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The effects of El Niño in Mexico: A survey

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RESUMEN

La ubicación geográfica de México lo sitúa entre los paises más expuestos a la expresión de El Niño en latitudes medias y bajas. Los efectos de El Niño se encuentran en la mayor parte de los mares costeros, en la atmósfera y, por ende, en tierra, alterando casi todas las formas de actividad humana en México. Los mares costeros perciben una 'tropicalización', en la que las aguas más cálidas y las especies tropicales migran hacia latitudes mayores a lo largo de la costa del Pacífico y del Golfo de California; los organismos motiles se ven desplazados o compiten en un ambiente nuevo, los organismos sésiles se agotan o mueren. El Niño, al tiempo que incrementa la precipitación en los estados del norte, reduce las lluvias en el resto del país; mientras algunas ciudades sufren inundaciones y deslizamientos de tierra y el desierto florece, la mayor parte de México padece la sequía, las cosechas de productos básicos disminuyen y las ciudades del centro del país acusan calores extremos y humedad reducida. Los retos que surgen de los estudios en este volumen incluyen el entender la respuesta del entorno a otras fluctuaciones climáticas de gran escala y sus interacciones, tanto para mitigar los efectos catastróficos de los eventos extremos que resulten, como para desarrollar modelos ambientales que induzcan a la búsqueda de formas sustentables de la actividad económica y social.

PALABRAS CLAVE: El Niño, México, clima, fluctuaciones.

ABSTRACT

Mexico's geographical location makes it one of the countries most exposed to the low and mid-latitudes expressions of El Niño. The effects El Niño are to be found almost everywhere in the ocean, in the atmosphere, and by natural extension, on land, affecting most forms of activity in Mexico. The coastal ocean undergoes a 'tropicalization', with warmer water and tropical species found at higher latitudes along the Pacific coast and in the Gulf of California; motile organisms are displaced or must compete in a new environment, sessile organisms are depleted or die off. El Niño increases rainfall over the northern states, but reduces precipitation elsewhere in the country; as some cities suffer floods and landslides and the desert blooms, most of Mexico suffers the effect of drought, yields of basic crops are reduced, and mainland cities sustain the warmest and driest conditions. The challenges that arise from the studies in this volume include understanding the response to other large-scale climatic fluctuations and their interactions, both to mitigate the catastrophic effects of extreme events, and to better model the response of the environment to properly design sustainable forms of economic and social activity.

KEY WORDS: El Niño, Mexico, climate, fluctuations.

1. MOTIVATION

El Niño is a climatic event of global consequences that starts as an anomalous warming in the equatorial Pacific off South America and in the eastern Tropical Pacific in general, and results principally from a rearrangement of the surface layers when the Trade winds, usually swift easterlies over the entire equatorial region, weaken, cease, or reverse. Various oceanic (wave propagations) and atmospheric (teleconnections) processes contribute to the establishment of the anomalous thermal and sea surface elevation fields. The consequences of El Niño on the environment and its social and economic repercussions are important and widespread.

In the early months of 1997, the Equatorial Pacific showed signs of an impending massive El Niño, and as a consequence of the early predictions, the event received enormous and unprecedented press coverage, drawing attention to the need to mitigate its catastrophic effects around the world, but also to factor its modulating effects on economic endeavors in order to enhance economic productivity. The effects of El Niño in Mexico were poorly understood, limited to some isolated observations of a probable causal relationship between large-scale weather fluctuations and the departure from 'normal' conditions of some environmental conditions, such as the annual regional rainfall, the success or failure of individual crops, or the fluctuations in the location and catches of a particular fishery.

Whether Mexico undergoes some influence of El Niño is no longer a matter of investigation. Even as the studies reported in this volume were getting under way, the presence of the 1997-98 event was evident everywhere, from the higher incidence of hurricanes in the Pacific, warmer waters offshore, to floods in some Baja California cities, and depleted reservoirs pretty much everywhere else. Since then, a number of publications have compiled the effects of El Niño in Mexico (Magaña *et al*., 1999; Escobar *et al*., 2001), as has happened in Peru (Tarazona and Castillo, 1999) and elsewhere; the subject of El Niño has even been popularized (Nash, 2002). The geographical location of Mexico, downstream along the coastal waveguide from the equatorial source of El Niño, and in between the subtropical jet stream and the Inter-Tropical Convergence Zone, makes it a primary target for the several effects of El Niño. The studies reported here, beyond documenting impacts of El Niño, quantify its effects on specific environments and provide a generalized picture of their response to climatic fluctuations. The challenge that arises from their results is to better understand the entire spectrum of climatic fluctuations, the interactions of various temporal and spatial scales, and to formulate specific policies to mitigate their potentially destructive effects, while harnessing their beneficial influence. Section 2 gives an overview of the results of the studies conducted under this special program to document the effects of El Niño in Mexico, section 3 offers a discussion of the main conclusions, and section 4 outlines some policies that might be adopted to better confront the challenge of climatic fluctuations in our environment.

2. A SUMMARY OF RESULTS IN THIS VOLUME

El Niño results from intricate ocean-atmosphere interactions and its own inherent physics, which sustain some of its outstanding and basic features, such as duration, intermittancy, and phase locking to the seasonal cycle, many of which remain poorly understood. The volume begins with a survey by *Sheinbaum* of prevailing theories on the subject. (Hereafter, references in italics are of papers found in this volume, as opposed to regular citations in the bibliography).

The most clearly perceived effect of El Niño in Mexico, as elsewhere, is its direct influence on the weather. *Magaña et al*., explain that during El Niño, a southward shift of the jet stream and of the Inter-Tropical Convergence Zone, together with more intense trade winds and fewer tropical cyclones over the western Atlantic, are followed by an increase of northerly winds over the southern Gulf of Mexico and a lower relative humidity. Precipitation is usually greatly dimished over most of Mexico, often resulting in severe droughts, except over the northern states where winter rains tend to be more abundant. A return to 'normal' conditions or a reverse scenario is brought about during La Niña. Records of the weather fluctuations are preserved in a number of natural media; five tree ring width chronologies, ranging in length from 101 to 155 years (*Martijena*), all had significant correlations with precipitation records from Baja California and California and with an ENSO-related index from instrumental records. Precipitation is able to explain from 8 to 57% of the variation in tree growth. On long-term scales, *Herguera et al*. track tropical oceanographic variability on decadal timescales for the past three centuries through ocean-driven feedbacks to show that winter sea surface temperatures are much more sensitive than summer temperatures to changes introduced by El Niño. Changes in winter SSTs on interannual to decadal timescales seem to be modulated by low-frequency ENSO variability, possibly through higher frequency and intensity of El Niño/La Niña events that temporarily lock surface ocean temperatures into warm/cold decadal periods in the Gulf of California.

In the ocean, El Niño effects appear most common off the Pacific coast and in the Gulf of California, the coastline being the meridional waveguide that conducts equatorial signals to higher latitudes. Monthly surveys off the coast of mainland Mexico by *Filonov et al.* show that a northward penetration along the coast of large amounts of warmer, fresher water of tropical origin occurred about one month after the manifestations of El Niño were reported in the eastern Tropical Pacific. Satellite observations in the region of the mouth of the Gulf of California (*Aguirre-Gómez et al.*) confirm the warming by about 3 to 5° C during El Niño and a reduction of the upwelling off Cabo Corrientes. Farther north, in the southern portion of the California Current, *Lavaniegos et al.* report a strong presence of tropical copepods at the peak of the El Niño, associated with a decrease of zooplankton biomass and only a moderate increase of integrated chlorophyll a. Similar positive SST anomalies were found in Magdalena Bay (*Palomares-García et al.*), with a maximum of +4.4 °C in the summer of 1997; zooplankton biomass was half that of the El Niño of 1982-83, with a chlorophyll maximum in late spring to early summer, and a minimum in winter. Temperate species of copepods from the California Current were found in the cool phase preceding El Niño, while tropical species appeared during the active phase of the event. The abundance of both temperate and tropical small pelagic fishes dropped from a half to one order of magnitude from previous reports. Kelp beds on two reefs off the western coast of Baja California also collapsed during El Niño (*Guzmán del Proo et al.*), most probably because of the thermal stress; of course, benthic invertebrates who depend on the kelp for food, such as the juvenile abalone, also suffered drastic reductions in their populations, but benthic invertebrates who do not rely on the kelp for food, such as spiny lobsters, can in turn increase in numbers. Whether this is due to a reduced competition, increased food availability, or the stimulating effects of the higher temperatures remains unclear. Populations recovered quickly, usually within a year or two as conditions returned to normal, but should nonetheless remain unexposed to fishing pressures while under the influence of El Niño. In another fundamental observation, the whale population in Laguna San Ignacio appeared to be unaffected by El Niño in terms of the number of single whales and dead calves (*Urban et al.*), but the mother-calf pairs were significantly fewer and dead adult whales were more abundant, suggesting the modified weather patterns impacted the whale's nutrition sources. Finally, Ochoa indicates that El Niño might have an influence on the spectrum of toxins produced by red tides off Mexico, with important consequences on coastal populations and wildlife.

Expressions of El Niño were also prevalent in the Gulf of California. *Lavín et al.* document statistically significant positive sea surface temperature anomalies associated to El Niño, especially to the 1997-98 event, and cold anomalies related to La Niña, some of which appear related to the large-scale thermal structure of the eastern Tropical Pacific, though others may originate only from local atmospheric forcings. Off the Bay of La Paz, over Espíritu Santo seamount, *Amador-Buenrostro et al.* report the unusual presence of Equatorial Surface Water during the El Niño; a 120 km diameter cyclonic eddy in Farallón basin presses an intense and narrow coastal jet flowing north along the Baja California coast, with convergence of the flow over the seamount. The mixed layer deepened to 70 m and sea surface temperature was about 2 °C higher than normal. El Niño also favors migration of tropical fishes to Espíritu Santo seamount (*Muhlia-Melo et al.*), increasing the diversity of adult species but decreasing the diversity of larval assemblages, even though more than 50 percent of larval fishes during El Niño conditions belong to mesopelagic species of tropical affinity. The benthic sessile communities were exposed to a considerable thermal anomaly during the summer and about 30 percent of the corals experienced bleaching, accompanied by a severe 60 percent mortality (*Iglesias et al.*). Coral bleaching was less severe in areas where they are normally exposed to higher temperatures, suggesting an adaptive capability; corals located in shallow areas experienced higher incidence of bleaching than those in deeper water, probably because of temperature stratification rather than differences in light conditions. The coral-associated fauna also showed variations related to coral bleaching and mortality. Farther north within the Gulf of California, in Bahia Concepción, higher temperatures in the water column, lower nutrient and peridinin concentrations, and a 2 to 3 month delay of the onset of stratification indicate the influence of Equatorial Surface Water inhibiting the proliferation of dinoflagellate groups during El Niño 1997-98 (*López-Cortés et al.*). Near the large islands of the Gulf of California, *Pacheco-Ruíz et al.* show that kelp beds and seaweed populations collapse with the warming caused by El Niño, recovering quickly, usually within a year or two; they confirm the cause to be thermal rather than an increased irradiance. In the extreme northern Gulf of California, waterbirds nesting on Isla San Jorge, at La Purinera and on Isla Montague, and the sea lions on Isla San Jorge, also reacted strongly to El Niño (*Mellink*). Brown boobies on San Jorge ceased breeding and left the island, replaced by a large influx of blue footed boobies, and increased nestings of least, elegant, and royal terns and black skimmers on Montague. Sea lions at Isla San Jorge about doubled, but the number of pups they produced remained about the same. During 1999, Heereman's gulls, which had stopped breeding on San Jorge, and Brandt's cormorants, which had never been reported there, were all on the island in 1999. La Niña conditions brought about population levels prevalent before El Niño.

Lakes and other inland bodies of water also reflect the changes of weather associated to El Niño. *Alcocer and Lugo* document such effects on tropical Lake Alchichica, a warm monomictic lake, which result in a narrower and slightly colder hypolimnion, larger thermal changes along a shallower thermocline, a warmer epilimnion, a delay of hypoxic/anoxic condition in the hypolimnion, a thinner hypolimnetic anoxic layer, and a more modest spring cyanobacterial bloom. But *Caballero et al.* have shown that the lake sediments are poor record-keepers of environmental series because the high pH and alkalinity of the lake destroy diatoms and pigments stored in the sediments. In a different realm, there have been fewer studies of the Caribbean and Gulf of Mexico suitable for the detection of a possible El Niño effect off the Atlantic coast of Mexico, where expressions of El Niño are themselves probably smaller. Nonetheless, *Escobar* is able to show an increase of episodic carbon inputs into the sediments of the shelf and slope of the southwestern Gulf of Mexico, through pulses of phytodetrital material that originates from increased wind-induced mixing of the upper water column, and lead to a significant increase of macrofaunal biomass during El Niño, an interesting example of a possible teleconnection over the isthmus of middle America.

The economic impacts of El Niño are felt through its effects on the primary production sectors, agriculture and fisheries, and on its impact on the urban environment, mainly through increased environmental hazards. An important consequence of El Niño is the variation of the yields of traditional crops, such as maize and beans. A very interesting crop-growth model by *Tiscareño et al.*, activated with climatic parameters, maps the regions of Mexico that are sensitive to weather changes and susceptible of crop yield variations resulting from deviations in air temperature and precipitation during El Niño and La Niña years. Some of these results are confirmed by the study of *Salinas-Zavala and Lluch-Cota,* who show that yields of winter-grown wheat under irrigation in the state of Sonora, while depending largely on technological advances, still report larger yields during El Niño because of inceased precipitation. Similarly, *Cortés-Calva and Álvarez-Castañeda* find that the effects of altered patterns of rainfall and temperature on rodent populations in desert habitats is most evident in a grazing pasture, with a larger population resulting from increased rainfall and a much smaller population during droughts, probably because of the significant change in the availability of perennial. These effects are much reduced in an undisturbed natural reserve.

On the urban front, *Tereshenko et al.* extract the expression of El Niño in the spectra of temperature and precipitation in various cities, including Guadalajara, Manzanillo, Guanajuato, Mexicali and Ensenada, and on the water levels of Lake Chapala, which reflect to a large extent the integral processes occurring within the Lerma-Chapala watershed. Periods of 2 to 7 years in the spectra are thought to be related to El Niño, whereas periods of 9 to 22 years might reflect solar influence. For the metropolitan area of Guadalajara, an El Niño year causes a significantly larger number of hours with temperatures over 25°C; higher-than-normal temperatures began in March 1998, and a relative humidity below 30 percent prevailed from late January till June of the same year. Near another large urban area, *Lizárraga et al*. document the intensive beach erosion that occurred off Rosarito during the winter of 1998 as a result of a very energetic wave regime and higher water levels caused by El Niño, requiring a long period of mild wave conditions to restore the initial profile height. Flooding and the destruction of several houses in the backshore resulted, and the recreational and protection capabilities of the beach were severely curtailed. The importance of the beach on the local economy evidences the need for the continuous monitoring of weather conditions. Finally, *Winckell and Le Page* provide a pilot study of the hydrologic response of the basins that include the city of Tijuana and the characterization by means of a Geographical Information System of the hazards resulting from the considerable rainfall brought about by the 1997-98 El Niño, provide an assessment of the actions needed to mitigate the dangers of future extreme meteorological events.

3. DISCUSSION

El Niño consists of a rearragement of large-scale oceanic and atmospheric patterns and its consequences. Off Mexico, the coastal ocean is invaded by tropical water and accompanying species, which replace in part, and compete, with the organisms usually present; it equates a virtual equatorward shift of several degrees of latitude, as it were, a 'tropicalization' of the coastal ocean. Since atmospheric features in reality shift to the south, the virtual latitudinal displacement for land-based systems appears to be in the opposite direction, as the usually moist and tropical portions of Mexico become temporarily drier, and the arid north and northwest acquire rainy weather characteristics more typical of, say, northern California or western Europe (Cavazos and Hastenrath, 1990). It would, in effect, be as if the country tore apart, the oceans moved south and the land slid north. The response of the ecosystems is very fast; tropical species colonize temperate waters within months, exhuberant vegetation covers the ususally arid northwest, and most of Mexico wilts under the effects of drought. The return to 'normal' or La Niña conditions is equally rapid. The effects of an El Niño cycle can thus be considerable.

As the studies reported here have made clear, the response to El Niño is important and fast in the sense that changes occur in a fraction of the El Niño cycle itself. This illustrates the susceptibility of the environment to climatic changes in general, of which El Niño is but one major component. Climatic fluctuations occur on many temporal and spatial scales (an excellent overview of some of these other oscillations may be found in Higgins *et al*., 2003). El Niño is the prevalent example of interannual changes; variations that appear to arise from the configuration of major oceanic basins, such as the North Pacific Oscillation or the North Atlantic Oscillation, seem to cause fluctuations on decadal scales; and intraseasonal fluctuations, such as the Madden-Julian oscillation, introduce variations on scales from one to three months. Much of the complexity of the weather, and the difficulty of its prediction, as well as the new challenge in understanding the effects of climatic changes, clearly arise from the interaccions of the components of this very rich spectrum of fluctuations.

El Niño variations are smaller than the seasonal signal, and longer-term fluctuations are usually smaller than El Niño, but the superposition of all signals produces extremes which could bring environmental systems to the limit of their resiliency and to the brink of irreversible disruption. Indentifying these limits is extremely important and an added challenge to the understanding of the effects of climatic fluctuations, because adding the human component to the natural causes can increase natural hazards to catastrophic levels, and the natural evolutive behavior of an ecosystem can be altered beyond repair, such as causing the collapse of an otherwise sustainable industry, or the extinction of species.

Natural hazards arise from the change in regimes, as the environment shifts from one state of equilibrium to another. The ground becomes unstable as rains exceed the basic absorption capacity of the soil, and the grasses that remain from exceptional rains are prone to brush or forest fires that can devastate large land surfaces. But, as was pointed by Arntz (1984) for Peru, not all effects of El Niño are damaging. Positive aspects of climatic fluctuations, usually less publicised than their harmful effects, are also many and important to be recognized for a proper response to weather fluctuations. The tropicalization of the coastal ocean causes some populations to rejuvenate and eliminate unadapted elements, excessive rains replenish acquifers, extreme temperatures keep unwanted pests in check, and some of the vegetation requires the wild fires to reproduce. Much more than a simple cause for catastrophic events, climatic variations are an important part of the complex background that sustains our environment. A thorough understanding of its elements is a fundamental condition for its proper management.

4. SOME IMPLICATIONS FOR PUBLIC POLICY

The purpose of funding the studies contained in this volume was to assess and quantify the effects of El Niño in Mexico with the combined aim of documenting the scientific relevance of the process and to draw some practical conclusions in terms of public policy. Begging the forgiveness of the specialists in the field who might approach the subject differently, this section lists some policy actions that appear desirable in light of what we now know about the effects of climatic fluctuations. Many have been mentioned before, others may seem self-evident, but all remain to be implemented at least in a thorough way. The list is also probably incomplete.

1. **Environmental monitoring.** No sound policies can be established without adequate environmental information on different time scales. The gathering of long-term series of the fundamental environmental variables, such as weather information, sea level, sea surface temperatures, and biogeochemical responses remains a critical goal.

2. **Data banks.** A proper data center for environmental information needs to be established, which should gather, process and verify the quality of the data, and make them readily available to public and private users.

3. **Predictive modeling.** The technology exists to develop complex operational numerical models with predictive capabilities. Most lacking is a weather model, which should interfase with those in use in the United States, and should assimilate the data from the numerous weather buoys already deployed in the North Pacific. Other operational models that need to be developed include one for agricultural production and risks (fire, frost, diseases), environmental hazards, such as fires, floods, landslides, and socioeconomic models, whose discussion I shall leave to specialists.

4. **Conservation and restoration.** The natural state of the environment is an expression of the ecological adaptation to a limited set of deterministic and stochastic ranges of climatic conditions. Extreme climatic events can topple that state into another equilibrium range to which organisms and human societies must adapt, although the nature of these new conditions remains largely unknown before they occur. Thus, one of the challenging endeavors for the future security and welfare of human societies has to do with the use and relation to the environment. Natural areas should be preserved to maintain the global biodiversity patterns, severely altered regions should be restored as much as possible, and new development should take place with the best understanding possible of what conditions abrupt climatic changes might create. This makes environmental, social, and economic sense.

Finally, it is imperative to underline that the social consequences of El Niño and other climatic fluctuations lie at the end of the chain of, and are the most important, of the reactions of natural systems to environmental variations. A proper discussion of that subject is beyond the scope of this work and of the author's field, but the careful study of the social response to climatic variations is indeed a fundamental and timely question that needs to be addressed.

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