SEASONAL SIGNATURES IN THE PHYSICAL PROPERTIES OF A TROPICAL ESTUARY IN THE CENTRAL AMERICA PACIFIC

VARIACIONES ESTACIONALES EN LAS PROPIEDADES FÍSICAS DE UN ESTUARIO TROPICAL EN EL PACÍFICO DE AMÉRICA CENTRAL

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Resumen: Auspiciado por el Proyecto PREPAC (Plan Regional de Pesca y Acuicultura Continental), se realizó un levantamiento hidrográfico en 10 estaciones, en el Estero de Jaltepeque, en el litoral pacífico de El Salvador. Los muestreos mensuales se extendieron de setiembre del 2005 a marzo del 2006 y se determinó la temperatura, salinidad, oxígeno disuelto y turbidez. La temperatura superficial osciló entre los 27°C y 30.6°C, con variaciones temporales extremas del orden de los 3°C. Los valores más bajos se ubican al final y principio de año (octubre-febrero). La salinidad superficial presentó un marcado ciclo estacional, con valores en la zona central superiores a 30 o/oo durante los meses secos, mientras que en la época lluviosa (setiembre-octubre) estuvo entre 2 o/oo y 22 o/oo. Los mayores valores del oxígeno superficial y turbidez se localizaron entre octubre y diciembre y los mínimos en marzo. En los meses secos (diciembre-marzo) las aguas presentaron niveles bajos de turbidez en todo el estero. Los campos verticales termohalinos mostraron un estero estratificado durante la época lluviosa. Esta estratificación desaparece en época seca, y el estero se comporta como un estuario muy bien mezclado. El oxígeno disuelto no mostró una estratificación vertical significativa en ninguna de las dos épocas.

Palabras claves: estuario tropical, hidrografía, Jaltepeque, El Salvador.

Abstract: A hydrographic survey was carried out in the Jaltepeque estuary in the Pacific coast of El Salvador. From September 2005 to March 2006, 10 sampling stations were occupied to measure temperature, salinity, dissolved oxygen and turbidity. Surface temperatures between 27 and 30.6 °C were observed during the survey, with extreme temporal variations close to 3°C. Minimum temperatures occur in October and February. Surface salinity shows a clear seasonal cycle, with values greater than 30 o/oo during the dry months over virtually the whole body of water, while in the rainy season (September-October), salinity ranges from 2 o/oo to 22 o/oo. Maximum surface oxygen and turbidity were observed from October to December and minimum values in March. During the dry months (December-March), turbidity levels are low throughout the estuary. The vertical termohaline fields show a stratified estuary during the rainy season. This stratification breaks down during the dry season and the system behaves as well-mixed estuary. Dissolved oxygen did not show significant vertical stratification during the survey.

Key words: tropical estuary, hydrography, Jaltepeque, El Salvador.

Introduction

Estuaries are shallow, semi enclosed water bodies with changing volumes in response to changing local hydrologic and climatologic conditions. Temperature and salinity are variable and the estuary's bed is predominantly muddy with irregular topography and high turbidity. The flora and fauna, of both marine, fresh water and land origins, show many evolutionary adaptations to environmental pressures. In these natural conditions the estuarine ecosystem functions on the base of a balanced matrix of biological interrelations. Such natural balance is vulnerable to human activities. The complexity of the biological-environmental matrix, the alternative pathways for the energy flux and the biological adaptations of the organisms provide the system with ecological stability features within a physically variable environment which is fragile to man-induced changes (Brenes & Castillo, 1999).

These coastal systems undergo a gradual mixing between sea-water and fresh-water from land drainage. Such mixing promotes the exchange of sediments, nutrients, biological organisms, and the existence of a diversity of environments and habitats which are important spawning zones for a variety of marine coastal species of fish and prawn. Sometimes estuaries host important ports for industrial, artisanal and recreational navigation. Mid-latitude estuaries have been the subject of a large number of studies, whereas small tropical estuaries of developing countries are much less studied (Palter, León & Ballestero, 2007).

The Jaltepeque estuary in the Pacific coast of El Salvador, is located between the Departamentos La Paz and San Vicente, (13°25´ °N – 13°34´°N, 89°00´ °W – 88°05´ °W). Its length and width are 17 km and 1.5 km respectively and comprises a network of thin channels with a total length of 15 km containing several mangrove islands. Mean depth is 2.5 m and the maximum, located at the mouth, is 12 m (PREPAC, 2006).

The rainy season, characterised by SW winds, runs from May to November. Dry weather prevails between November and April with NE Trade winds from the Caribbean and events of intense northerly wind. Semidiurnal tides, dominated by M2, N2 and S2 components, have a mean tidal range of 2.5 m (Valle-Levinston & Bosley, 2003).

The second most extensive mangrove vegetation in the country, after the Bahía de Jiquilisco (Yanes *et al.,* 1991) mangrove system, is located in this estuary. However, knowledge about its floristic composition is limited to a small number of studies. According to Vasquez (2003) the Jaltepeque estuary experienced an important reduction of its mangrove zones.

A total of 2158 fishermen live in the estuary distributed in fifteen communities. The annual catch is estimated in 316 290.24 kg of fish product extracted exclusively in the estuary. This ecosystem, used for leisure, artisanal and sport fishing and for aquaculture, has great potential for research, education and tourism activities due to its biological diversity and scenic beauty (PREPAC, 2006).

Regional differences between coastal zones are determined by their morphologic, oceanographic, climatic and biological characteristics. However, most regions share the common feature that their occupation, their use and the ownership of their renewable and non-renewable resources took place without any planning and no knowledge of their local dynamics and the ecosystem tolerance to human intervention. Environmental fluctuations due to anthropogenic impact in these systems are particularly important and complex due to the dual character of the marine and fresh-water influences.

Knowledge about the hydrographic conditions of the estuary derived from the results of this study could be of great value for the inhabitants of the zone. The goal of this work is to generate information useful to support the evaluation and management of the resources of this ecosystem.

Methodology

A hydrographic survey of the Jaltepeque estuary took place between September 2005 and March 2006. Ten sampling stations were occupied at high water with monthly frequency, seven of them along the central axis (figure 1). A HYDROLAB MINISONDE SURVEYOR4 was used to measure temperature (±0.01°C), dissolved oxygen (± 0.01 mg/L), salinity (± 0.2) and turbidity (NTU ± 1.5 %). Measurements were obtained every 1 m from the surface to the bottom at each sampling station. Only the central axis stations (stations 2 to 8) were used for the hydrographic characterization.

Results and Discussion

Although water temperature remained high throughout the whole survey, two different thermal regimes were identified. The highest temperatures were observed in September and March, whereas relatively lower temperatures occurred at the end and the beginning of the year (Figure 2A). This pattern is consistent with the annual thermal cycle of the adjacent sea surface temperature (SST), where values around 28 °C occur from October through December, and values around 30 °C occur between April and September (Fiedler & Talley, 2006). Similar results were obtained by Brenes *et al.* (2001) and Lizano and Vargas (1994) for the inner part of the Gulf of Nicoya in the Costa Rica Pacific coast. These values characterize tropical regions where thermal stability prevails all year round.

The lowest temperatures observed in the last and first parts of the year match the period of intensified wind and corresponding enhancement of vertical mixing processes in the water column. In March the water temperature augments reaching a maximum of 30.6 °C. This increased temperature probably persists until September closing the annual cycle of surface temperature.

Near horizontal isotherms show a negligible spatial gradient and very uniform temperature. The lowest temperatures were generally located at station 6, near the mouth of the estuary.

Strong seasonality in tropical precipitation regimes dominate climatic variability in these regions and has a direct impact on several physical properties of the waters of estuarine systems (D'Avanzo & Kremer, 1996).

Surface salinity distribution in the Jaltepeque estuary (Figure 2B) is primarily influenced by the influx of sea water across the mouth (station 6) and by the input of fresh water from the Lempa river (station 8). Salinity exhibits a clear seasonal pattern with low values in the rainy months and high values in the dry months. During the dry season (November-March) salinity is higher than 30 o/oo in the estuary. Fresh water run-off becomes the dominant mechanism governing the distribution of salinity in almost the whole water body during the rainy season (September-October). A large fraction of the estuary acquires fresh-water characteristics in this period, particularly in regions located far away from the mouth (stations 2, 7 and 8).The range of variation of salinity in the estuary observed in this survey was 2 o/oo to 34 o/oo.

In the inner part of the estuary, near the mouth of the Lempa river (stations 7 and 8), strong spatial gradients of salinity were observed during the whole survey as a result of the convergence of salt-water and fresh-water, a feature which was not observed in the opposite end of the estuary (stations 2 and 3). Therefore, two different zones are identified starting from the mouth: toward the mouth of the Lempa river there is an area characterized by a strong horizontal gradient of salinity (3.62 km^{-1})with an important input of fresh-water during the whole survey, and toward the left there is a zone characterized by higher salinity where, during the dry months, the horizontal gradient of salinity is weak.

The Jaltepeque estuary is subjected to tidal action and seasonal atmospheric forcing with contrasting wind and precipitation regimes. Figure 3 shows one year of monthly precipitation from March 2005 through April 2006 near the study area. In 2005 the rainy season was more intense than the long term mean due in part to the effect of the cold phase of the ENOS phenomena, known as La Niña, on the Central America Isthmus. One of the most intense cyclonic seasons of the last decades in the Caribbean, Atlantic Ocean and Gulf of Mexico was recorded in 2005. Under such conditions, precipitation and river discharge increased while salinity diminished substantially in the Pacific coast. For instance, as a result of the storm Stan, cumulative precipitation in October 2005 was well above the long-term mean and river discharge doubled historic values (SNET 2006, a).

The presence of low salinity water and the strong surface salinity gradients observed in stations 7 and 8 even during the dry season (November to March) are related to the fact that, from November 2005 to April 2006, river volumes remained close to normal, while in the rivers of the west and central coastal zone, discharges were above normal or the historical mean. Unlike other years when the decrease in the discharge from rivers is about 70 %, discharge diminution during the dry season 2005-2006 was only 40 % (SNET 2006, b). As a consequence, fresh water input from the Río Lempa was not negligible and sea water dilution in the estuary persisted during the dry season 2005-2006.

Maximum levels of dissolved oxygen were measured between September and December 2005. The east end of the estuary in particular (stations 6 to 8) shows dissolved oxygen levels above 6 mg/L (Figure 2C). Sea water entering the system through the mouth (station 6) and fresh water input from the Lempa river have a significant influence on the salinity distribution pattern in this area of the estuary.

In November dissolved oxygen decreased in all stations but station 6, very likely as a consequence of organic matter degradation following strong riverine discharge during the rainy season. Minimum oxygen levels were measured in January and February (between 4 and 5 mg/L), when the spatial distribution was quite uniform compared to the other months.

The west part of the estuary (stations 2 to 4) shows the lowest levels of dissolved oxygen. This is the shallowest part of the system, where temperatures are higher than in the rest of the water body (Figure 2A). Turbulent mixing may be weak in this area, relatively isolated from the main streams of the system.

Surface turbidity shows maximum values between October and December with 20 NTU at the western end of the estuary and 160 NTU at the eastern end, with a maximum centred in November (figure 2-d), where water from the Río Lempa enters the system. From December to January, when fresh water run-off decreases, turbidity considerably decreases (10 NTU). The observed high turbidity during the rainy season indicates a significative input of suspended solids to the estuary.

Turbidity and dissolved oxygen are related to the magnitude of the fresh water and organic matter fluxes in the Lempa river. High turbidity in the eastern end of the estuary (stations 6 to 8) coincide with increased surface oxygen contents, probably related to increased nutrients concentrations, increased primary production levels and increased turbulent mixing in the surface layer.

Vertical distributions of the variables during the survey are discussed using only October and February as the months representative of the rainy and dry seasons respectively (Figure 4).

Figure 5 shows monthly wind streamlines for October 2005 and February 2006 at the 850 hPa level. Cyclonic conditions are observed in October 2005, when the Caribbean was crossed by three hurricanes: Stan (1-5 October), Wilma (15-25 October) and Beta (26-31 de October), generating anomalous winds over the study zone.

The vertical distribution of temperature in October (Figure 4A) shows significative thermal stratification, with a surface to bottom difference of 1.5 °C between stations 3 and 5. Well mixed conditions prevail in February as shown by the vertical isotherms in figure 4-b, when wind-induced vertical mixing can break the stratification. No significant differences in surface temperature were observed between October and February.

Salinity fields show the stratification in October more clearly (Figure 4C), with differences up to 12 o/oo between the bed of the estuary and the surface in station 5. In the inner estuary (stations 2 and 7), incoming fresh water produces low salinity conditions in nearly the whole water column, while sea water enters the estuary at the bottom layers in station 6. The shape of the isohalines (Figure 4C) shows that salt transport is more important in the west part of the estuary (stations 2 to 5), while in the opposite end the Lempa river flux limits such transport and the isohalines bend in the opposite direction producing a well defined lower salinity front, mainly evident in the layer above 3 m. A frontal zone is defined between stations 6 and 8, originated by the presence of a lower salinity water mass which pushes from the eastern sector on a saltier water mass in the central part of the estuary near the mouth.

Salinities lower than 20 o/oo are present, from the estuary bed to the surface, in a large part of the water body in October. The strongest vertical gradients occupy the inner estuary, where a salt-wedge sits on the bottom and significant mixing takes place in the upper layers, probably induced by tidal action. Station 5 represents the central part of the estuary, where salinity varies between 16 o/oo and 30 o/oo showing strong stratification.

In October and February surface salinity in the outer shelf is generally lower than 32 o/oo (Fiedler & Talley, 2006), so run-off and mixing result in salinities under 29 o/oo in the mouth of the estuary.

Stratification breaks down when the wind intensity increases in February (figure 5) and the estuary becomes well-mixed (Figure 4D). Salinities are consistently higher than during the rainy season, with values above 22 o/oo in all stations. Salinity increases markedly in the inner parts of the system due to low river discharge. Maximum values occur in the mouth (station 6) and minimum salinities occur at both ends of the estuary (Figures 4C and 4D).

During the rainy season the Jaltepeque estuary presents a mesohaline (salinities between 5 o/oo and 18 o/oo) pattern in its interior extremes, while in the central zone polihaline (salinities between 18 and 30) prevail (Figure 4C). This separation does not occur in the dry season, when polihaline conditions prevail in the whole water body (Figure 4D).The importance of precipitation on this ecosystem is clearly shown by the remarkable difference in the vertical distributions of salinity between the dry and rainy seasons.

Dissolved oxygen does not show vertical stratification in either month (Figures 4E and 4F), but increased concentrations are found in the rainy season. In February dissolved oxygen concentrations were lower than5 mg/L, whereas in October they were between 5 and 7 mg/L. These increased values can be linked to increased turbulence due to large river discharge and to a reduced residence time for the estuary. Additionally, increased primary production during the rainy season related to increased nutrients concentrations (PREPAC, 2006) could contribute to augment the levels of oxygen.

Water column turbidity in October is much larger than in February (Figures 4G and 4H). The input of solids, sediments and suspended particles by river discharge augment the turbidity values above 125 NUT in October. The eastern end of the estuary (stations 7 and 8) shows maximum values due to the discharge of the Lempa river. Very high run-off due to the storm Stan in October 2005 is reflected in the high turbidity measured values, between 15 and 125 NUT, while in February measured turbidity values were in the range 5-29 NUT.

Conclusions

The results of this study contribute to the understanding of natural cycles in tropical estuarine ecosystems subjected to seasonal atmospheric forcing of wind and precipitation. The Jaltepeque estuary showed seasonal, well defined structures of salinity and turbidity associated to meteorological conditions identified as dry and rainy periods. The variation and distribution of salinity during the dry season revealed the substantial influence of sea water in the system. Horizontal salinity gradients were strong in the area of influence of the Lempa river, in the western end of the estuary, especially during the rainy season. Surface salinity is above 30 o/oo during the dry months in almost the whole body of water, whereas in the rainy season (September-October) its value varies between 2 o/oo and 22 o/oo. Regarding surface turbidity maximum values occurred in October and November near the mouth of the Lempa river. In the dry months (December-March) much more clear water occupies the whole estuary.

Surface temperature during the survey ranged between 27°C and 30.6°C, with extreme temporal fluctuations of about 3°C. Minimum temperatures occurred between October and February. Maximum surface dissolved oxygen occurred between October and December and the minimum levels occurred in March, consistent with increased turbulence during the rainy season and increased primary production in the first case, and decreased fresh water run-off and increased temperature in the second.

Thermohaline vertical distributions showed a stratified estuary during the rainy season. The strongest vertical salinity gradients occur in the inner estuary where sea water meets river water. This stratification breaks down in the dry season when the system becomes a well mixed estuary. Dissolved oxygen does not show vertical stratification in either period, but its concentrations are much greater in the rainy season. Water column turbidity is much greater during the rainy season and, again, greater turbidity occurs near the Lempa river mouth during the whole survey.

The findings above are the first step to understand the seasonal structures of salinity and turbidity fields in the Jaltepeque estuary in response to wind forcing and fresh water input. Further research is required to understand the variability of this ecosystem in other relevant temporal and spatial scales.

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Figures List

Figure1. Posición de las estaciones de muestreo.

Figure 1. Hydrographic stations position.

Figure 2. Variación espacio-temporal de la temperatura superficial (°C)(A), salinidad (B),oxígeno disuelto (mg/L)(C) y turbidez (NUT)(D) en el transepto central en el Estero de Jaltepeque.

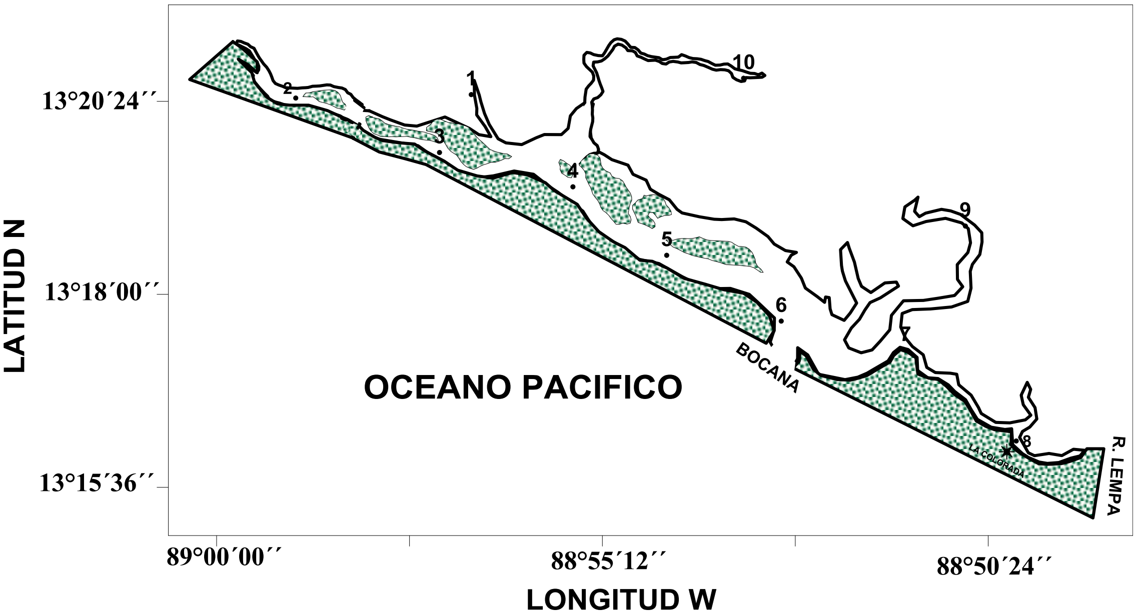
Figure 2. Space-temporary variation of the surface temperature (°C)(A), salinity (B), dissolved oxygen (mg/L)(C) and turbity (NUT)(D) along the central axis in Jaltepeque estuary.

Figura 3. Precipitación mensual (mm) durante el 2005 y parte del 2006 en la Estación Meteorológica de Santa Cruz Porrillo (SNET, 2006).

Figure 3. Monthly precipitation at the station Santa Cruz Portillo for the period 2005-2006 (SNET, 2006).

Figura 4. Distribuciones verticales de temperatura (°C) en octubre (A), febrero (B), salinidad en octubre (C), febrero (D), oxígeno disuelto (mg/L) en octubre (E), febrero (F), turbidez (NUT) en octubre (G) y febrero (H).

Figure 4. Vertical distributions of temperature (°C) in October (A), February (B), salinity in October (C), February (D), dissolved oxygen (mg/L) in October (E), February (F), turbity (NUT) in October (G) and February (H).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13°15´36´´
LATITUD N
89°00´00´´
88°55´12´´
88°50´24´´
LONGITUD W
OCEANO PACIFICO
BOCANA
LA COLORADA
R. LEMPA
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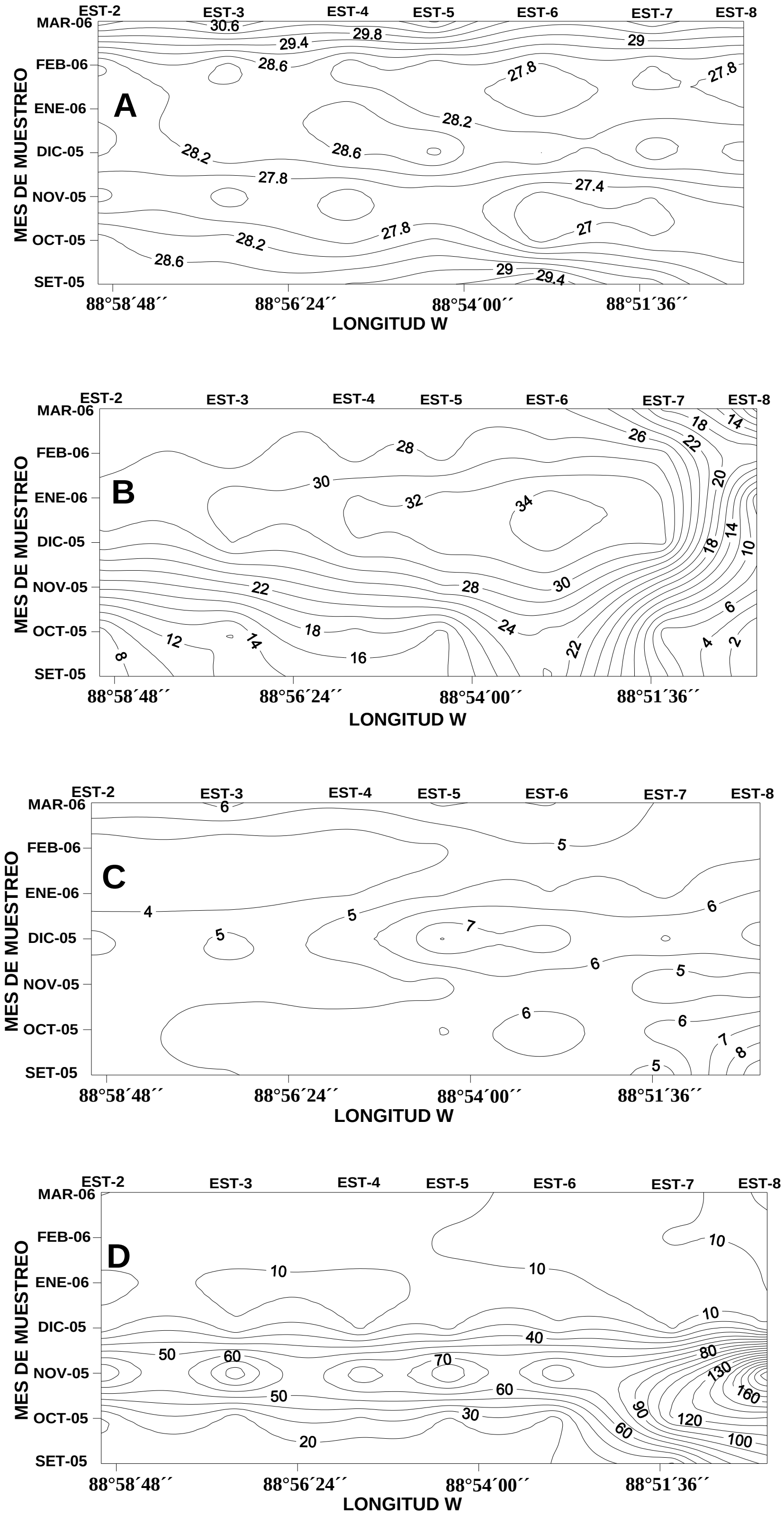
Figura 1.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B
C
D
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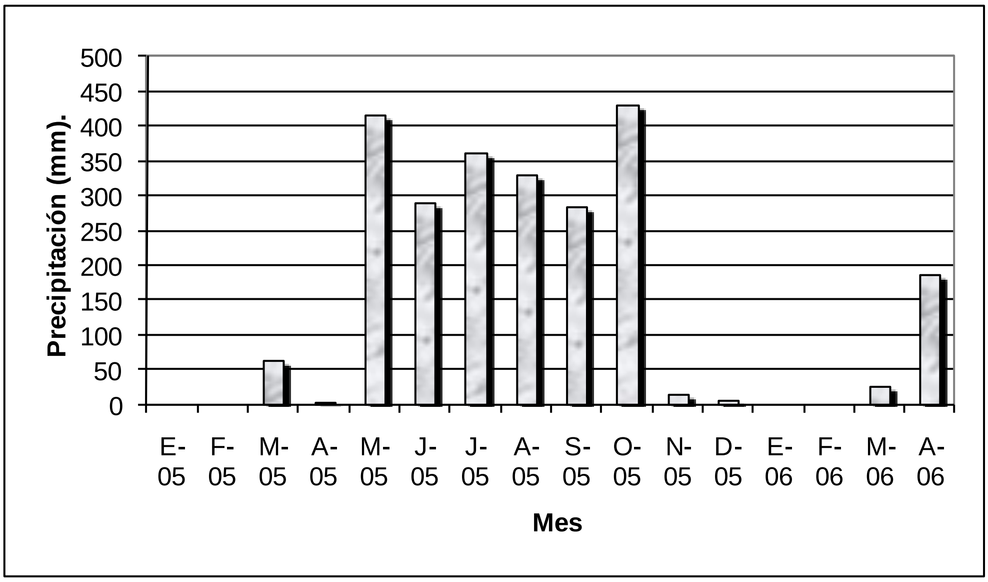
EST-3
EST-4
EST-5
EST-6
EST-7
EST-8
MAR-06
FEB-06
ENE-06
DIC-05
NOV-05
OCT-05
SET-05
MES DE MUESTREO
88°58´48´´
88°56´24´´
88°54´00´´
88°51´36´´
LONGITUD W

Figura 2.


Precipitación (mm).
500
450
400
350
300
250
200
150
100
50
0
E-05
F-05
M-05
A-05
M-05
J-05
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A-05
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O-05
N-05
D-05
E-06
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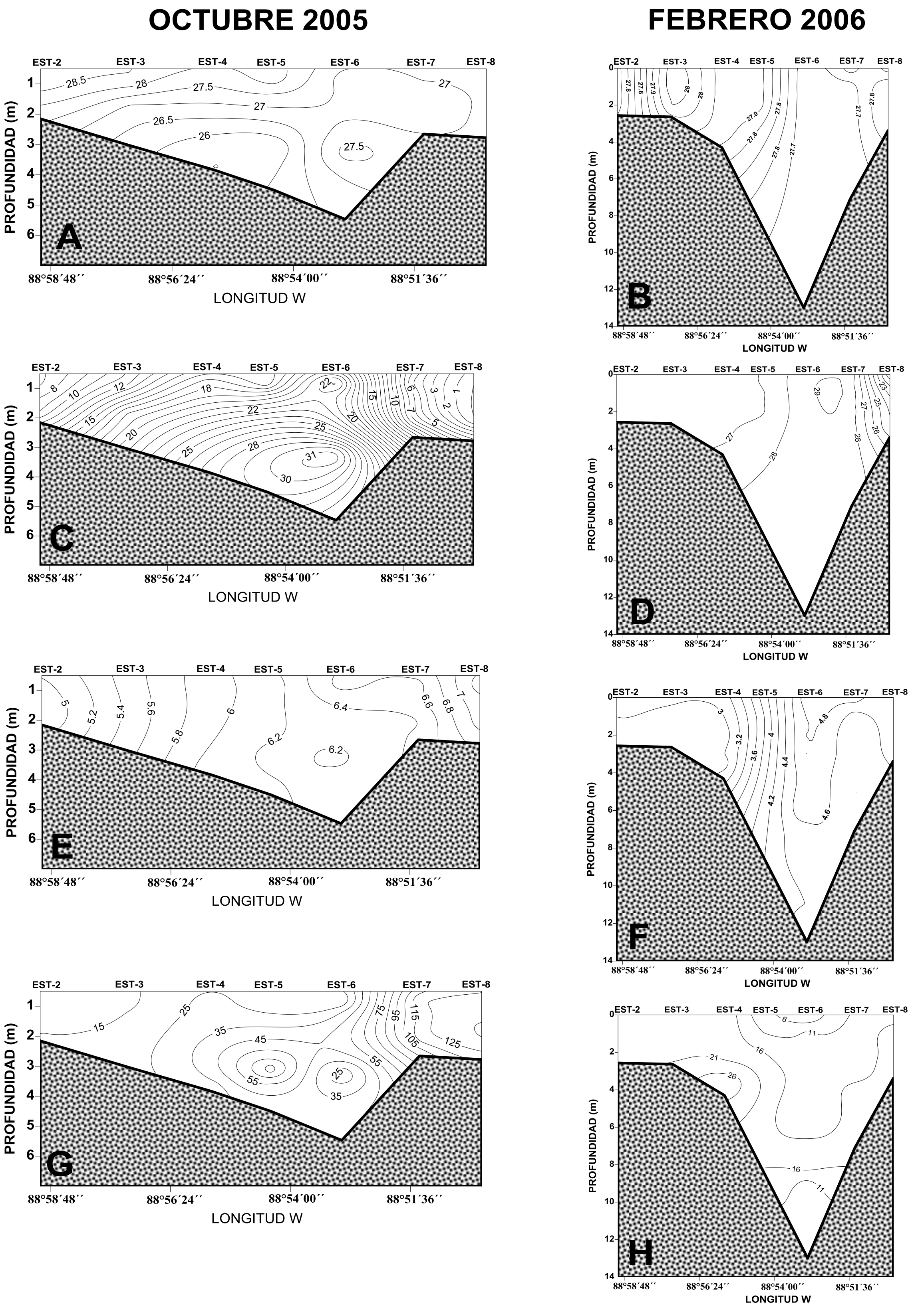
A-06
Mes

Figura 3


OCTUBRE 2005
FEBRERO 2006
EST-2
EST-3
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EST-5
EST-6
EST-7
EST-8
PROFUNDIDAD (m)
LONGITUD W
88°58´48´´
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A
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G
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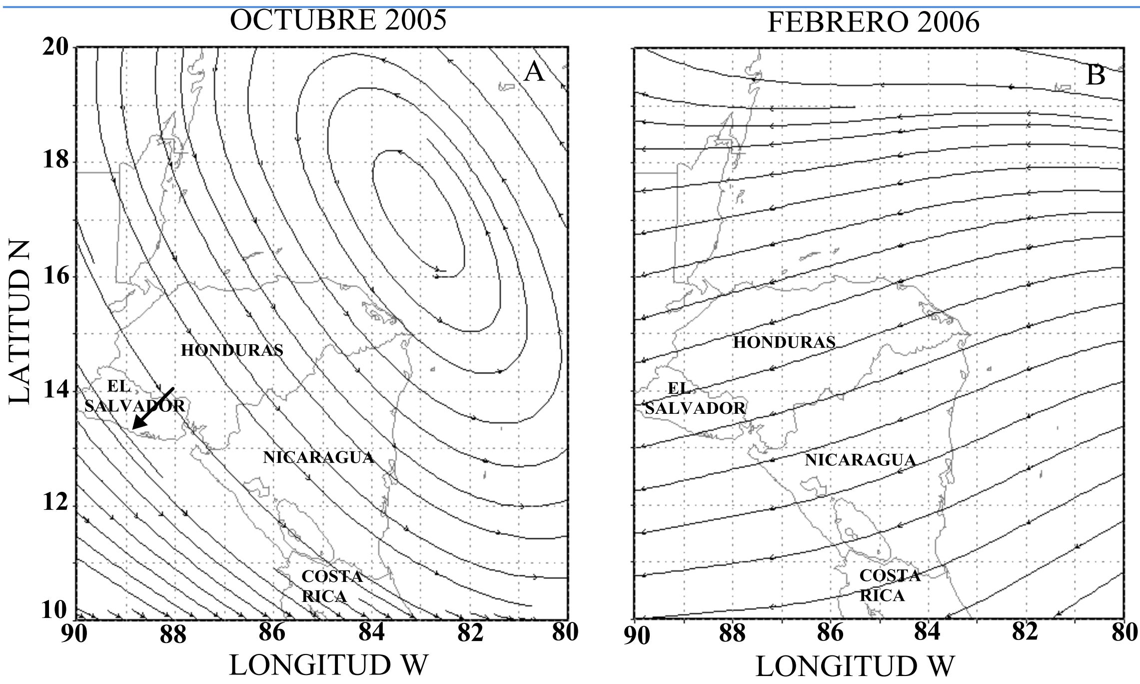
Figura 4.


OCTUBRE 2005
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LONGITUD W
HONDURAS
EL SALVADOR
NICARAGUA
COSTA RICA
HONDURAS
EL SALVADOR
NICARAGUA
COSTA RICA
20
18
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14
12
10
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Figura 5.