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Equatorial Subsurface Water and the nutrient seasonality distribution of the Gulf of Nicoya, Costa Rica

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Abstract: A dry season nutrient survey was conducted in the Gulf of Nicoya, Costa Rica. The highest concentrations of nitrate and phosphate over the surveyed range ocurred at the deep waters off the gulf mouth. Vertical stratification kept the nutrient rich Equatorial Subsurface Water (ESW) at the deeper levels below the thermocline over most of the lower (outer) section of the Gulf. Higher tidal energy dissipation on the mid Gulf appears to be mixing this nutrients over the entire water column. Additionally two anchor stations were set at the western and eastern lower (outer) Gulf. There was a net flux into the Gulf of nitrate and phosphate at the west end, while at the east side nutrients are exported offshore. Survey data suggests that the major source of nitrate and phosphate for the embayment is the ESW, whereas silicate would be mostly provided by rivers. Our data and that of previous workers indicate that this pattern does not change in the rainy season. The influx of the ESW water into the Gulf of Nicoya may be dampening the seasonal signal due to runoff, at least for inorganic nitrogen and phosphorus, keeping relatively steady levels of these nutrients throughout the year over most of the Gulf.

Key words: Tropical, estuary, nutrients, biogeochemistry, seasonality, Central America, Costa Rica.

The relative importance of different sources of nutrients to primary productivity of estuaries is still an issue of debate among estuarine ecologists. Most workers have emphasized the importance of rivers and sewage discharge because of the increasing anthropogenic loads of nutrients since the begining of the industrial revolution (Nixon 1995). Recognition of offshore waters as a major source of nutrients contributing to estuarine productivity has been less common, despite the fact that several influential authors have stressed their potentially major role. According to Riley (1967), "...the usual pattern of exchange between inshore and offshore waters tends to enrich the coastal zone irrespective of enrichment by freshwater drainage...".

After the first nutrient survey in the Gulf of Nicoya on the Pacific coast of Costa Rica (Fig. 1), Epifanio *et al.* (1983) concluded that this tropical estuary differs from most temperate estuaries that have been studied, in that much of the nitrogen entering the bay is from offshore waters. Nevertheless, they supported the idea that a seasonal pattern occurred in the concentrations of nutrients, especially in the upper (inner) gulf, due to the changes in river runoff between rainy (May-November) and dry seasons (December-April), and reported that "levels of nutrients varied by an order of magnitude seasonally" in the upper (inner) Gulf. After a one year physical-chemical survey mainly on the upper (inner) Gulf of Nicoya, Valdes *et al.* (1987) also concluded that threre was a seasonal variation in nutrients due to the change in river flux. In contrast to the earlier survey, however, Valdes *et al* (1987) found the highest concentrations of nutrients during the dry season. For reasons that are unclear, they attributted the nutrient enrichment to runoff during the rainy season, even though their nutrient time series showed a maximum during the dry season. More recently, in an assessment of the annual cycle of primary productivity at a man-

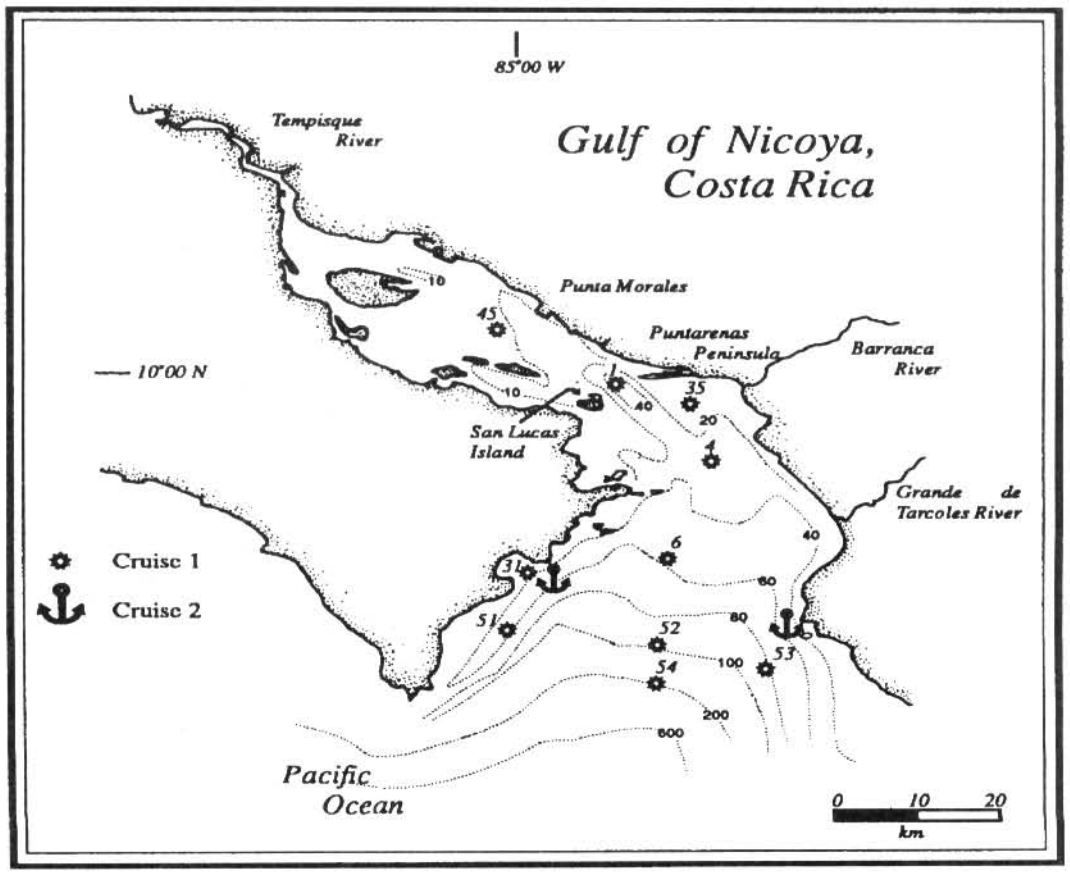

Fig. 1. Gulf of Nicoya, Costa Rica. Location of the sampling stations.

grove inlet in the upper (inner) gulf,Cordoba-Muñoz (1993) found no significative seasonal pattern in nutrient concentrations.

In the present paper we present the results of an additional nutrient survey in the Gulf of Nicoya, and use our results and those of previous workers to revisit the question of the role of river runnof in influencing the seasonal cycles of nutrients in the Gulf.

MATERIAL AND METHODS

In December, 1993 and February, 1994 (dry season) two cruises were carried out on board the RV Victor Hensen in the Gulf of Nicoya. Ten stations were sampled on the first cruise, while two anchor stations were occupied over a semidiurnal tidal cycle on the second cruise. The latter were located on the west and east sides of the lower (outer) gulf, as these are the areas where (Fig. 1) the main water exchange between the ocean and the Gulf of Nicoya takes place (Voorhis *et al.* 1983). Sampling was done with Niskin bottles at two or three depths. At depths <20 m, a surface and near bottom sample were taken; at deeper stations, a third sample was taken from the thermocline as determined by a Conductivity-Temperature-Depth (CTD) sensor cast. At the anchor stations, samples were taken at five and seven depths on the east and west stations, respectively.

Samples for nitrate, phosphate, and silicate were stored frozen in 500 ml polyethylene bottles. Analytical problems prevented us from analyzing ammonia. Spectrophotometric analyses were carried out in triplicate after each cruise at a laboratory on the mainland. We used the procedures of Strickland and Parsons (1972) modified in order to handle 10 ml samples for nitrate and phosphate, and 5 ml samples for silicate.

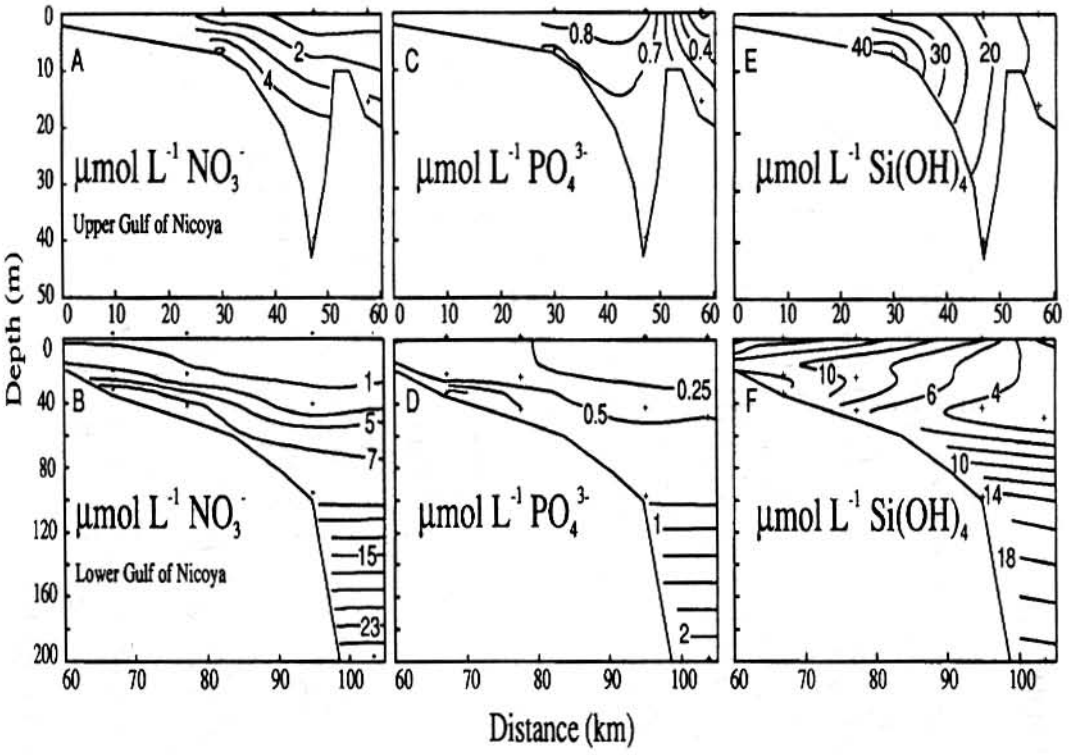

Fig. 2. Distribution of nutrients (µmol L^{-1}) along a central transect in the Gulf of Nicoya in December 1993. upper (inner) Gulf: stations No. 45, 01 and 35 (A= nitrate, C= phosphate, E= silicate) and lower (outer) Gulf: station No. 4, 6, 52 and 54 (B= Nitrate, D= phosphate, F= silicate).

RESULTS AND DISCUSSION

The distribution of nutrients along a central transect in the Gulf of Nicoya in December (sta. 45, 1, 35, 30, 6, 52, 54) showed a vertically stratified pattern over most of the gulf (Fig. 2), with higher concentrations at the deeper levels. This pattern broke down over the bottom depression at the mid gulf area, between San Lucas Island and Puntarenas Peninsula, where the tidal kinetic energy dissipation and wind stress are large enough during the dry season to mix almost the entire water column (Peterson 1960, Voorhis *et al.* 1983). With the notable exception of silicate, the highest nutrient concentrations were found in the deep water at the mouth of the Gulf (Fig. 2). The source of this deep water is the Equatorial Subsurface Water (ESW) (Wirtky 1964, Voorhis *et al.* 1983), which is characterized by very low oxygen concentrations which allow denitrification to take place (Cline and Richards 1972). For this reason, the water entering the mouth of the Gulf has a low N/P ratio compared to the Redfield Ratio (Redfield 1934), that may contribute to nitrogen limitation in this embayment. The amount of nutrient rich ESW water that makes its way into the Gulf of Nicoya has not been estimated, but it must certainly dwarf that coming from the major freshwater inputs to the Gulf (i.e. Tempisque and Grande de Tárcoles rivers).

The influence of the tide in carrying the deep water into the Gulf is shown by a marked increase in the concentrations below the thermocline of both nitrate and phosphate around the high tide at the western anchor station. We interpret this as indicating a net flux of both nutrients along the bottom. However, water leaving the bay in this area appeared, to be enriched in silica relative to that coming in. At the eastern anchor station (Fig. 3 d-f), the entire water column became nutrient enriched during

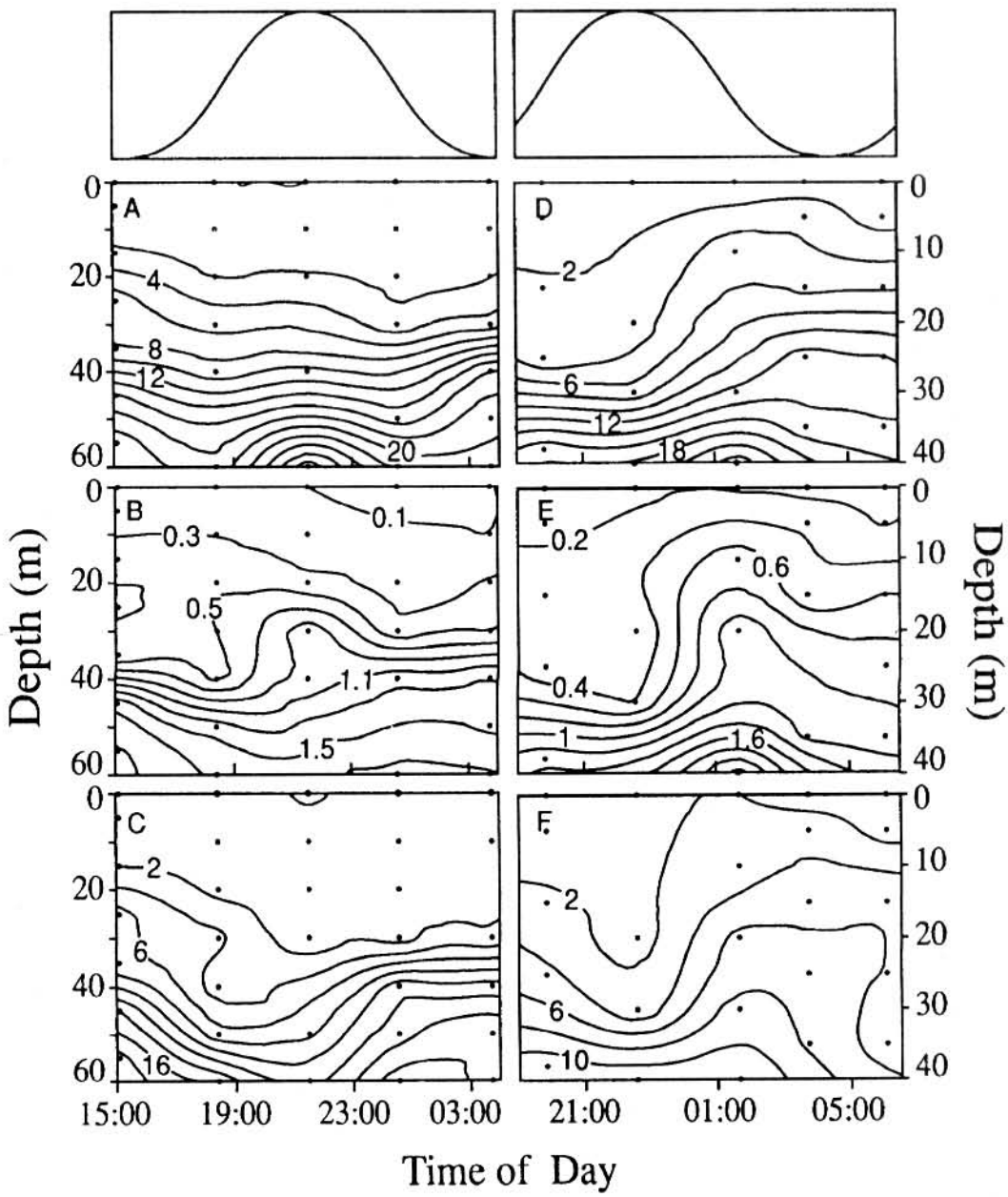

Fig. 3. Vertical variation of nutrients concentration (μmol L^{-1}) during a semidiurnal tidal cycle at the western lower (outer) Gulf of Nicoya: A) nitrate, B) phosphate and C) silicate; and at the eastern lower (outer) Gulf (D-F) with the same nutrient sequence respectively. An approximate depiction of the tide phase during the sampling period is presented in the panels above each column correspondent to each station.

the ebb tide, perhaps indicating that there is a net export of nutrients along this side of the Gulf. Mixing diagrams based on measurements taken during the December cruise were consistent with the view that the deep water at the mouth of the Gulf is a major source of nitrate and phosphate for the system (Fig. 4). When data of Epifanio *et al.* (1983), are presented in

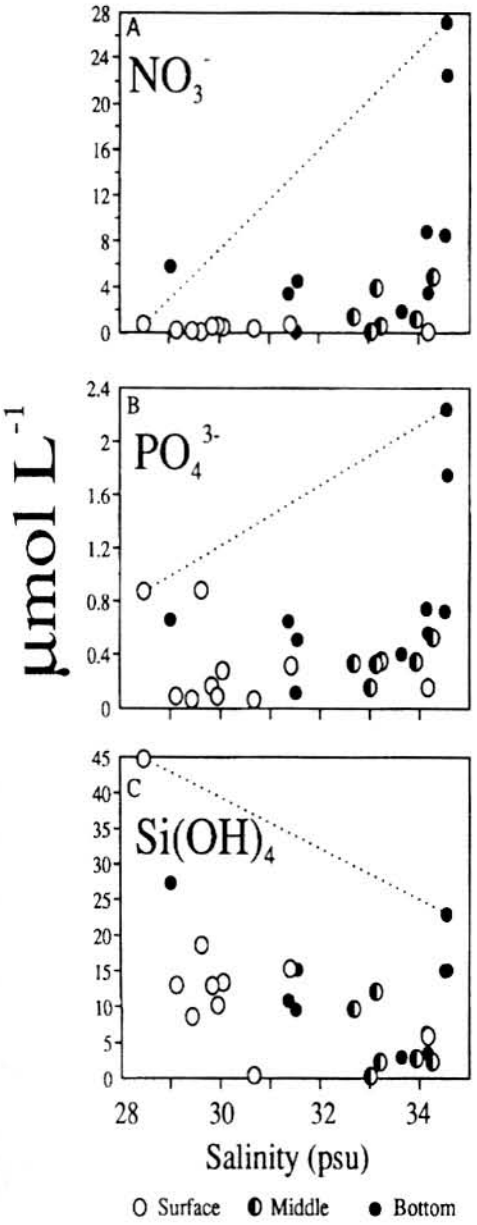

Fig. 4. Mixing diagrams of salinity (practical salinity units) vs. nutrient concentration (µmol L^{-1}), for A) nitrate, B) phosphate and C) silicate, in the Gulf of Nicoya during December 1993. The dotted line represents the conservative mixing path in the salinity-concentration space between the estuarine and oceanic end members.

the same fashion, they also suggest that the ocean is a major source of nitrate and phosphate during both rainy and dry seasons (Fig. 5).

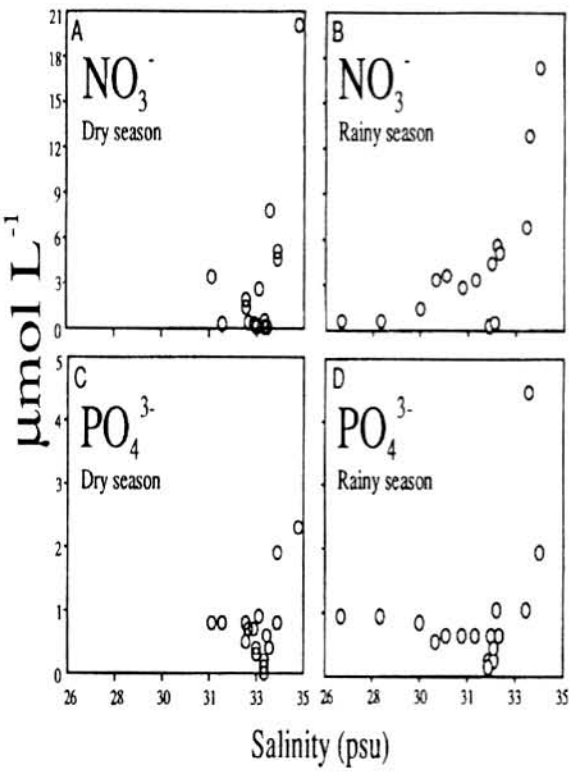

Fig. 5. Mixing diagrams of salinity (practical salinity units) vs. nutrient concentration (µM), for A, B) nitrate and C, D) phosphate, in the Gulf of Nicoya during the rainy season (July, 1979) and dry season (January, 1980). Data from Epifanio *et al.* (1983).

It is evident from the stratification illustrated in Fig. 2 that the ESW remains under the thermocline off the mouth of the lower (outer) gulf. However, we speculate that under the appropriate meteorological and/or oceanographic conditions, the deep water enters the mouth of Gulf and proceeds perhaps as far as 50 km, where it is mixed vertically and the nutrients it contains contribute to the primary production of the system. This enrichment mechanism could account for the results of others authors such as Valdes *et al.* (1987) and Córdoba-Muñoz (1993), which do not appear to be consistent with runoff-driven nutrient seasonality. During her one year study, Cordoba-Muñoz (1993) found that nutrient concentrations and chlorophyll-a standing stocks in Punta Morales (a mangrove bound inlet on the eastern margin of the upper (inner) Gulf) showed no significant differences between dry and rainy seasons.

Moreover, average primary productivity by the phytoplankton was higher during the dry season. Other studies on the red tides of the Gulf of Nicoya (Hargraves and Víquez 1981, 1985, Gocke *et al.* 1990) have also found that algal blooms are more common during the dry season. In their description of red tide outbreaks between 1979 and 1984, Hargraves and Víquez (1985) pointed out that all ocurred in the middle to lower (outer) Gulf in the form of "surface slicks" which they attributed at least in part to "enriched nutrient patches". Such patches might result from enrichment due to vertical mixing of offshore water at the mid Gulf.

The rate at which nutrients become available may increase during the dry season due to an increase in intensity of the NE trade winds. During the dry months, winds may persist for periods from half to five days at wind speeds up to 65 km h-1 and lead to the breakdown of the stratification that builds up during the rainy season (Peterson 1958). A similar situation was reported by Yin *et al.* (1995) for the Fraser River estuary (British Columbia), where strong winds raised nitrate levels by three fold and algal blooms appeared inmediatly after some wind events.

While we believe that under the present conditions the major source of inorganic nitrogen and phosphorus for the Gulf of Nicoya is the offshore deep water, this does not mean that anthropogenic enrichment should be neglected. In many temperate estuaries where nutrients were once suplied mostly by offshore waters, human activities have turn rivers and sewage discharges into the major sources with deletereous effects on these ecosystems. One example is Narragansett Bay, Rhode Island in the NE coast of the United States, where offshore waters were the prime source of nitrogen before european settlement, but anthropogenic sources now provide most of the nutrients (Nixon *et al.* 1996).

The next step in advancing our understanding of the relative importance of the different sources of nutrients that support the productivity of the Gulf of Nicoya should be to develop a much more complete inventory of nutrient inputs to the system. Quantifying the flux from offshore will be a challenging but clearly important part of the task.

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RESUMEN

Se hizo una campaña de monitoreo de nutrientes en el Golfo de Nicoya, Costa Rica, durante la estación seca. Las mayores concentraciones de nitrato y fosfato se hallaron en las aguas profundas en la zona exterior de la boca del golfo. La estratificación vertical mantuvo el agua ecuatorial subsuperficial (ESW), rica en nutrientes, a profundidades por debajo de la termoclina en la mayor parte de la sección externa del golfo. En la parte central del golfo, la mayor energía disipativa de las mareas parece ser responsable del mezclado de estos nutrientes a través de toda la columna de agua. Adicionalmente, dos estaciones fijas fueron muestreadas en la parte occidental y oriental de la sección externa del golfo. Los datos mostraron un flujo neto de nitrato y fosfato que entra al golfo por su extremo occidental, mientras que por la parte oriental los nutrientes eran exportados mar afuera. Los datos del monitoreo sugieren que la mayor fuente de nitrato y fosfato para la bahía es la ESW, mientras el silicato sería mayormente provisto por los ríos. Nuestros datos y los de otros autores indican que este comportamiento no cambia entre la estación seca y lluviosa. El ingreso de ESW en el Golfo de Nicoya puede estar amortiguando la señal estacional debida al aporte terrígeno, al menos para el nitrógeno y fósforo inorgánico, manteniendo niveles relativamente constantes de estos nutrientes a lo largo del año en la mayor parte del golfo.

REFERENCES

Cline, J.D. & F.A. Richards. 1972. Oxygen deficient conditions and nitrate reductions in the Eastern Tropical Pacific Ocean. Limnol. Oceanogr. 17: 885-900.

Córdoba-Muñoz, M. del R. 1993. Productividad primaria en la columna de agua. Golfo de Nicoya, Costa Rica. M.Sc. thesis, Universidad de Costa Rica, San José, Costa Rica.

Epifanio, C.E. D. Maurer & A.I. Dittel. 1983. Seasonal changes in nutrients and dissolved oxygen in the Gulf of Nicoya, a tropical estuary in the Pacific coast of Central America. Hydrobiologia 101: 231-238.

Gocke, K. J. Cortés & C. Villalobos. 1990. Effects of red tides on oxygen concentration and distribution in the Golfo de Nicoya, Costa Rica. Rev. Biol. Trop. 38: 401-407.

Hargraves, P.E. & R. Víquez. 1981. The dinoflagellate red tide in Golfo de Nicoya, Costa Rica. Rev. Biol. Trop. 29: 31-38.

Hargraves, P.E. & R. Víquez. 1985. Spatial and temporal distribution of phytoplankton in the Gulf of Nicoya, Costa Rica. Bull. Mar. Sci. 37: 577-585.

Nixon, S.W. 1995. Coastal marine eutrophication: a definition, social causes, and future concerns. Ophelia 41: 199-219.

Nixon, S.W. S.L. Granger & B.L. Nowicki. 1996. An assessment of the annual mass balance of carbon, nitrogen, and phosphorus in Narragansett Bay. Biogeochemistry.31: 15-61.

Peterson, C.L. 1960. The physical oceanography of the Gulf of Nicoya, Costa Rica, a tropical estuary. Bull. inter-am. trop. Tuna Commn. 3: 139-216.

Redfield, A.C. 1934. On the proportions of organic derivatives in seawater and their relation to the composition of plankton, pp 176-172. *In* R.J. Daniel (ed.). James Johnston Memorial Volume. Univ. Liverpool, Liverpool.

Riley, G.A. 1967. Mathematical model of nutrient conditions in coastal waters. Bull. Bingham Oceanogr.Coll. 19: 72-80.

Strickland, J.D.H. & T.R. Parsons. 1972. A practical handbook of seawater analysis, Fish. Res. Bd. Can. 167: 310 p.

Valdes, J. C.L. Brenes, E. Solis & M. Mendelewicz. 1987. Propiedades físico químicas de las aguas del Golfo de Nicoya, Costa Rica. Ing. Cienc. Quim. 11: 21-25.

Voorhis, A. D. C.E. Epifanio, D. Maurer, A.I. Dittel & J.A. Vargas. 1983. The estuarine character of the Gulf of Nicoya, an embayment on the Pacific coast of Central America. Hydrobiologia 99: 225-237.

Yin, K. P.J. Harrison, S. Pond & R.J. Beamish. 1995. Entrainment of nitrate in the Fraser River Estuary and its biological implications. III. Effects of Winds. Estuar. Coast. Shelf Sci. 40: 545-558.

Wyrtki, K. 1964. Upwelling in the Costa Rica Dome. Fish. Bull. 63: 355-372.