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Source: Journal of Coastal Research, 34(1) : 193-201

Published By: Coastal Education and Research Foundation

URL: https://doi.org/10.2112/JCOASTRES-D-16-00114.1

Journal of Coastal Research	34	1	193–201	Coconut Creek, Florida	January 2018

Redefining the Seasons in the Términos Lagoon Region of Southeastern México: May Is a Transition Month, Not a Dry Month

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ABSTRACT

Guerra-Santos, J.J. and Kahl, J.D.W., 2018. Redefining the seasons in the Términos Lagoon region of southeastern México: May is a transition month, not a dry month. *Journal of Coastal Research,* 34(1), 193–201. Coconut Creek (Florida), ISSN 0749-0208.

The Términos Lagoon is the largest estuary in Mexico, with numerous important animal and plant interrelationships. Its dominant feature is the largest mangrove surface in Latin America. A Natural Protected Area under Mexican law as well as an internationally recognized Ramsar site, this unique ecosystem is a frequent location for research projects concerning marine, wetlands, and terrestrial ecosystems. Located in the southern Gulf of Mexico and characterized by a tropical climate, the primary characteristic determining the region's meteorological seasons is the annual variation in rainfall. In 1982, an oft-cited article was published that defined the seasons as dry (February–May), wet (June–September), and an overlapping season of "nortes" or winter storms (October–March). Here evidence is presented, on the basis of an analysis of diverse meteorological parameters including 220 station-years of rainfall observations in the region, that May should be considered a transitional month, not part of the dry season. Because sampling and analysis protocols are often based on the definition of meteorological seasons, this result has implications for a wide range of environmental science research in the Términos Lagoon region.

ADDITIONAL INDEX WORDS: *Climate seasons, wet season, dry season, Laguna de Términos, Candelaria, Carmen, Palizada, Chumpán, Campeche.*

INTRODUCTION

The Términos Lagoon in southeastern Mexico (18°40′ N, 91°45′ W) is Mexico's largest and most important lagoon–estuary ecosystem (Figure 1). The lagoon is recognized as a Flora and Fauna Protected Area by the Mexican government (DOF, 1994) and is a Ramsar site (a wetland of international importance) due to its importance as a refuge of waterfowl (RAMSAR, 1971). Activities in the region are regulated by federal law (INE, 1997).

The Términos Lagoon, along with Laguna Madre in the state of Tamaulipas, is the largest coastal lagoon in the Gulf of Mexico. The surface area of the Términos Lagoon region, including surrounding rivers, estuaries, inlets, swamps, and rain forests, is 7.05×10^9 m^2, representing 17% of the land area of the state of Campeche. Moreover, the Términos Lagoon is located in a zone where a significant portion of Mexico's infrastructure for oil extraction and production is located. Approximately 1.27×10^9 m^2 are covered by mangroves, making Términos Lagoon the largest mangrove forest in Latin America, with an annual production of over 6.35×10^8 kg of organic matter (RAMSAR, 1971).

In 1982, Yañez-Arancibia and Day (1982) made the following observations about the climate of the Términos Lagoon region:

> There are three "seasons" in this region. From June until the end of September, there are almost daily afternoon and evening showers. From October into March is the season of "nortes" or winter storms. These storms are generally strongest and associated with rains during November, December and January. February through May is the dry season.

The seasonal definition provided by Yañez-Arancibia and Day (1982) has had a very large impact on subsequent studies. To date, over 100 refereed journal articles have cited this paper. Numerous studies of various aspects of flora, fauna, and earth sciences in the Términos Lagoon region reported experimental designs based on the seasons proposed by Yañez-Arancibia and Day (1982) (Table 1). These design considerations include both sampling (*i.e.* "*N*" samples collected during each season) and analysis (stratification of results by season) protocols.

This paper presents evidence that the definition of meteorological seasons in the Términos Lagoon region requires an adjustment: May is a transition month and should not be considered part of the dry season. This adjustment has implications for the timing and interpretation of a wide range of environmental studies in the region. Some seasonally-varying attributes of wildlife biology, such as migration and reproductive behavior patterns, are linked to the onset of the wet (rainy) season. Interseasonal comparisons of environmental factors such as nutrient fluxes and the distribution of submerged vegetation, or cross-species comparisons of seasonal behaviors such as feeding habits and habitat construction, are

DOI: 10.2112/JCOASTRES-D-16-00114.1 received 16 June 2016; accepted in revision 1 February 2017; corrected proofs received 12 March 2017; published pre-print online 25 August 2017.
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Table 1. *Examples of studies in the Términos Lagoon area with design considerations based on the meteorological seasons defined by Yañez-Arancibia and Day (1982).*

Research Area	Reference
Fish	
Eugerres plumieri	Aguirre-León and Díaz-Ruiz, 2000
Diapterus rhombeus	Aguirre-León and Díaz-Ruiz, 2006
Cathorops melanopus	Ayala-Pérez *et al*., 2008
Strombus pugilis	Ariste-Zelisse *et al*., 2010
Fish trophic chains	Guevara-Carrió *et al*., 2007
Fish parasites	Santana-Pineros, Pech, and Vidal-Martínez, 2012
Fish abundance	Ayala-Pérez *et al*., 2012
Fish Behavior	Sirot *et al*., 2015
Gastropods	Rodríguez, 2010
Crabs	Mascaró *et al*., 2007
Oysters	Gold-Bouchot *et al*., 2007
	Gullian and Aguirre-Macedo, 2009
Shrimp	Del Río-Rodríguez *et al*., 2013
Sponges	Ávila, Ávila-García, and Cruz-Barraza, 2015
Seagrass	Ávila, Yáñez, and Vázquez-Maldonado, 2015
Phytobenthos	Ortega, 1995
Diatoms	Licea *et al*., 2011
Lizards	Hernández-Gallegos *et al*., 2015
Land, Water, Forestry	
Trace metals	Rosales-Hoz *et al*., 1994
Cover changes	Soto-Galera, Piera, and López, 2010
Litterfall	Coronado-Molina *et al*., 2012
Tidal dynamics	Contreras-RuizEsparza, Douillet, and Zavala-Hidalgo, 2014
Nutrient fluxes	Ruiz-Marín *et al*., 2014
Hydrological variations	Medina-Gómez, Villalobos-Zapata, and Herrera-Silveira, 2015
Bacteria	Ruiz-Marín *et al*., 2013

among the many issues that could be affected by an adjustment of the seasonal definition.

METHODS

Historical measurements for four meteorological stations in the Términos Lagoon region (Figure 1) were obtained from the Mexican Servicio Meteorológico Nacional. These data were used to examine the daily, monthly, and annual variation of rainfall and other parameters in the Términos Lagoon region. Details of the sites and meteorological data presented in this paper are shown in Table 2.

The prevalent climate types at the meteorological stations utilized are *A*w: tropical wet and dry (savanna) and *A*m: tropical monsoon (García, 2004; Griffiths, 1985), and include urban, wetland (including mangrove, tular, and popal), forest, and grassland environments. A total of 220 station-years of meteorological observations was obtained, with at least 30 years of observations for each station. Data processing procedures following Livneh *et al*. (2015) ensured the quality and completeness of the precipitation records. Additional information on the Mexican precipitation data has been provided by Zhu and Lettenmaier (2007). The station data were supplemented with daily values of insolation (incoming solar radiation) provided by the U.S. National Aeronautics and Space Administration, and gridded wind and temperature fields provided by the National Centers for Environmental Prediction/National Center for Atmospheric Research reanalysis system (Saha *et al*., 2006). Precipitation, evaporation, and insolation measured during different months were compared by generating large numbers ($N = 100,000$) of bootstrapped distributions (Efron and Tibshirani, 1993), with differences statistically evaluated using the signs test (Mendenhall, Wackerly, and Scheaffer, 1989).

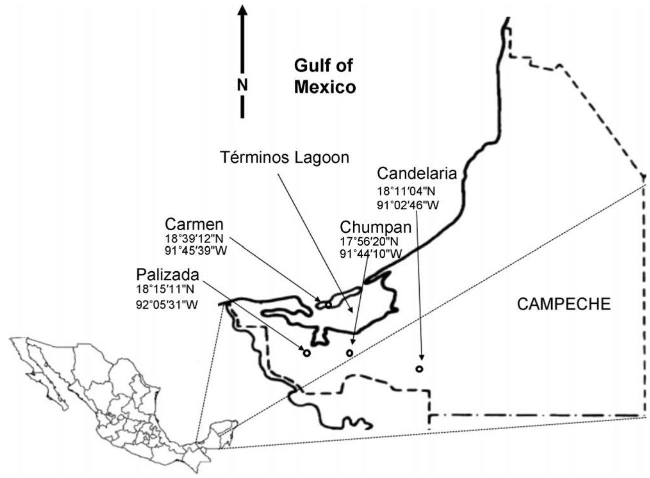

Figure 1. Map of the Términos Lagoon region and the locations for which historical precipitation data were obtained.

RESULTS

Precipitation climatologies for sites within the Términos Lagoon region are quite homogeneous (Figure 2). The monthly variation in mean, median, interquartile range, and extreme rainfall values is similar at all sites, including those closest (Carmen) and farthest (Candelaria) from the Términos Lagoon. Between 30 and 62 years of monthly rainfall data were analyzed for each site.

Yañez-Arancibia and Day (1982) define the dry season as February–May. However, the precipitation climatology shows

Table 2. *Meteorological data and station details*.

Station	Latitude N	Longitude W	Altitude (m above sea level)	Period of Record (Monthly; *Daily)	Site Description
Candelaria	18°11′4″	91°2′46″	40	1950–2012	Popal, tular, rain forest (selva baja y mediana perennifolia)
Carmen	18°39′12″	91°45′39″	5	1951–2012	Urban, mangrove, popal, tular, rain forest (selva mediana perennifolia)
Palizada	18°15′11″	92°5′31″	4	1958–2012 1953–2012*	Popal, tular, grasslands
Chumpan	17°56′20″	91°44′10″	10	1978–2012	Mangrove, popal, tular, grasslands, rain forest (selva mediana perennifolia)

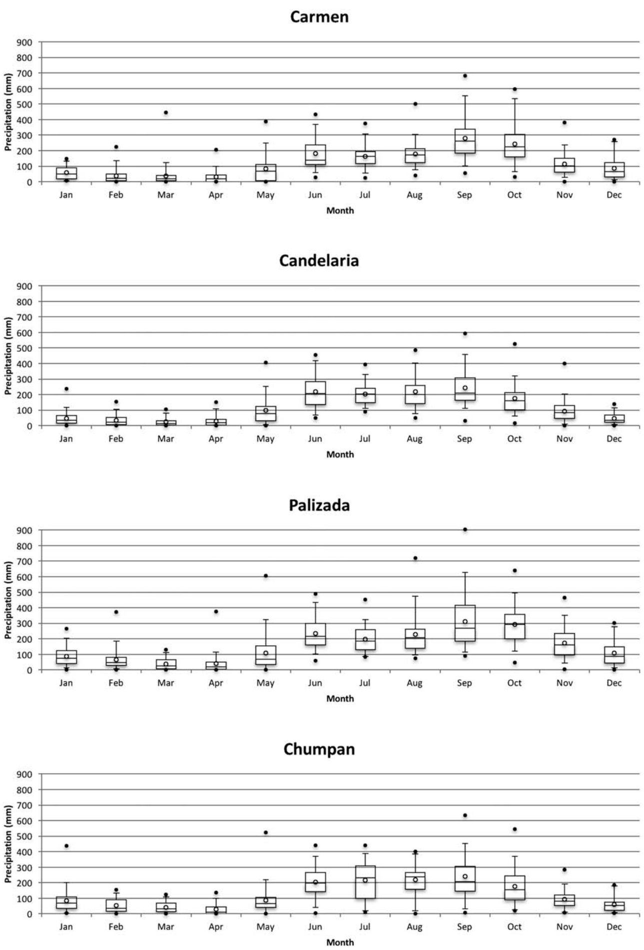

Figure 2. Box plots for monthly precipitation totals at four locations within the Términos Lagoon region. The lower and upper boundaries of each box show the 25th and 75th percentiles; the lower and upper "whiskers" identify the 5th and 95th percentiles; the horizontal line within the box denotes the median; open circles indicate the mean; and closed circles denote the minimum and maximum values for each month.

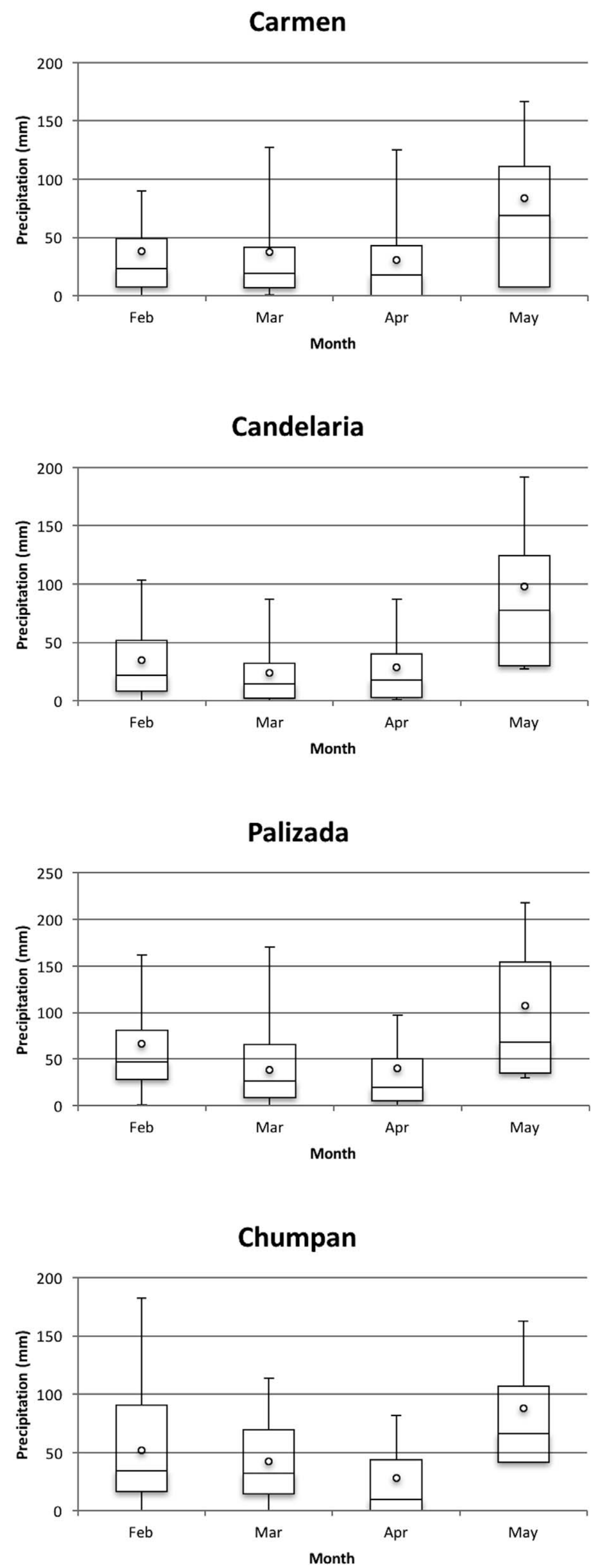

Figure 3. Zoomed-in view of monthly precipitation box plots during February through May.

that both the quantity and variability of May rainfall is substantially larger than that of February, March, and April (Figure 3). Median May rainfall totals range from 66 to 78 mm, roughly two to four times larger than corresponding values for February, March, and April. A rainfall threshold of 60 mm is commonly used to distinguish between dry and wet months for tropical climate types within the Köppen climate classification system (Griffiths, 1985). May rainfall exceeded 60 mm 52–61% of the time at the four sites analyzed, or 57% of the combined 220 station-years (Figure 4).

May rainfall is also much more variable than that of February, March, and April (Figure 3). The interquartile range of May rainfall is about 2.5 times larger than that of February–April at all sites except Chumpan. The standard deviation of monthly rainfall (Figure 5) provides another measure of intra-annual rainfall variability. May values are again substantially larger than during February–April, and indeed are consistent

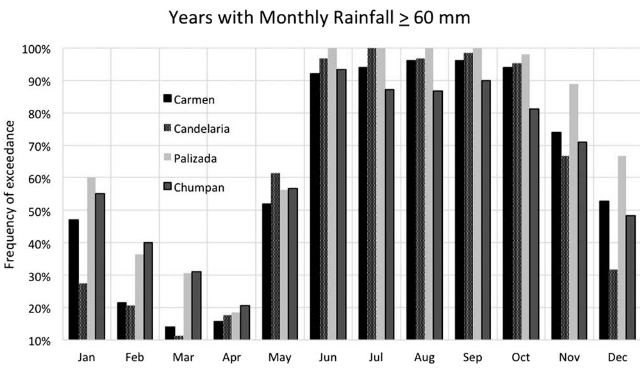

Figure 4. Frequency with which monthly rainfall at sites within the Términos Lagoon region exceeds 60 mm, the threshold used to distinguish between dry and wet months for tropical climate types within the Koppen climate classification system.

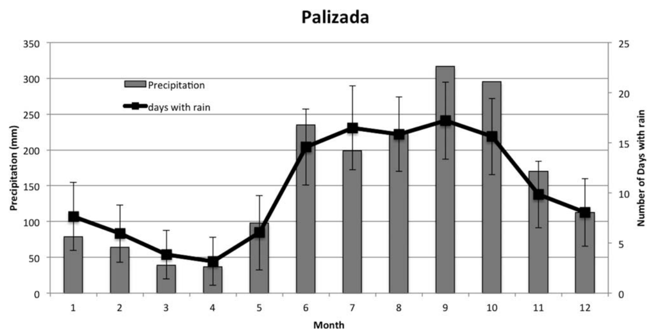

Figure 6. Mean monthly precipitation and days with rain at Palizada. Error bars represent ±1 standard deviation.

with rainfall variability in the wettest months of the year rather than the driest months.

Analysis of daily rainfall observations was conducted for Palizada. Mean May rainfall at Palizada is 98 mm, with rain typically occurring on 6 days within the month (Figure 6). By dividing the mean monthly rainfall by the mean number of rainy days in that month, the mean daily precipitation on rainy days within that month can be estimated. The mean daily precipitation for rainy days in May is 16 mm, which is a considerably larger daily total than observed during the dry months of February, March, and April (11, 10, and 12 mm, respectively). These substantial rains can occur on any day within May (Figure 7), although the heaviest rains are more common in the latter half of the month. Similar results (not shown) were obtained for daily rainfall analysis at Carmen, Candelaria, and Chumpan.

The transitional nature of May precipitation is particularly evident when considering daily rainfall throughout the entire year (Figure 8). During the dry months of February–April the probability of measureable daily precipitation ranges from 6 to 25%. During June–September this probability climbs to 50–65%. Statistically significant differences (>99.9% confidence level) were found when distributions of May rainfall characteristics – monthly totals, probability of measurable daily rainfall, and daily rain intensity – were compared with those of the preceding (February–April) and following (June–September) periods.

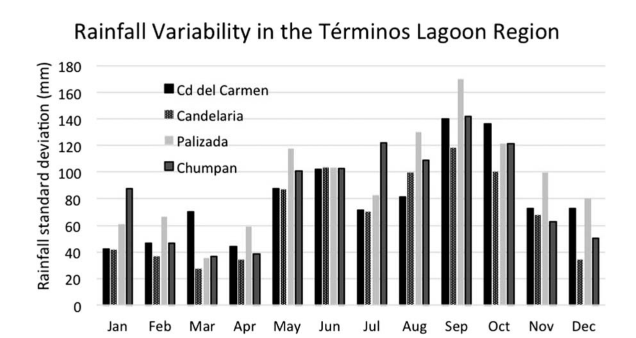

Figure 5. Standard deviation of monthly rainfall at four locations within the Términos Lagoon region.

The changing precipitation regime observed during May is accompanied by annual maxima in temperature and evaporation, and the beginning of a 3-month-long peak in insolation (Figure 9). Cloud cover exhibits little intra-annual variability and causes the daily fluctuations in insolation. Statistically significant differences (>99.9% confidence level) were again found when distributions of May evaporation and insolation characteristics were compared with those of both the preceding (February–April) and following (June–September) periods.

DISCUSSION

In their oft-cited paper, Yañez-Arancibia and Day (1982) defined the dry season in the Términos Lagoon region as February through May. The present analysis, however, shows that May is a transitional month and should not be considered part of the dry season. There is two to four times more rainfall in May than during February–April, and the variability in May rainfall is 2.5 times larger than during February–April and consistent with the variability during the wettest months of the year. May rainfall exceeded the Köppen climate classification threshold for distinguishing between dry and wet months in tropical climates in 57% of the 220 station-years analyzed. Moreover, May rainfall is statistically distinct from that of both the preceding February–April and subsequent June–September periods, as is insolation and evaporation.

To supplement the arguments for the removal of May from being designated as a 'dry season,' the rainfall measurements analyzed by Yañez-Arancibia and Day (1982) were revisited; the 1982 report explained that the monthly precipitation amounts used to define the seasons were adapted from Bravo-Núñez and Yáñez-Arancibia (1979). Bravo-Núñez and Yáñez-Arancibia (1979) presented climate data for four locations within the Términos Lagoon region: Ciudad del Carmen, Champotón, Palizada, and Sabancuy, with 7–38 years of data analyzed for each station. The interannual variability in

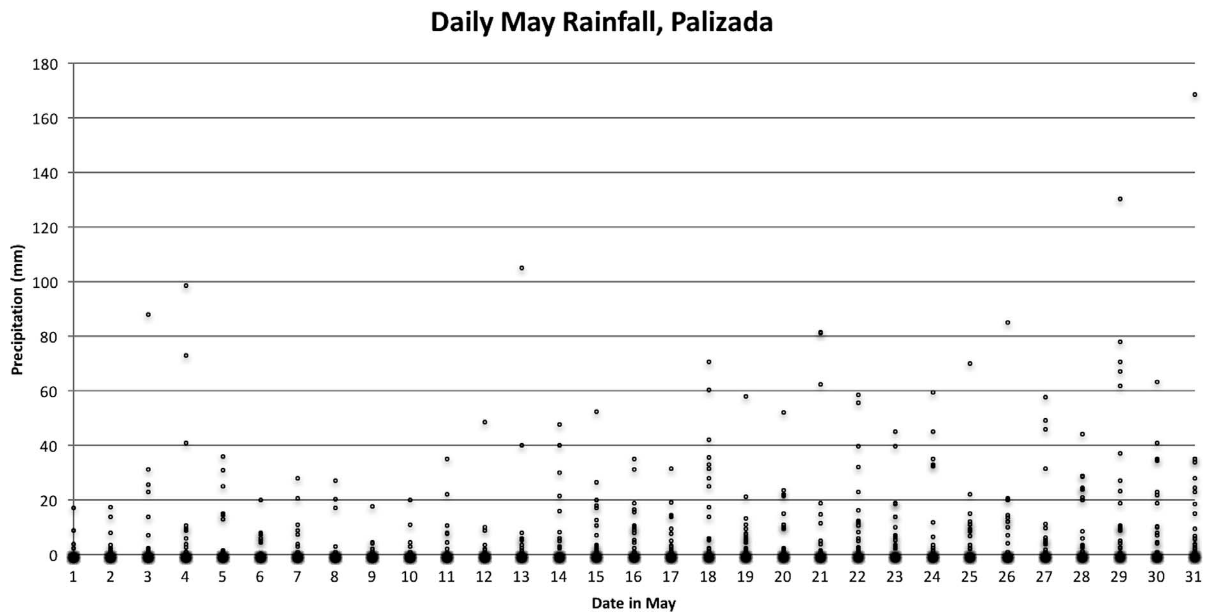

Figure 7. Daily rainfall during May at Palizada. Each circle represents a daily rainfall amount in May during the years 1953–2012. The large, solid circles represent a preponderance of days with zero rain.

monthly rainfall was not described by Bravo-Núñez and Yáñez-Arancibia (1979) or Yañez-Arancibia and Day (1982).

The rainfall data from Bravo-Núñez and Yáñez-Arancibia (1979) and Yañez-Arancibia and Day (1982) are shown in Figure 10, from which it is clear that the "adapted" data (Yañez-Arancibia and Day, 1982) consist of monthly precipitation for Ciudad del Carmen only. Average May rainfall at the four locations ranged from 61 to 116 mm. All of these values exceed the 60-mm threshold for distinguishing between wet and dry months in tropical climates and, consistent with the analysis presented in this paper, are two to four times more than monthly rainfall amounts during February–April. It is unclear, therefore, why Yañez-Arancibia and Day (1982) classified May as part of the dry season. It appears to be an incorrect designation.

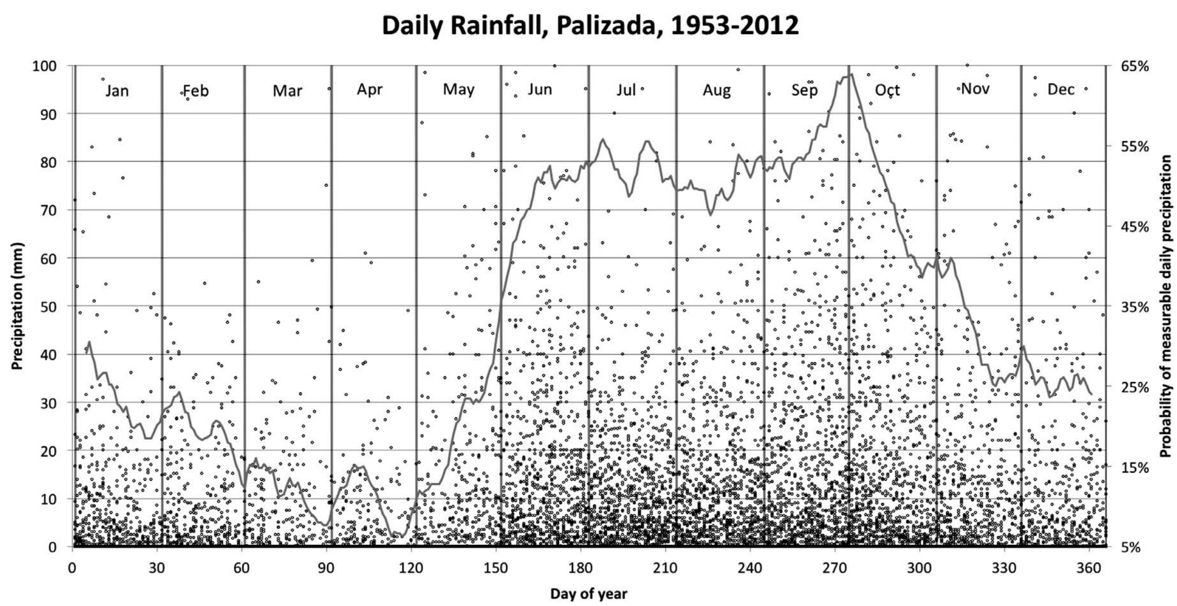

Figure 8. Annual progression of daily rainfall (dots) at Palizada. The line shows the probability of precipitation, *i.e.* the percentage of years within the 1953–2012 observation period for which measurable rainfall occurred on each day. A 10-d running average was applied.

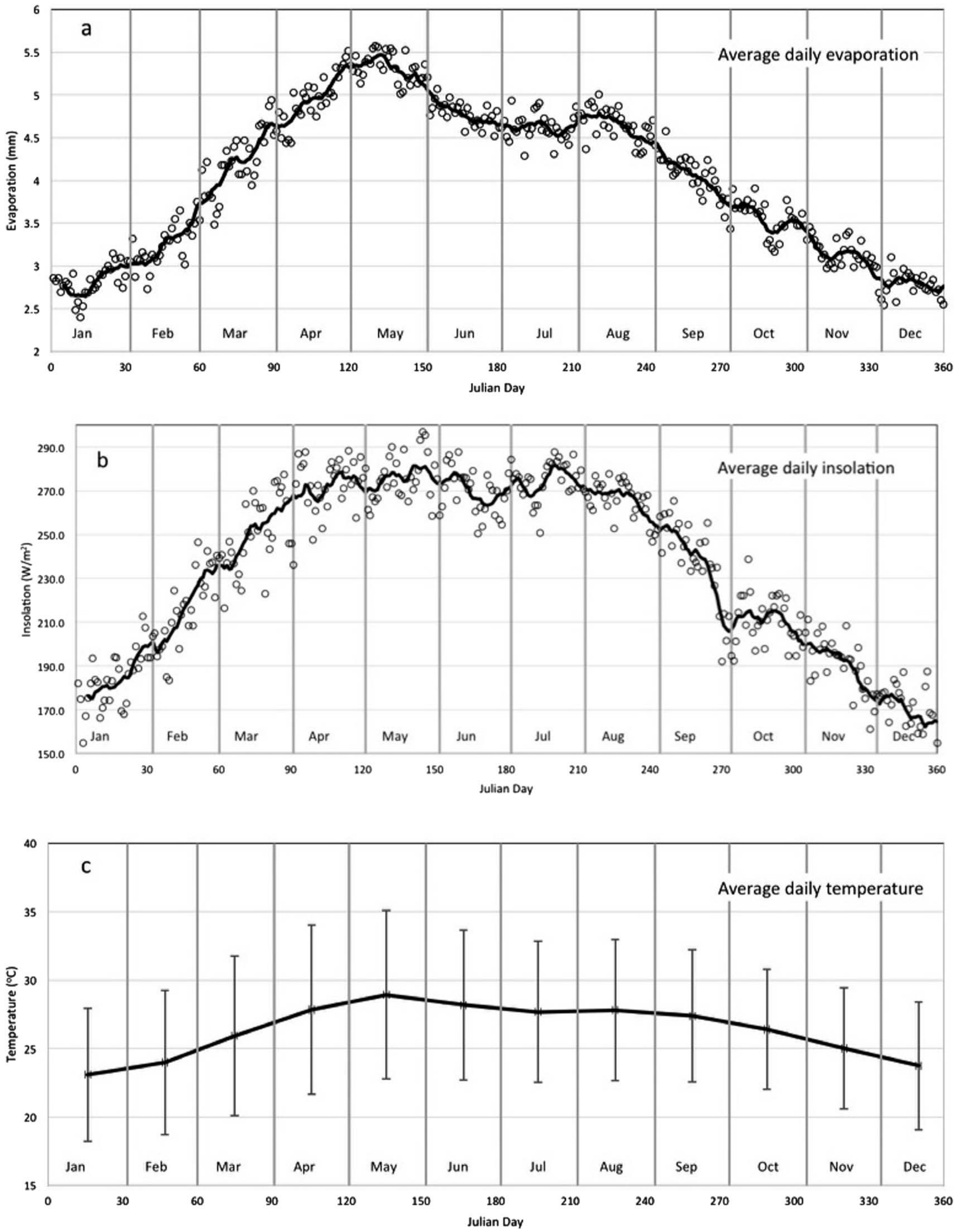

Figure 9. Daily evaporation at Palizada (a) and insolation in the Términos Lagoon region (b), with solid lines depicting 10-d running means, and (c) average temperature at Palizada, with bars depicting monthly average maximum (top) and minimum (bottom) temperatures.

The designation of October–March as the season of nortes (winter storms) by Yañez-Arancibia and Day (1982) appears to be robust, despite the fact that monthly rainfall within this season is comparable with months within both the dry and rainy seasons (Figure 10). The distinguishing characteristic of nortes is precipitation combined with decreasing temperatures accompanying cold fronts entering the Términos Lagoon region from North America. Whereas winds in southern Mexico have an easterly component throughout the year, a northerly wind component is common only during September–April (Kahl *et*

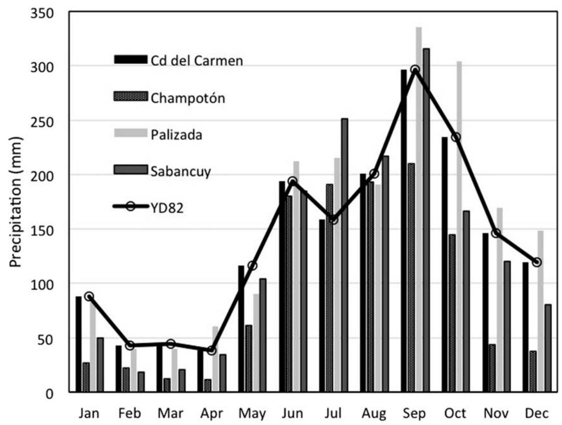

Figure 10. Monthly rainfall data from Bravo-Núñez and Yáñez-Arancibia (1979) (bars) and Yañez-Arancibia and Day (1982) (line).

al., 2007). Strong meridional (N-S) temperature gradients across the northern Gulf of Mexico are present from October to March, and during these months the northerly winds bring cool, rainy weather to the Términos Lagoon region. The strength and frequency of nortes were examined by determining the meridional temperature advection using gridded meteorological data (Saha *et al*., 2006). The meridional temperature advection, $-v\frac{\partial T}{\partial y}$, where v is the meridional component of the wind and $\frac{\partial T}{\partial y}$ is the meridional temperature gradient, is shown in Figure 11. The months of October–March are characterized by negative values, indicating advection of cooler air by northerly winds, consistent with the lower temperatures (Figure 9c) observed during the nortes season.

Environmental Indicators to Consider May as a Transitional Month

In addition to meteorological considerations, several environmental indicators also support the characterization of May as a transitional rather than a dry month. One example is salinity, which is strongly controlled by rainfall. The spawning period of the eastern oyster *Crassostrea virginica* (Rogers and García-Cubas, 1981) and various fish species (Sirot *et al*., 2015) have been linked to the annual decrease in salinity that begins with the onset of the rainy season. Milestones in the annual growth cycle of *Rhizophora mangle* (red mangrove) are linked to groundwater salinity (Agraz Hernandez *et al*., 2015; Saenger, 2002). Another example is river dynamics, an important seasonally varying hydrological feature that is also strongly controlled by rainfall (Contreras-RuizEsparza, Douillet, and Zavala-Hidalgo, 2014; David and Kjerfve 1998). The highest abundance period of the catfish *Pterygoplichthys pardalis* is closely associated with river level (Wakida and Amador, 2011). River discharge, providing significant inputs of energy, organic matter, nutrients, and sometimes toxic materials to the Términos Lagoon ecosystem, peaks during the wet season (Medina-Gómez, Villalobos-Zapata, and Herrera-Silveira, 2015).

Impacts of the Revised Seasonal Definition

The redesignation of May as a transition month has a large potential impact on environmental research in the Términos Lagoon region. Examples of physical, botanical, and biological characteristics that vary seasonally include the following:

(1) Litterfall production, soil salinity, and *Rhizophora mangle* (red mangrove) growth rate are influenced by precipitation (Agraz Hernandez *et al*., 2015; Coronado-Molina *et al*., 2012).
(2) The abundance of seagrass-dwelling sponges varies by season and is influenced by precipitation (Ávila, Ávila-García, and Cruz-Barraza, 2015).
(3) River discharge is influenced strongly by rainfall (Medina-Gómez, Villalobos-Zapata, and Herrera-Silveira, 2015).
(4) Marine salinity varies throughout the year because of multiple driving forces including river discharges (Contreras-RuizEsparza, Douillet, and Zavala-Hidalgo, 2014).

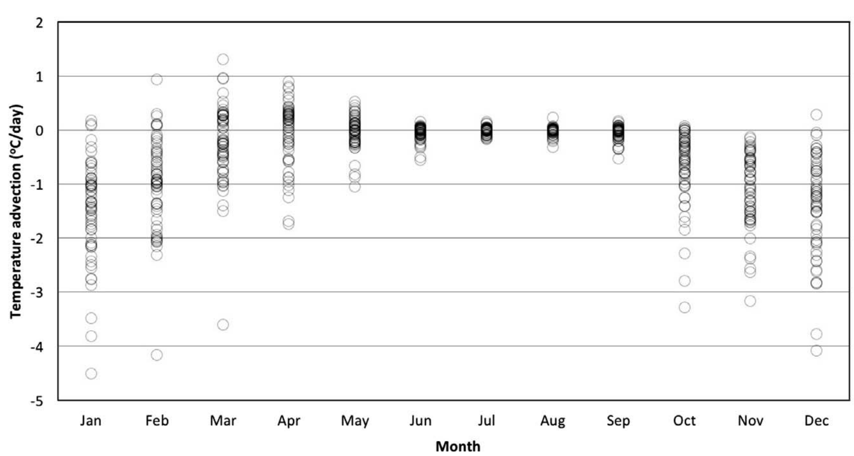

Figure 11. Monthly meridional temperature advection in the Términos Lagoon region. Each circle represents a monthly value during the years 1953–2012.

(5) Water renovation, affected by the flow of nutrients, is dominated by nutrient export from estuaries and mangroves during the wet and dry seasons, respectively (Ruiz-Marin *et al*., 2014).

Experimental sampling and analysis protocols in studies addressing these and other seasonally varying environmental features of the Términos Lagoon region may be negatively affected if May continues to be considered part of the dry season.

CONCLUSIONS

The present analysis of rainfall measurements, together with a reinterpretation of data presented by Yañez-Aranacibia and Day (1982), necessitates the following revision to the definition of the seasons in the Términos Lagoon region: dry (February–April), transition (May), wet (June–September), and nortes (October–March). May rainfall is substantially greater and more variable than that of the drier months of February, March, and April. There is no compelling reason to include May in the dry season.

The Términos Lagoon is an internationally recognized, federally protected, environmentally sensitive ecosystem. The region is an active area of study for research involving flora, fauna, and other environmental parameters. The recommendation put forth here is that sampling and analysis protocols for future environmental studies in the region take into consideration the new designation of May as a transition month.

ACKNOWLEDGMENTS

We gratefully acknowledge support from PROFOCIE 2014 (Programa de Fortalecimiento de la Calidad en Instituciones Educativas), a program within SEP (Mexican Secretaría de Educación Pública), and helpful discussions with Dr. Sergey Kravtsov. The University of Wisconsin-Milwaukee kindly provided the facilities needed to conduct this research.

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