

## A synthesis of ENSO effects on drylands in Australia, North America and South America

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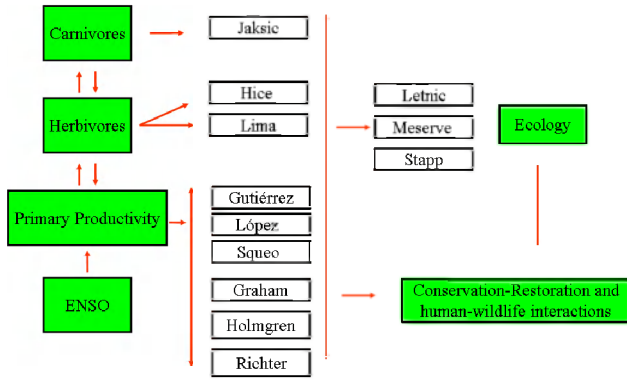
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**Abstract.** Fundamentally, El Niño Southern Oscillation (ENSO) is a climatic and oceanographic phenomenon, but it has profound effects on terrestrial ecosystems. Although the ecological effects of ENSO are becoming increasingly known from a wide range of terrestrial ecosystems (Holmgren et al., 2001), their impacts have been more intensively studied in arid and semiarid systems. In this brief communication, we summarize the main conclusions of a recent symposium on the effects of ENSO in these ecosystems, which was convened as part of the First Alexander von Humboldt International Conference on the El Niño Phenomenon and its Global Impact, in Guayaquil, Ecuador, from 16–20 May 2005. Participants in the symposium shared results and perspectives from research conducted in North and South America and Australia, regions where the ecological effects of ENSO have been studied in depth. Although the reports covered a wide array of organisms and ecological systems (Fig. 1), a recurring theme was the strong increase in rainfall associated with ENSO events in dry ecosystems (during the El Niño phase of the oscillation in the Americas and the La Niña phase in Australia). Because inter-annual variability

in precipitation is such a strong determinant of productivity in arid and semiarid ecosystems, increased ENSO rainfall is crucial for plant recruitment, productivity and diversity in these ecosystems. Several long-term studies show that this pulse in primary productivity causes a subsequent increase in herbivores, followed by an increase in carnivores, with consequences for changes in ecosystem structure and functioning that can be quite complex.

Much of the work presented at the symposium represents research that was or will be published elsewhere. However, we take this opportunity to summarize some of the main points that emerged from our presentations and the resulting discussion on the general effects of ENSO on arid and semiarid ecosystems.



**Fig. 1.** Research lines on ENSO effects in dry ecosystems presented at this conference.

1. Because of its episodic and unpredictable timing and potentially overwhelming impact, ENSO events may be considered a disturbance in many arid and semiarid systems. The nature of the disturbance can be direct (flooding, erosion, drought) or indirect (changes in disease hosts, predator-prey interactions) and from a human perspective, positive or negative.
2. Species clearly differ in their response to ENSO events, often in surprising ways that may be mediated by interactions with other species. Further, there may be important regional differences in relative importance of ENSO events, within an area, as well as in the magnitude of effects of a given ENSO that may or may not be predictable based on climate data.
3. The extraordinary boost in primary productivity associated with ENSO rainfall involves rapid increases in plant cover and seed production of herbaceous species (Hamman, 1985; Dillon and Rundel, 1990; Polis et al., 1997; Vidiella et al., 1999; Block and Richter, 2000; Gutiérrez et al., 2000), as well as enhanced growth and recruitment of trees and shrubs (Austin and Williams, 1988; Nicholls, 1992; López et al., 2005).
4. Herbivores respond to ENSO-induced changes in food (plant) availability by increasing numerically during pulses of abundant primary productivity and by emigrating or having population crashes during ENSO associated droughts. Many different types of herbivores and granivores respond to these fluctuations, including arthropods (Polis et al., 1997, 1998), birds (Grant et al., 2000), and small mammals, whose response has been particularly well studied in Australia (Dickman et al., 1999, 2001; Letnic et al., 2005), in South America (Meserve et al., 2003; Jaksic and Lima, 2003) and in North America (Brown and Ernest, 2002; Stapp and Polis, 2003). Small mammal species differences in their response to ENSO events seem to depend on their feeding habits, reproductive rates and interactions with competitors and predators.
5. Vertebrate predators (including carnivorous mammals and birds of prey) display a variety of responses at all levels of organization. At the individual level, predators shift their consumption of prey over time depending on the abundance of alternative prey (Jaksic et al., 1992; Silva et al., 1995; Meserve et al., 1999). At the population level, predators increase numerically tracking the prey temporal course of abundance (Jaksic et al., 1992; Silva et al., 1995; Lima et al., 2002a; Letnic et al., 2005). Finally, at the community level, the predator assemblage as a whole shows important rearrangements of its richness, composition and structure (Jaksic et al., 1993). The most prevalent guild response is for predators to have lower diet similarity during rainy ENSO events because there is greater abundance and a broader variety of available prey.
6. In arid and semiarid systems, effects on consumers and food webs are mediated by increases in primary productivity, which result from temporary elimination of water shortage (Jaksic, 2001). Although most studies reveal that ENSO events have important bottom-up effects (i.e., plants-herbivores-predators), they are also known to interact with top-down processes (i.e., predators-herbivores-plants) in influencing abundance and dynamics of lower trophic levels (Gutiérrez et al., 1997; Polis et al., 1998; Lima et al., 2002b; Letnic et al., 2005).
7. On arid islands, there is a tight interdependence of ocean and terrestrial systems mainly through the role of seabirds as providers of carrion (dead animals) for consumers and guano as a source of nutrients for plants (Sánchez-Piñero and Polis, 2000). A major consequence of ENSO is to change the relative contributions of terrestrial vs. marine sources to insular food webs (Stapp et al., 1999). The response of these insular systems to ENSO rainy pulses depend very strongly on the presence of seabirds which underscores the importance of a healthy marine environment and the protection of seabirds to the conservation of insular ecosystems.
8. The effects of ENSO events persist for months or even years beyond the actual period of abnormal ENSO conditions, in seed or litter banks or in the tissues of long-lived consumers. Such pulse-reserve dynamics are characteristic of many arid and semiarid systems, and ENSO climatic events are a major driving force of these dynamics in many systems.
9. The consequences of ENSO are best illuminated by long-term, comparative studies that measure multiple resource and trophic levels (producers and consumers). Additional experimental manipulations of ENSO-related changes in resources or abiotic conditions, however, are also needed to elucidate the mechanisms involved (e.g. rainfall augmentation or food addition).

10. ENSO-related changes in terrestrial productivity have substantial effects on human communities and land use, with important implications for restoration, natural resources management and conservation. For example, enhanced establishment of trees during rainy ENSO years could be used to restore degraded arid and semi-arid ecosystems (e.g., Holmgren and Scheffer, 2001; Quispe, 2002; Vilela, 2002); conversely, dry years can reduce the success of reforestation programs (Howden et al., 2004) and increase damage to plant communities and soil via overgrazing by livestock (Ludwig et al., 1997). At the same time, the large plant biomass produced during the wet phase of ENSO provides ample fuel for fires in the subsequent dry years (Skidmore, 1987; Kitzberger et al., 2001; Letnic et al., 2004, 2005; Richter and Ise, 2005). Moreover, ENSO-related changes have strong implications for wildlife conservation and management. For instance, food abundance during rainy years can potentially increase population growth and recovery of some species; however, it can also trigger rodent irruptions that can have severe consequences for agriculture and the spread of zoonotic diseases, such as hantavirus (Hjelle and Glass, 2000; Yates et al., 2002) and plague (Stapp et al., 2004). Additionally, the subsequent increase of exotic predators may endanger native mammal or bird species (Dickman, 1996). Clearly, seasonal ENSO forecasting could be applied to adaptive management and conservation of arid and semiarid ecosystems.
11. The consequences of interactions between global climate change and ENSO are still largely unknown for terrestrial ecosystems, but given the important role of ENSO as a driver of terrestrial productivity, any effects are likely to be profound.

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