

El Niño 1997-1998 impact on the plankton dynamics in the Gulf of Nicoya, Pacific coast of Costa Rica

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Abstract: The impact of the El Niño 1997-1998 phenomenon on plankton dynamics was studied during 1997 at the Punta Morales estuary, Gulf of Nicoya, Pacific coast of Costa Rica. The study covered dry season/transition and the rainy season. Phytoplankton (microphytoplankton > 30µm and nanophytoplankton) were collected at two depths (50 and 10% light incidence) using a 5 L Niskin bottle, and samples taken to determine chlorophyll *a*. Temperature, salinity, oxygen, and Secchi depth were measured. Horizontal sub-surface zooplankton hauls were conducted with a conic zooplankton net of 0.49 m diameter and 280µm mesh width, supplied with a flowmeter. Surface sea water temperature average was $29.9 \pm 0.9^\circ\text{C}$, with a maximum of 31.5°C in April and a minimum of 28°C in March and October. Chlorophyll *a* concentration (phytoplankton net) averaged $3.1 \pm 1.7 \text{ mg/m}^3$, with higher values during the rainy season and lower values during the transition. Nanophytoplankton chlorophyll *a* concentration averaged $2.5 \pm 1.2 \text{ mg/m}^3$, with a maximum during the transition season. For both fractions there were significant differences between transition and rainy seasons, and for nanophytoplankton between dry and transition seasons ($p < 0.05$). In the last case, differences were explained by temperature. Herbivorous copepods dominated the abundance and biomass of zooplankton, with a biomass maximum of 167.3 in October and a minimum of 7.1 mg DW/m³ in December. These values are higher than those found some years ago in the same zone and those reported for some places in the Caribbean. The El Niño 1997-1998 phenomenon in the plankton dynamics appears to have produced a change in the phytoplankton structure. This is the first attempt to evaluate the possible impact of El Niño on the plankton dynamics of the Pacific coast of Central America.

Key words: Plankton, Pacific, El Niño, Costa Rica, copepods.

The effects of interannual variation associated with the oceanic-atmospheric interface are better recognized in the Pacific in the form of the phenomenon known as El Niño or the Southern Oscillation. This system owes its origin to the displacement of a high pressure center from the South American Pacific coast

toward the northeast followed by the development of a center of low pressure in the Indo-Pacific which shifts to the southeast, eventually covering the entire equatorial Pacific (Man and Lazier 1991). This phenomenon produces a displacement of the Intertropical Convergence Zone and consequent changes in

continental climate. The study of interannual variation in physical conditions along the entire Pacific coast of the Americas has confirmed the existence of local anomalies that are produced by changes in the entire system of equatorial currents in response to El Niño-Southern Oscillation (McGowan 1984, Cole and McLain 1989). In turn, the biological populations change in response to the climatic events. At least in the case of the Pacific, the major changes in biological populations have occurred during the last 20 years (McGowan *et al.* 1998). Plankton also respond to the climatic events of El Niño on a correspondingly large scale. Studies of the Alaskan Gyre and in the California Current (Fulton & Le Brasseur, 1985, Palomares-García & Gómez-Gutiérrez 1996) have demonstrated structural changes in the composition of the zooplankton as a consequence of the interannual variation frequently associated with the El Niño-Southern Oscillation. Furthermore, in the California current system, large warming episodes are linked to equatorial El Niño, which produce episodic lowering of the nutricline, the development of a deep chlorophyll maximum, and a decrease in the secondary productivity of zooplankton (McGowan *et al.* 1998). In the same work, the authors give some examples how El Niño in other periods has changed the composition of zooplankton, with important changes in the abundance of larval fish. More recently, larvae of *Sardinops caeruleus* (Clupeidae) were nearly absent during the El Niño 1997-1998, when the temperature in the Gulf of California increased 4°C (Sánchez-Velasco *et al.* 2000). On the other hand, changes in the volume of water transported by the California Current cause changes in the biomass of zooplankton (Chelton *et al.* 1982), biomass of phytoplankton (Mullin 1994) and in the relative abundance and egg production of the copepod *Calanus pacificus* (Mullin 1995).

The El Niño phenomenon has had an important impact on various groups of organisms along the Pacific coast of Costa Rica (Guzmán *et al.* 1987). The objective of this work is to analyse the possible impact of the El Niño of 1997-1998 on the dynamics of the plankton at

Punta Morales in the Gulf of Nicoya, an estuarine ecosystem on the Pacific coast of Costa Rica.

MATERIALS AND METHODS

Gulf of Nicoya: The Gulf of Nicoya is a tropical estuary, with an area of 1 543 km², located at 10° N and 85° W on the Pacific Coast of Costa Rica. From an oceanographic perspective, two main regions may be identified (Voorhis *et al.* 1983): an external zone delimited by the open ocean to the south and to the north by a line defined by San Lucas Island and the Puntarenas peninsula, and a shallow internal zone representing the remainder of the Gulf. The external zone is bordered by a rocky coast with sandy beaches while the bottom drops abruptly toward the mouth. In contrast, the internal zone is shallow (less than 20 meters) and is bordered by mangroves, muddy or sandy beaches and rocky headlands (Vargas 1995).

The dynamic structure of the Gulf is controlled principally by variations in salinity (Peterson 1958, Lizano & Vargas 1994) and strong gradients in physical and chemical parameters during the rainy season. In particular, the internal region of the Gulf behaves as an estuary, becoming stratified during the rainy season because of the reduced surface salinity (Epifanio *et al.* 1983). The external region is less influenced by the seasonal change in precipitation but exhibits a permanent thermocline between 30 and 40 meters with temperature differences between surface and bottom of up to 14° C (Voorhis *et al.* 1983). More recently, it has been shown that the strong haline stratification in the internal region may have an important impact on fisheries in the Gulf (Lizano 1998).

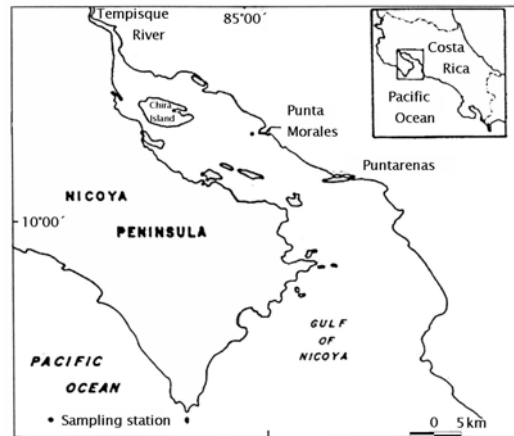
The marked seasonality observed in the pattern of stratification also influences the distribution and concentration of nutrients and dissolved oxygen (Epifanio *et al.* 1983, Chaves & Birkicht 1996) which in turn leads directly to biological differences between the two regions of the Gulf. For example, seasonal differences have been observed in ichthyofauna (Price *et al.* 1980, Bartels *et al.* 1983),

brachiuran larvae (Epifanio & Dittel 1984), copepods (Morales & Vargas 1995, Morales-Ramírez 1996) and benthic communities (Maurer & Vargas 1984). Studies of the plankton have concentrated on the distribution of phytoplankton, characterization of non-toxic red tides (Hargraves & Viquez 1981, 1985), decapod larvae (Dittel & Epifanio 1982, 1990, Werthmann & Dittel 1990), ichthyoplankton (Ramírez *et al.* 1989), primary productivity (Córdoba 1993) and distribution, abundance and biomass of zooplankton (Morales-Ramírez *in prep.*). Thus, the Gulf of Nicoya is recognized as one of the best studied tropical ecosystems in the world (Vargas 1995).

Methods: A sampling station was located in the internal zone of the Gulf of Nicoya at the Punta Morales (Fig. 1). During 1997, in March, April, May, September, October, November and December, water samples were collected regularly two times per month, from two depths (representing 50% and 10% surface light intensity: 0.40 and 1.35 times the Secchi disk respectively, Gocke 1986) during a tide cycle (low tide, rising tide, high tide and falling tide) using a 5 L Niskin bottle for the measurement of chlorophyll-*a* by size fraction (microphytoplankton and nanophytoplankton). Furthermore for each depth, salinity was measured with a refractometer (Sper Scientific 300011), and surface water temperature and dissolved oxygen were measured with a YSI model 57. Samples for the determination of zooplankton biomass were collected with surface tows using a 0.49 m diameter net with 280 μ m mesh size. A flowmeter (General Oceanic 2030 R) was used to measure the filtered water. Samples were preserved with 5% formalin (Omori & Ikeda 1984).

Samples of water for chlorophyll-*a* were kept in 500 ml dark plastic bottles and refrigerated for further analysis in the field laboratory. A sieve of 30 μ m mesh was used to separate nano and microphytoplankton. Nanophytoplankton and total plankton were collected on 47 mm diameter Whatman GF/C filters (1.2 μ m pore size), which were kept at -20 °C. In the laboratory pigments were ex-

tracted with 90% acetone according to Strickland and Parsons (1972) and SCOR/UNESCO (1978). Filters were ground with a Glas-Col tissue grinder and the absorbance measured with a Shimadzu model UV-160 spectrophotometer. The concentration of chlorophyll-*a* in the microphytoplankton fraction



(larger than 30 μ m) was determined after removing the nanophytoplankton value from the total plankton.

Fig. 1. Localization of the study area.

Zooplankton samples were washed, and placed in distilled water using a Folsom plankton splitter. Depending on the sample volume, a fraction of 1/16, 1/32 or 1/64 of the total was processed. One fraction was used to determine dry weight of zooplankton by collecting onto a pre-weighed 47mm Whatman GF/C filter, and dried for 24 hours at 60°C in an oven. Because *Acartia lilljeborgii*, *Paracalanus parvus* and *Pseudodiaptomus* were the most abundant copepod species during 1997 (95%, Brugnoli 1998), herbivorous copepod biomass was recalculated using a relation between copepod concentration, its percent of biomass contribution to the total zooplankton biomass and then a correction for 95%. Biomass values are expressed in mg DW/m³.

Statistical analyses were performed with SYSTAT (Wilkinson 1987) with a confidence level of 95% (Gutiérrez 1986). The results

were analysed using the Mann Whitney and Kruskal-Wallis tests to detect differences between samples (phytoplankton biomass: nano vs microphytoplankton, phytoplankton biomass vs season change, herbivorous biomass and season, zooplankton abundance vs season), whereas the Spearman Rank correlation was used to detect associations between plankton biomass and environmental variables (Gutiérrez 1995, Zar 1996).

RESULTS

Based on precipitation data from the Puntarenas Meteorological Station, March and December were designated dry season, April and May as transitional and September, October and November were representative of the rainy season (Brugnoli 1998). During the study period, surface temperature averaged $29.9 \pm 0.9^\circ\text{C}$. The maximum temperature was 31.5°C , and occurred in April while the minimum (28.0°C) occurred in March and October (Fig. 2). The temperatures observed agree with those observed by Epifanio *et al.* (1983), Voorhis *et al.* (1983) and Lizano & Vargas (1994) in the same zone. However, whereas the surface temperatures observed during March agree with the studies by Epifanio *et al.* (1983) and Lizano & Vargas (1994), the temperatures observed in March during this study were higher than those observed in March for the lower part of the gulf some (3) years ago. The table 1 summarizes the phytoplankton chlorophyll-*a*, tide condition, % light and total zooplankton biomass values during 1997.

The concentration of chlorophyll-*a* may be used as an index of phytoplankton biomass (Raymont 1980). The average concentration of chlorophyll-*a* in the microphytoplankton averaged $3.1 \pm 1.7\text{ mg Chl-}a/\text{m}^3$ (Fig. 3) while nanophytoplankton chlorophyll-*a* concentration averaged $2.5 \pm 1.2\text{ mg Chl-}a/\text{m}^3$ (Fig. 3). Significant differences in chlorophyll-*a* concentration were detected, for both micro and nanophytoplankton fractions between the transitional season and the rainy season (Mann Whitney U test, $p < 0.05$). A significant difference

in the nanophytoplankton chlorophyll-*a* concentration between the transitional season and the dry season was also observed (Fig. 3). During the period of study, the maximum microphytoplankton biomass occurred during the rainy season whereas the minimum value occurred during the transitional season (Fig. 3). The variation in biomass with the change in season was significant at the 95% confidence level (Spearman $r_s = 0.357$). There was also a significant association between the oxygen concentration and the season ($r_s = 0.808$) and between the oxygen concentration and the microphytoplankton biomass ($r_s = 0.509$), as like as a significant association correlation between the temperature and the biomass of the nanophytoplankton (95% confidence level, $r = -0.259$).

Copepods were the most abundant group of zooplankton at Punta Morales area, followed by crustacean larvae, chaetognaths and ichthyoplankton. Among the copepods, *Acartia lilljeborgii*, *Pseudodiaptomus* sp. y *Paracalanus parvus* were dominant throughout the study, and in other years (Morales-Ramírez, pers. obs.). The maximum herbivorous copepod biomass was observed in April and October (146.5 and $167.3\text{ mg}/\text{m}^3$ dry weight, Fig. 4) with an average of $55.4 \pm 46.6\text{ mg}/\text{m}^3$ during the entire study.

DISCUSSION

According to Brugnoli & Morales (in press), this increased temperature may be the result of El Niño 1997-1998 warming and thus provide an explanation for the presence of a water mass with low dissolved oxygen concentration and higher salinity during December, in the dry season. On the other hand, various studies in Gulf of Nicoya have reported seasonal variation in the plankton communities. For example, Córdoba (1993) observed differences (although not statistically significant) in the seasonal primary production and Gocke *et al.* (1990) reported a seasonal pattern in the occurrence of red tides. According to Brugnoli (1998) the correlation

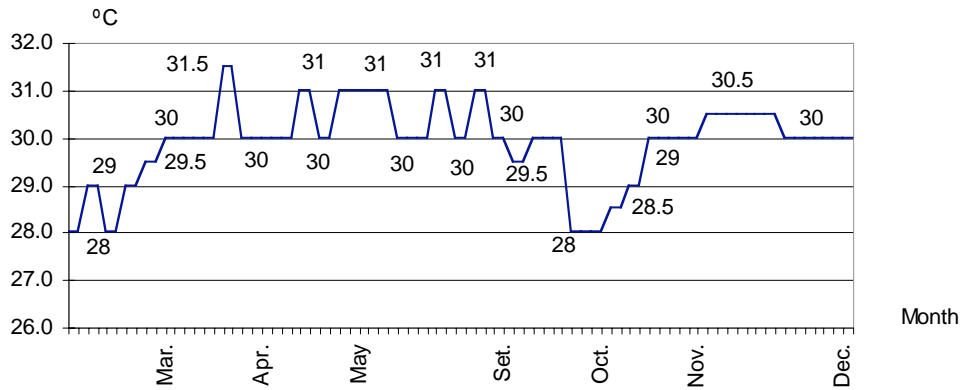


Fig. 2. Temperature in Punta Morales, Gulf of Nicoya, during 1997.

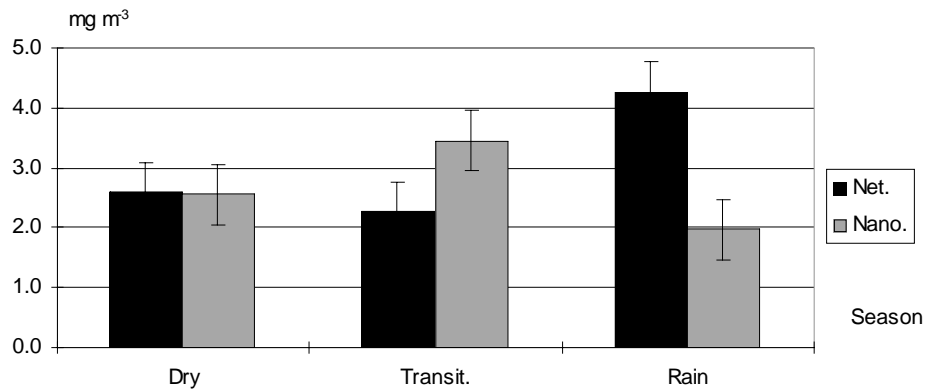


Fig. 3. Average chlorophyll *a* concentration (mg Chl *a*/m³) by phytoplankton size fraction during the different seasons study, Punta Morales, Gulf of Nicoya, 1997.

results from an increase in the biomass of the nanophytoplankton beginning in December, coinciding with an increase in the surface temperature. The increase in biomass may be the result of an increase in the growth rate at the optimal temperature for this size fraction (Goldman & Carpenter 1974). Lenz (1992) reported that small cells of phytoplankton, with a high surface to volume ratio, grow more rapidly at higher temperatures. These results, obtained during a El Niño year, suggest that the effect of temperature differences may produce episodic variation in the relative abundance and biomass of the

micro- and nanophytoplankton. Previous studies have indicated that phytoplankton communities change under the influence of factors such as temperature, the concentration of chemical species or the rate of assimilation of nutrients (Stolte 1996). Variation in the size fractions of phytoplankton may be explained as a consequence of the relative abundance of species of nitrogen in the water (Brugnoli *et al.* in prep.). In a more detailed analysis of the plankton communities at Punta Morales, Brugnoli & Morales (in this issue) report that both micro and nanophytoplankton were dominated by diatoms, with an important

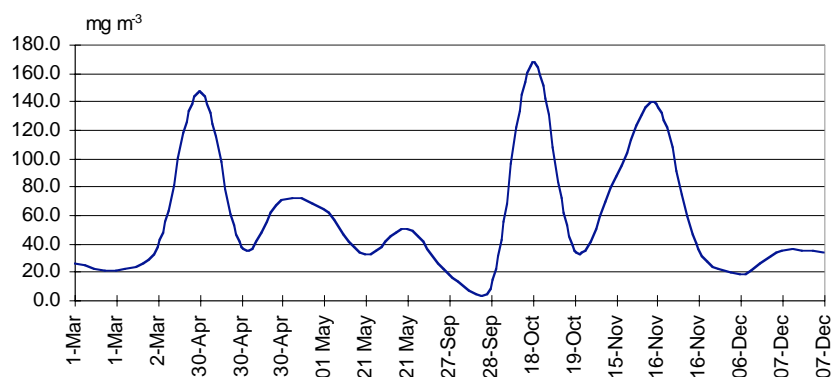


Fig. 4. Dry weight biomass (mg/m^3) of herbivorous copepods during the study, Punta Morales, Gulf of Nicoya, 1997.

contribution of small flagellates into the least functional group, where centric diatoms were the most abundant during both the wet season and the dry season, whereas during the transitional season centric diatoms, pennate diatoms and small flagellates were equally abundant. The significant differences observed in the biomass and species composition of the nanophytoplankton with the change in season suggest that this fraction responded differently to changes in environmental conditions during the period of study, changes that we associate with El Niño. According to Margalef (1997) phytoplankton cells may regulate their relative abundance, size and cell type in response to adverse environmental conditions.

It is probable that El Niño has less effect on secondary production in estuaries because the dominant species are adapted to the strong environmental changes that characterize estuaries. What have been observed are important changes in the biomass and community structure of the phytoplankton (Nienhuis 1986, Garati 1992 in Palomares-García & Gómez-Gutiérrez 1996) as observed in this study. It appears that the zooplankton at Punta Morales, especially the herbivorous copepodes, must be able to successfully assimilate the nanophytoplankton (cells less than $30\ \mu\text{m}$), the dominant size fraction of primary producers during the transition season (Fig. 2). It is common

that in estuarine zones a few species are numerically dominant in zooplankton communities (Kimmerer & McKinnon 1987). At Punta Morales, *A. lilljeborgii* constituted an average of 80% of the copepods emphasizing again the ecological success of this genus in tropical and temperate estuaries (Paffenhöffer & Stearns 1988).

In other regions, such as Magdalena Bay, during the El Niño of 1982-1983, significant changes in species dominance were observed. In these study, *A. lilljeborgii* and *A. tonsa* were the dominant species during the warm period and *P. parvus* was dominant during colder periods (Palomares-García & Gómez-Gutiérrez 1996). Nevertheless, these authors concluded that in general terms the seasonal succession of species was altered only by the presence of a few tropical species during the warmest period. El Niño of 1992-1993 brought about important changes in some copepod populations of the San Lorenzo channel, Gulf of California, where *Nannocalanus minor* was replaced by *Clausocalanus arcuicornis* and *Undinula vulgaris* and where the population of *Euchaeta marina* declined (Lavaniegos & González-Navarro 1999).

The genus *Acartia* maintains high levels of consumption in estuaries (Paffenhöffer & Stearns 1988). It has been shown that nauplii larvae of *A. tonsa* consume cells from 10 to 14

μm (Berggreen *et al.* 1988), which along with their euryhaline nature (Tester & Turner 1991), may explain the ability of this genus to remain dominant in estuaries. On the other hand, *P. parvus* ingests cells with a diameter of 12 μm most efficiently (Paffenhöffer 1984). Little is known about the pattern of feeding by Pseudodiaptomidae but it is probable that species of *Pseudodiaptomus* are similar to *Acartia* and *Paracalanus* given that *Pseudodiaptomus*

Rainy season

Sep. 27	Rising	10	7.61	0.89	37.30
		50	7.21	1.41	
	High	10	4.74	0.56	50.73
		50	2.50	1.96	
	Ebbing	10	5.36	1.26	15.71
		50	2.02	2.86	
Sep. 28	Low	10	4.52	0.61	100.5
		50	2.60	1.37	
	Rising	10	5.37	0.98	34.68
		50	2.06	1.65	
	Ebbing	10	3.90	0.79	20.72
		50	5.61	1.03	
Oct. 18	Ebbing	10	5.23	2.04	57.73
		50	4.78	2.05	143.8
	Rising	10	3.34	2.67	121.8
		50	2.49	2.60	
Oct. 19	Low	10	7.10	2.74	51.43
		50	5.09	2.86	
	High	10	1.12	1.12	86.15
		50	1.63	1.25	
Nov. 15	Low	10	5.20	2.89	44.60
		50	4.38	2.77	
	Rising	10	1.35	2.91	94.96
		50	0.39	4.77	
Nov. 16	Low	10	5.06	2.38	102.2
		50	4.90	1.96	
	Rising	10	5.76	2.89	29.76
		50	5.42	2.21	
	High	10	5.76	1.54	52.50
		50	5.50	1.40	

Transition season

Abril 30	High	10	2.58	3.23	215.8
		50	3.11	2.76	
	Low	10	6.11	3.40	53.80
		50	3.66	3.12	
	High	10	2.76	2.03	103.4
		50	1.12	2.06	
May 1	Rising	10	1.86	1.92	150.7
		50	1.38	2.08	
	Ebbing	10	3.79	1.64	53.06
		50	4.02	2.44	
	Rising	10	1.23	1.86	94.74
		50	1.32	1.74	
May 21	Low	10	1.03	3.82	46.07
		50	1.36	4.04	
	High	10	2.15	4.33	
		50	2.02	4.26	
	Ebbing	10	1.45	5.30	35.99
		50	1.00	4.10	
May 22	Low	10	1.10	4.40	52.93
		50	2.50	4.64	
	Rising	10	2.33	5.01	71.11
		50	1.63	4.98	
	Ebbing	10	2.33	3.69	70.85

also often abundant in estuaries (Walter 1986).

Overall, the opportunistic nature of this group can be emphasized (Kleppel 1993).

In other tropical areas, such as the Caribbean and the Gulf of Mexico, biomasses of copepods of 22.1 (Hopcroft *et al.* 1998), 26.6 (Hopkins 1977) and 32 mg/m³ dry weight (Newbery & Bartholomew 1976) have been observed, using a net with 200 µm mesh size. In earlier years (1994 and 1995) at a nearby station in the Gulf of Nicoya (Cortezas Islands) the average biomass of the total zooplankton in the size fraction 500 to 1000 µm was 18.2 and 22.69 mg/m³ respectively, with higher values during the dry season of both years (26.33 and 32.26 mg/m³ respectively) (Morales-Ramírez unpublished data). However, it can be seen that herbivorous copepod biomass values are higher than those reported for copepods in the Caribbean and for total zooplankton in earlier years at a nearby station in the Gulf of Nicoya.

Although it appears that the phenomenon of El Niño had little effect on the composition of the zooplankton, it is apparent that the principal effect has been at the level of the phytoplankton, affecting species composition and nutrient assimilation. These changes effected changes in the biomass of the zooplankton, principally in the herbivorous copepods which maintained a high level of herbivory during the periods when nanophytoplankton were dominant (Morales & Brugnoli, in prep.) With the arrival of more nutrients during the rainy season, owing to the increase in flow of fresh water and increased turbulence, the microphytoplankton fraction became dominant. Diatoms in particular are adapted to these conditions (Margalef 1978). On the other hand, important changes have been reported for the gelatinous zooplankton from Golfo Dulce, pacific coast of Costa Rica, where the composition, biomass and dominance of different species changed during the transition phase between rainy and dry season in 1997 and 1998 (Nowaczyk 1998, Morales-Ramírez & Nowaczyk, in prep.) and these changes were associated with El Niño 1997-1998.

It is important to understand the dynamics of the zooplankton, especially the copepods,

because of their importance to higher trophic levels, including fish larvae (Poulet & Williams 1991); ultimately the zooplankton populations dynamics have repercussions for the exploitation of commercial fish.

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RESUMEN

La influencia del fenómeno El Niño sobre la dinámica del plancton fue investigada durante 1997 en el estero de Punta Morales, Golfo de Nicoya, pacífico de Costa Rica. El estudio incluyó una época seca, de transición y lluviosa. El fitoplancton (fraccionado: microfitoplancton > 30µm, y nanofitoplancton) fue recolectado a dos profundidades de muestreo (50 y 10% incidencia de luz), con una botella Niskin de 5 L para la determinación de clorofila *a*. Temperatura, salinidad, oxígeno disuelto y profundidad del disco Secchi también fueron medidos. Arrastres horizontales de zooplancton fueron realizados con una red cónica de 0.49m de diámetro y 280 µm de poro, provista de un medidor de flujo. La temperatura superficial del agua tuvo un promedio de 29.9 ± 0.9° C, con valores máximos en abril (31.5°C) y mínimos en marzo y octubre (28.0°C). La concentración promedio de clorofila *a* (fitoplancton de red) fue de 3.1 ± 1.7 mg/m³, con un máximo en la época lluviosa y valores mínimos en la época de transición. Por su parte, la concentración promedio de clorofila *a* en el nanofitoplancton fue de 2.5 ± 1.2 mg/m³, con un máximo en la época de transición. Para ambas fracciones se observaron diferencias significativas entre la época de transición y la época lluviosa, además la biomasa nanofitopláncica mostró

también diferencias significativas entre las épocas seca y de transición ($p < 0.05$). En este último caso, las diferencias son atribuidas a la temperatura. Los copépodos herbívoros dominaron la abundancia y biomasa del zooplancton, con un máximo de biomasa de 167.3 en Octubre y un mínimo de 7.1 mg PS /m³ in Mayo. Estos valores de biomasa son más altos que aquellos encontrados en años anteriores en la misma zona y que aquellos informados para algunas zonas del Caribe. Parece ser que el mayor efecto del fenómeno El Niño 1997-1998 en la dinámica del plancton se produjo en el fitoplancton y cuyo efecto se comprobó en la biomasa y composición. Este es el primer intento para evaluar posibles impactos de El Niño en la dinámica del plancton en la costa del Pacífico de Centro América.

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