tropical coastal systems such as Cananeia Lagoon in Brazil (TUNDISI 1969) and El Verde Lagoon on the Pacific coast of Mexico near Mazatlan (FLORES-VERDUGO 1985). In Terminos Lagoon on the Gulf coast of Mexico, DAY *et al.* (1982, 1987) reported strong relationships between river flow and net production and chlorophyll *a* concentrations. They concluded that these patterns were a result of nutrient enrichment by the river input.

In July, there was a pronounced minimum in net production and respiration at the riverine site and a

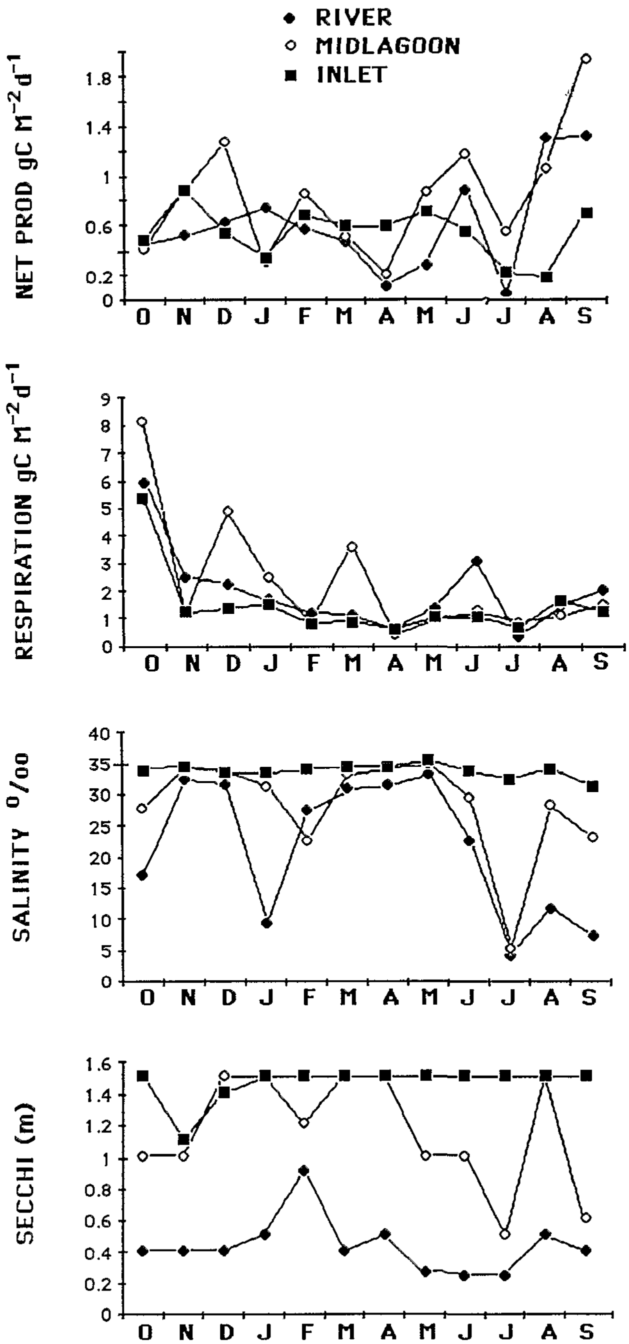

FIG. 3. — Seasonal patterns in Barra de Navidad Lagoon of : A. net daytime production, B. Total respiration, C. salinity, and D. Secchi depth. When the transparency was greater than the depth, the Secchi depth is shown as the total depth (1.5 m)
Évolution saisonnière dans la lagune Barra de Navidad. A. production nette diurne; B. respiration totale (24 h), C. salinité; D. visibilité du disque de Secchi, quand la transparence était plus grande que la profondeur, la profondeur du Secchi est montée comme la profondeur totale (1,5 m)

slight decrease at the mid-lagoon site. This was probably due to two factors. During this time the lowest Secchi depth measurement encountered during the study (0.24 m) was observed at the riverine site (fig. 3). Thus light limitation undoubtedly limited phytoplankton photosynthesis as a result of the extreme turbidity caused by the river flow. It is also possible that strong river flow washed out much of the normal plankton standing stock leading to a low respiration rate. July had the highest rainfall (fig. 2) and salinity decreased to about 4‰ at both the riverine and mid-lagoon sites during this period (fig. 3). The same phenomenon was observed in Cananeia lagoon, Brazil, where changes in salinity were correlated with production, being low when salinity decreased to 3.5‰ (TUNDISI 1969). Flushing of plankton due to high river discharge has been reported for Agua Brava lagoon to the north of Barra de Navidad (FLORES-VERDUGO 1986) and for the Potomac River (BENNETT 1986). Light limitation has commonly been reported to limit phytoplankton production (BOYNTON *et al.* 1983) and turbidity due to river inflow has been reported to limit production in San Francisco Bay, California (COLE and CLOREN 1984) and Fourleague Bay, Louisiana (RANDALL and DAY 1987).

There were spatial differences in both the patterns and levels of production in the lagoon (fig. 3). As indicated earlier, there was a distinct seasonality at the riverine station which was probably related to river flow affecting nutrient levels and turbidity. The pattern was also evident at the mid-lagoon station. The station near the inlet evidenced little clear seasonal changes. There was also a gradient in total productivity per m^3 across the lagoon. The riverine station had the highest production (mean annual rate = 1.88 g O_2 $m^{-3}d^{-1}$), the rate at the mid-lagoon site was somewhat lower (1.66 g O_2 $m^{-3}d^{-1}$), and the inlet had the lowest productivity (1.18 g O_2 $m^{-3}d^{-1}$). When production is considered on a m^2 basis, however, the mid-lagoon had the higest net production (2.65 g O_2 $m^{-3}d^{-1}$) with the riverine and inlet stations similar and somewhat lower. This spatial result was almost certainly related to the fertilizing effect of the river combined with clearer water. The lower values near the river and ocean were probably because of low tranparency and lower nutrient levels, respectively. Secchi depth was generally less than 0.5 m at the river station, averaged about 1.0 m at the mid-lagoon, and was higher than 1.5 m at the inlet station (fig. 3), indicating that the depth of the euphotic zone markedly decreased toward the river. We conclude that an optimum mixes of light and nutrients led to higher productivity per m^2 at the mid-lagoon station.

A number of authors have reported similar spatial patterns with the highest productivities at intermediate salinities. These include Biscayne Bay, Florida (ROMAN *et al.* 1983), Fourleague Bay, Louisiana (RANDALL and DAY 1987), San Francisco Bay, California (COLE and CLOREN 1984), and Terminos Lagoon, Mexico (DAY *et al.* 1987). It is also possible that humic substances washed from surrounding wetlands stimulated productivity. Several studies have shown that humic substances stimulate phytoplankton production (PRAKASH and RASHID 1968, PRAKASH *et al.* 1972, COOKSEY and COOKSEY 1978, DAY *et al.* 1987). DAY *et al.* (1987) added filtered water collected from the surface of a mangrove swamp to samples of Terminos Lagoon water and found stimulation of both production and respiration during four hour incubations.

There appeared to be a seasonality in respiration rates, especially at the mid-lagoon and riverine stations. Respiration was generally lower than gross production during the rainy season indicating that the lagoon water was autotrophic during this season, a result of the high phyplankton production at that time. Respiration was generally higher than production early in the dry season, but the difference diminished as the dry season progressed. There was an especially high peak of respiration in October throughout the lagoon. This heterotrophy early in the dry season is likely the result of organic material accumulated in the lagoon during the wet season, both from in situ phytoplankton production and benthic algae as well as input from the river and surrounding mangroves. The higher rates in the central lagoon indicate that organic material may accumulate there. A number of studies have shown that organic input from rivers or surrounding wetlands can be important sources of organic matter for tropical lagoon systems on the Pacific (MEE 1977, GONZÁLEZ-FARIAS *et al.* 1986, FLORES-VERDUGO 1985) and Gulf of Mexico (LEY-LOU 1985, DAY *et al.* 1982) coasts.

The P/R ratios reflect the seasonal shift in trophic status from autotrophic in the rainy season to heterotrophic during the dry season. Over the whole year, the P/R ratio for the water column was 1.03 indicating that the system is slightly autrophic. Heterotrophic conditions following the rainy season have been reported for several lagoon systems on the Pacific coast of Mexico including El Verde Lagoon (FLORES-VERDUGO 1985), Estero de Urias (ROBLES-JARERO 1985), and Agua Brava (FLORES-VERDUGO 1986). The P/R ratio changed spatially with the riverine station being slightly heterotrophic and the ratio being autotrophic for the mid-lagoon and inlet station. This probably reflects higher levels of organic matter and less water column net production near the river mouth.

TABLE I

Average phytoplankton net primary productivity in several tropical coastal lagoons. All values derived from measurements over an annual cycle except for Concepcion Bay, which is for July and August. All systems have a permanently open inlet except for Chautengo, which has a seasonal inlet

Production nette diurne moyenne dans plusieurs lagunes tropicales. Toutes les valeurs sont calculées à partie de mesures couvrant un cycle annuel, sauf pour Conception Bay qui porte sur juillet et août. Les plans d'eau sont reliés de façon permanente à la mer sauf Chautengo et El Verde, qui ont des bras de mer saisonniers. Urias reçoit des effluents domestiques

Area	Mean Annual Net Production $gCm^{-3}day^{-1}$	Source
Barra de Navidad, Mexico (*)		
Riverine Station	0.59	This Study
Mid Lagoon Station	0.51	
High Salinity Station	0.37	
Chautengo Lagoon, Pacific Coast, Mexico	1.40	Mee 1977
El Verde Lagoon, (*) Pacific Coast, Mexico	1.29	Flores-Verdugo 1985
Estero de Urias, (*) Pacific Coast, Mexico	1.70	Robles-Jarero 1985
Terminos Lagoon, Gulf Coast, Mexico	0.82	Day et al. 1983
Rookery Bay, Florida, U.S.	0.37	Twilley 1982
Cananeia, Brasil	0.1 - 0.8	Tundisi 1960
Concenpcion Bay, Gulf of California, Mexico (*)	0.22	Gilmartin and Revelante 1978

* Using a factor of 8.6 to convert from hourly to daily measurements. See text for discussion.

The net daytime production rates measured for Barra de Navidad Lagoon are in the range of other similar systems (table I). A comparison with production values from several other systems suggests some generalizations about aquatic primary production in these coastal lagoons. The rates for Barra de Navidad are similar to two other lagoons with permanently open inlets : Terminos Lagoon and Rookery Bay (table I). Higher values were reported for lagoons with seasonal inlets (Chautengo and El Verde) and for Estero de Urias which is eutrophic due to high nutrient loading of domestic wastes from the City of Mazatlan. This suggests that in lagoons with permanently open inlets, continual dilution by the ocean, especially during the dry season, results in a significant loss of nutrients. In systems with seasonal inlets, this dilution does not occur during the dry season and nutrients are retained in the system. For example, FLORES-VERDUGO (1985) reported significant production in El Verde Lagoon during the dry season and MEE (1977) found that production in Chautengo Lagoon was higher when the inlet was closed than when it remained open. Thus these lagoons are at the interface between terrestrial and riverine systems on one hand and the ocean on the other. Fresh water input provides inorganic nutrients and organic matter which stimulates metabolism while the ocean is a sink for these materials. The relative degree of coupling at the upland/lagoon and lagoon/ocean interfaces determines the productivity of a specific lagoon.

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