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REVIEW

The multiple facets of El Niño/Southern Oscillation in Chile

Las múltiples facetas de El Niño/Oscilación del Sur en Chile

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ABSTRACT

The coupling between ocean (El Niño) and atmosphere (Southern Oscillation) conditions has only recently come under sharp focus. El Niño/Southern Oscillation (ENSO) has been labeled an excellent natural experiment that empirically demonstrates the teleconnections that may occur in planet Earth, illustrating how atmospheric-oceanographic phenomena may affect the biota, no only marine but also terrestrial. I make a summary review of how ENSO determines peculiar atmospheric and oceanographic conditions, thus affecting precipitation patterns in land masses, with cascading effects on marine and terrestrial plants, and on sea and land birds and mammals. I propose that the alternate phases of ENSO, namely El Niño/La Niña, should be explored in greater detail in order to make reasonable extrapolations about where global climate change may lead us. The latter has been considered simply as a steady increase in the temperature of the planet, but the Southern Oscillation shows that warm and cool phases alternate on very large geographical scales such as the entire Pacific Basin. That the two strongest ENSO events occurred at the end of the XX century (1982-83 and 1997-98) suggest that we should be more worried about the occurrence of increasingly more extreme events of El Niño and La Niña, rather than about a gradual warming of the climate.

Key words: El Niño, Southern Oscillation, ENSO, western South America, cascading effects, global climate change.

RESUMEN

El acoplamiento entre condiciones oceánicas (El Niño) y atmosféricas (Oscilación del Sur) sólo recientemente está siendo examinado en detalle. El Niño/Oscilación del Sur (ENOS) se ha considerado como un excelente experimento natural que demuestra empíricamente las teleconexiones que pueden darse en el planeta Tierra, ilustrando cómo los fenómenos atmosférico-oceanográficos pueden afectar la biota, no sólo marina sino también terrestre. Hago una revisión sumaria de cómo ENOS determina condiciones atmosféricas y oceanográficas peculiares, que afectan los patrones de precipitación en las tierras emergidas, con efectos en cascada sobre plantas marinas y terrestres, así como sobre aves y mamíferos en ambos ambientes. Propongo que las fases alternadas de ENOS (El Niño/La Niña), debieran explorarse en mayor detalle para poder hacer extrapolaciones razonables sobre dónde nos puede llevar el cambio climático global. Este último ha sido considerado simplemente como un aumento sostenido de la temperatura del planeta, pero La Oscilación del Sur muestra que fases cálidas y frescas se alternan a escalas geográficas tan extensas como la cuenca completa del Océano Pacífico. Que los dos eventos ENOS más fuertes hayan ocurrido al final del siglo XX (1982-83 y 1997-98) sugiere que debiéramos estar más preocupados sobre la ocurrencia de eventos cada vez más extremos de El Niño/La Niña, antes que a un calentamiento gradual del clima.

Palabras clave: El Niño, Oscilación del Sur, ENOS, Sudamérica occidental, efectos en cascada, cambio climático global.

INTRODUCTION

It is puzzling that the realization of the coupling between ocean (El Niño) and atmosphere (Southern Oscillation) may have become only recently part of cultivated knowledge, since the ENSO phenomenon has been well known for long among meteorologists, climatologists and oceanographers (cf. reviews by Diaz &

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Markgraf 1992, Allan et al. 1996), in addition to glaciologists (Thompson et al. 1984), geoarcheologists (Rollins et al. 1986), and palinologists (Villagrán 1993). In fact, ENSO has visited the western coasts of the Americas frequently over the last 5000 years, when the present-day system of atmospheric and oceanographic circulation became consolidated in the Pacific Ocean (Rollins et al. 1986). The most recent reviews of the origin and consequences of this phenomenon are updated until 1985 in Mariátegui et al. (1985), until 1990 in Arntz & Fahrbach (1991, 1996), until 1991 in Machare & Ortlieb (1993), and until 1994 in Glantz (1996) and in Allan et al. (1996). I hereby provide an update to the end of 1997.

The name El Niño, coined by Peruvian fishermen, indicates that uneducated people were well aware of the aperiodic intrusions of the oceanographic phenomenon and of its sequels (specially those pertaining artisanal fisheries). Scientists, however, were only mildly interested in the oceanographically moderate ENSO of 1972-73 (Zuta et al. 1980). But they did jump quickly with the arrival of the formidable ENSO of 1982-83 (Barber & Chavez 1983, Philander 1983, Caviedes 1984, McGowan 1984, Ramage 1986, Glynn 1988, 1990, Arntz & Fahrbach 1991, 1996). Up to now the biggest in the century (and the century is not yet over), the economic and human losses caused by that event raised the consciousness of both scientists and public authorities to the importance of studying the phenomenon, but the interest soon waned. Indeed, the oceanographically mild ENSO events of 1986-87 and 1991-92 did not attract much the attention of scientists (Arntz & Fahrbach 1991, 1996).

It must be recognized, tough, that a few perceptive scientists soon realized the importance of considering ENSO as a natural experiment that would enable knowledge of the responses of ecosystems faced with global climate change (Schreiber & Schreiber 1989, Trillmich 1991, Arntz & Fahrbach 1991, 1996). Nevertheless, the following-up of such opportunities has been slow. Only recently are results being published on the effects of the ENSO 1991-92 (Karl et al. 1995, Jaksic 1997, Jaksic et al. 1997, Polis et al. 1997), even though its most spectacular aspects were being released or predicted almost simultaneously to the cultivated public (Monatersky 1991, 1992, 1993).

ENSO AND THE ATMOSPHERE

For complex reasons, sporadically a difference in atmospheric pressure occurs between the eastern and western fringes of the Pacific Ocean. An index known as SOI (Southern Oscillation Index) estimates the difference in pressure between Darwin (Australia) and Tahiti (in the eastern Pacific). When this index yields negative values, a weakening in the strength of the westerly winds is observed (those that blow from America to Australasia). This enables the intrusion of warm tropical waters from Australasia to the American coastlines and the sinking or furthering of the cool currents that bathe those coasts (the Humboldt Current in South America, the California Current in North America). The mean occurrence of this phenomenon varies from 1 to 11,5 years (Rasmusson & Wallace 1983) and its intensity (strength) is practically unpredictable (Rasmusson 1984). For instance, during the 100 years spanning from 1880 to 1980 ca. 25 ENSO events were recorded, three of which were very strong (category 6 of Glynn 1988).

Because warmer ocean water evaporates more easily, when ENSO events occur, the potential for the atmosphere to contain water vapor increases, and thus its potential to precipitate it when faced with cooler temperatures (usually as rainfall but sometimes as snowfall). Apparently, the first authors who noted a correlation between the sea surface temperature (SST index) and higher than usual precipitations in California, were Markham & McLain (1977), who were quickly followed by Quinn et al. (1978), who noted that ENSO events were associated with droughts on the opposite side of the Pacific Ocean (in Australasia). In fact, because of its significant meteorological causality, atmospheric scientists have been those who have invested most efforts in studying ENSO (Canby 1984, Ropelewski & Halpert 1986, Quinn et al. 1987).

ENSO AND THE OCEAN

Oceanographers have not lagged behind meteorologists and climatologists, owing to the obvious implications that the intrusion of a warm water mass, of high salinity, low oxygen contents, and poor in nutrients, has on the circulation regimes of currents, and accompanying depression of the thermoclines, obliteration of upwellings, and increases in normal sea levels along the American rim of the Pacific Ocean (Cane 1983, Firing et al. 1983, McGowan 1984, Cucalon 1987, Huyer et al. 1987, Wilkerson et al. 1987, Glynn 1990).

Almost concurrently, both in the northeastern (North America) and in the southeastern Pacific (South America), marine biologists had consigned in the literature a relationship between El Niño intrusions and mass dieoffs of phytoplankton and zooplankton, macroalgae, and marine animals (Dayton & Tegner 1984, Gunnill 1985, Tarazona et al. 1985, Paine 1986, Torres-Moye & Alvarez-Borrego 1987, Silva-Cota & Alvarez-Borrego 1988), with abundant occurrences of unusual organisms (Tershy et al. 1991), with migrations to high-sea or to deeper layers by fishes of commercial concern (Arntz & Fahrbach 1991, 1996), and even with the collapse of an entire industrial fishery, that of the anchovy (Jordan 1991). Further, important changes in abundance and composition of artisanal fishery resources were documented in Peru (Valdivia & Arntz 1985).

As it should be clear from the above, none of the cited authors is Chilean (they are chiefly North Americans and Peruvians). This changed when an entire issue of the Chilean journal Investigación Pesquera (1985), was dedicated to analyzing the putative effects of ENSO 1982-83 regarding meteorological, oceanographic, marine-biological, and fishery aspects. Among others, it was remarked that the major effects were observed between Arica (latitude 19 South) and Chañaral (latitude 26 South) (Blanco & Diaz 1985), and that those included massive dieoffs of brown algae (Soto 1985) and of littoral invertebrates (Tomicic 1985), as well as changes in the composition of phytoplankton (Avaria 1985), ichthyofauna (Kong et al. 1985) and fishery resources (Martínez et al. 1985). Up to now, that issue of Investigación Pesquera is the best summary of the effects of ENSO in Chile. In a pioneering long shot, Camus (1990) proposed that ENSO occurrences may explain the biogeographic patterns of macroalgae along the Peruvian-Chilean coast. Indeed, later on Camus and coworkers were able to demonstrate convincingly: (a) That the 1982-83 ENSO changed the patterns of exploitation of three marine benthic resources by humans (a gastropod and a kelp went down in landings while a cephalopod went up, Castilla & Camus 1992). (b) That the 1982-83 ENSO resulted in the local extinction of a dominant kelp species from many localities, that the success of its recolonization was lower in the northernmost localities of Chile –those most heavily affected by El Niño incursions– and that herbivory by invertebrates was superimposed on ENSO effects (Camus 1994a, 1994b). (c) That the 1982-83 ENSO affected species richness, dominance, and evenness of both benthic algae and invertebrates, which displayed complex patterns along a 6-degree latitudinal range in northern Chile (Camus et al. 1994). (d) That the strong 1982-83

ENSO resulted in a decline to 23% of pre-ENSO kelp landings, whereas the moderate 1986-87 and 1991-92 ENSO events caused no relevant changes in the respective landings (Camus & Martínez 1995).

Despite the inspiration that Chilean scientists could have received out of the impressive gathering of detailed information contained in Investigación Pesquera (1985), the chief agency for the funding of Chilean basic science (Fondecyt = Fondo Nacional de Desarrollo Científico y Tecnológico) did not receive a fundable proposal on marine-biological aspects of ENSO until 1990 (Camus & Ojeda 1990). And that project aimed at investigating the ecological effects of ENSO 1982-83 on community structure of marine invertebrates and algae around Antofagasta. Indeed, most of the papers by Camus, cited above, resulted from that single project.

Perhaps as a consequence of emphasizing so much the relationship of ENSO with marine phenomena (Allan et al. 1996), only very recently Chilean scientists began to become interested in the association of that phenomenon with increased precipitation in the land mass and with some biological phenomena such as the "blooming desert" and "rodent irruptions". It is noticeable that among the 28 contributions published in Investigación Pesquera (1985), only two made any reference to ENSO-driven effects in terrestrial ecosystems: Soto (1985) made general remarks on the vegetation blooming of the Atacama Desert, and Vargas et al. (1985, in actuality an abstract) mentioned crop damage owing to both hydric stress and insect outbreaks. Only in 1996 a proposal was submitted to Fondecyt, requesting support to study the response of terrestrial ecosystems to ENSO events (Jaksic et al. 1996c). That same year, a Presidential Chair in Science was awarded to analyze ENSO in the broader context of global climate change (Jaksic 1996).

ENSO AND THE RAINS

Ropelewski & Halpert (1986) in North America, Goldberg et al. (1987) in Peru, Quinn & Neal (1983), Rutllant (1985), Romero & Garrido (1985), Mardones & Silva (1985), Fuenzalida (1985), Aceituno & Montecinos (1992) and Ortlieb (1994) in Chile, are among the authors who have associated ENSO intrusions with increased precipitation in lowland areas of northern and central Chile (and with droughts in the high-Andean plateau shared by Chile, Peru, Bolivia, and Argentina). Very recently, Lima et al. (in press) demonstrated statistically a significant association between ENSO and high precipitation in the semiarid region of northern Chile. For sure, every time that excessive precipitation occurs, ensuing runoffs, floods, and inundations follow, and they are very well documented in Peru (Caviedes 1984, Waylen & Caviedes 1986, Arntz & Fahrbach 1991, 1996). As a counterpart to these phenomena, droughts and associated fires occur in the southwestern Pacific –Australia, southeast Asia– and in India (Quinn et al. 1978).

ENSO AND THE VEGETATION

That high rainfall associated with ENSO incursions somehow affects the vegetation, was first noted by Hamann (1985) in the Galapagos Islands (Ecuador), by Soto (1985) in northernmost Chile, and by Arntz & Fahrbach 1991) in Peru. In turn, Dillon & Rundel (1990), Nicholls (1991), and Armesto et al. (1993) were the first botanists that associated the massive germination and flowering of desert plants in Chile and Australia with periods of high precipitation. In fact, Armesto et al. (1993) determined that in northern Chile at least 20 mm should precipitate during a single storm in order to trigger seed germination. It is interesting to note that the study by Armesto et al. (1993) was conducted from 1989 to early 1991, spanning a dry period without occurrence of ENSO, which apparently did not inspire these authors to relate their findings with the phenomenon of the "blooming desert." ENSO and rains did come later in 1991, and the desert duly bloomed.

A different situation was faced by Gutiérrez et al. (1993), who were analyzing vegetation characteristics during a long-term study in Fray Jorge National Park, and where lucky to receive the intrusion of ENSO 1991-92. These authors demonstrated that shrub cover remained constant at ca. 60% from 1989 to 1994, but herb cover changed substantially (from 11-28% during pre-ENSO 1989-90, to 55-97% during ENSO 1991-92, and to 13-21% during post-ENSO 1993-94). And so did the seed bank (from 15,000-17,000/m^2 during pre-ENSO 1989-90, to 30,000-32,000/m^2 during ENSO 1991-92, and to 22,000-26,000/m^2 during post-ENSO 1993-94). This study indicates that two rainy years resulted in important increases in primary production, specifically that of herbs and seeds. The occurrence of ENSO 1997 is still too recent to determine whether the vegetation's response will be the same as in 1991-92, but unpublished data by Gutiérrez & Jaksic indicate that this is really a fact.

ENSO AND THE BIRDS

Among the most easily spotted effects of ENSO intrusions are the massive migrations and subsequent dieoffs of seabirds (Schreiber & Schreiber 1984, 1989, Duffy & Merlen 1986, Ainley et al. 1987, Duffy 1990, Wilson 1991, Massey et al. 1992, Arntz & Fahrbach 1991, 1996). This happens because when fishes migrate to high seas, seabirds cannot keep up with them and begin to starve and soon fail to reproduce (Tovar et al. 1987, Guerra et al. 1988). Even terrestrial birds that inhabit oceanic islands suffer great population losses, although for a different reason (Gibbs & Grant 1987, Grant & Grant 1987, 1993, Hall et al. 1988, Miskelly 1990, Lindsey et al. 1997). In the latter case, when ENSO comes, excessive precipitations result in reproductive failures, and the subsequent drought years that follow (the reverse phenomenon of La Niña), further decimate bird populations because of depleted food resources.

The above being said, it is worth noting that up to now all studies refer to ENSO effects on seabird colonies or of terrestrial birds on small oceanic islands (e.g., the Galapagos). Continental landbirds have not been studied under this perspective, except for a recent paper by Lazo & Jaksic (submitted for publication). These authors show that when ENSO arrived, there was both an increase in bird species richness and abundance from 29 spp. and 15-20/ha in autumn 1996 to 42 spp. and 55-60 birds/ha in summer 1997, in a representative locality of northern Chile (Las Chinchillas National Reserve). They explained these increases as consequences of augmented primary (vegetational resources) and secondary productivity (arthropod abundance).

ENSO AND THE MAMMALS

Sea lions and elephant seals (pinnipeds) also suffer from ENSO intrusions chiefly because their staple food, fish and squid, migrate off and down: This results in an increase in the duration of pinniped "forays to the sea," which in turn translates into more energy spent searching for food than what is obtained when food is actually found and processed. This negative balance shows off in the wearing away of body fat and muscle and in mass mortality of pinnipeds (Arntz & Fahrbach 1991, 1996). For sure, the first to be affected are puppies and juveniles, incapable of feeding by themselves and with lower capabilities for swimming than have adults. Massive mortality of pinniped puppies has been reported during ENSO events along the Peruvian and Chilean coasts (Limberger

1990, Majluf 1991, Arntz & Fahrbach 1991, 1996) and in the Galapagos Islands (Trillmich & Limberger 1985, Trillmich & Dellinger 1991). The arrival of Peruvian sea lions at northern Chilean waters has been proposed as an early warning that El Niño is coming down to Chile (Torres 1985).

Suspicions that rodent outbreaks (or irruptions) were somehow related with unusually high precipitation existed since Pearson (1975) documented the outbreak of 1972-73 along the Peruvian coastal desert. Coincidentally, Fulk (1975) and Péfaur et al. (1979) reported a rodent outbreak during 1972-73 in several localities of northern Chile. A problem with these studies was that nothing was known about the baseline or "normal" population abundances of the rodents involved. An exception was the work of Meserve & Le Boulengé (1987), who followed up for two years the irruption of 1972-73 first reported by Fulk (1975) in Fray Jorge National Park. Another exception was the work of Jiménez et al. (1992), who followed up the irruption of 1987-88 in Las Chinchillas National Reserve.

All of the above-mentioned authors concurred that rodent outbreaks were triggered by unusually high precipitations. For instance, Pearson (1975) showed that the irruption in coastal Peru occurred after an 81-mm winter rainfall at a locality characterized by an average precipitation of 32 mm. Péfaur et al. (1979) showed that 1972 was the wettest year in a series of six (1970-1975). Meserve & Le Boulengé (1987) reported that annual precipitation in Fray Jorge National Park averaged 69 mm from 1969 to 1976, but shot up to 255 mm during 1972. Jiménez et al. (1992) noted that the irruption in Las Chinchillas National Reserve (mean annual precipitation = 206 mm during 1980-1989), occurred in 1987, when yearly rainfall was 513 mm. Summarizing previous studies, Fuentes & Campusano (1985) detected a significant association between years of high precipitation and rodent outbreaks in northern Chile. The same result was obtained by Lima et al. (in press), though with more sophisticated statistical tools.

A major problem with the previous studies is that all took place after ENSO events. Only two recent works have spanned the entire period before-during-after ENSO. Meserve et al. (1995) reported population trends of small mammals in Fray Jorge National Park from early-1989 to mid-1993. An ENSO event started in mid-1991 and ended in mid-1992. These authors showed that seven small mammal species started increasing during spring 1991, some of them immediately after winter 1991 (e.g., *Abrothrix olivaceus* while others lagged one year behind (e.g., *Octodon degus*). In general, small mammals increased their population levels from 12-15/ha in pre-ENSO (1989-90) to 26-117 during ENSO, and decreased gradually in the next two years post-ENSO (from 111 to 43/ha in 1993-94). Jaksic et al. (1996a) spanned the same period, at Las Chinchillas National Reserve, only 100 km south of Fray Jorge National Park. At the former site, however, the increase in rodent abundance was too modest to deserve being labeled an outbreak (> 100 small mammals/ha).

ENSO AND THE TOP PREDATORS

Jaksic et al. (1996b) analyzed the effects the ENSO 1991-92 in Fray Jorge National Park. They gathered 30 months of data before ENSO, and 36 months during and after the event (total = 5.5 years). The rainy winter of 1991 brought an increase of 3X to the seed bank (perennials and ephemerals pooled; see above). Consumers of seeds and herbs (chiefly rodents) increased their population levels 10X during the ENSO years (see details above). Carnivorous predators (hawks, owls, and foxes) displayed a one-year delayed response to small mammal abundance: from 7 individuals/750 ha during 1991 to 17/750 ha during 1992, keeping at that same level during 1993, but decreasing to 14/750 ha during 1994.

Jaksic et al. (1996b) also documented a counterclockwise trajectory of predator abundance versus small mammal abundance, which suggests that the dynamics of the predator/prey system depends on prey levels (The same was concluded by Jaksic et al. 1996a, in Las Chinchillas National Reserve). These authors speculated that the effects of ENSO do not propagate from top trophic levels (predators) to those at the bottom (prey), but in the opposite direction. Based on this scenario, Jaksic et al. (1996b) predicted that as primary productivity varied with precipitation, the same should happen with secondary (small mammal abundance) and tertiary productivity (that of vertebrate predators). The current ENSO 1997-98 should enable to test this prediction.

EFFECTS NOT ATTRIBUTABLE TO ENSO

Evidently, El Niño/Southern Oscillation affects the functioning of terrestrial ecosystems in at least central and northern Chile, but the evidence is inconclusive for southern Chile. For instance, rodent outbreaks were first detected in that part of the country (Philippi 1879), and the chief species involved is the rodent *Oligoryzomys longicaudatus* (Murúa et al. 1986), a known vector of Hanta virus, Andes variant. Despite the remarkable coincidence of the 1997 *Oligoryzomys* irruption –and subsequent spread of the Hanta virus epidemic– with the incursion of ENSO 1997, outbreaks of this rodent seem more related to the masting of several bamboo species of the genus *Chusquea* (Hershkovitz 1962, Murúa et al. 1996, Meserve et al. unpublished ms.), whose long period of recurrence (12-25 years) does not coincide with the more frequent ENSO. A puzzle still unresolved is the outbreak of "*Oryzomys xanthaeolus*" reported in Peru by Gilmore (1944). Inspection of the SST index reported in Allan et al. (1996), indicates that an ENSO may have occurred in 1944-45, but there are no reliable records of precipitation.

CONCLUSIONS

El Niño/Southern Oscillation constitutes an excellent natural experiment that empirically demonstrates the teleconnections that may occur in planet Earth, and at the same time illustrates how atmospheric-oceanographic phenomena may affect the biota, not only marine but also terrestrial. The alternate phases of ENSO, namely El Niño/La Niña, should be explored in greater detail to make reasonable extrapolations about where global climate change may lead us. Global climate change has been thought of as simply a steady increase in the temperature of the planet, but the Southern Oscillation shows that warm and cool phases alternate on such large geographical scales as the entire Pacific Basin. That the two strongest ENSO events occurred at the end of the XX century (1983-84 and 1997-98) suggest that we should be more worried about the occurrence of increasingly more extreme events of El Niño and La Niña, rather than about a gradual warming of the climate.

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