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Facing the Desertification Challenge in a Climatically Fluctuating World

M. Holmgren
Forest Ecology and Forest Management Group, Wageningen University, P.O. Box 342, 6700 AH Wageningen, The Netherlands

Abstract: Semi-arid ecosystems can show distinct vegetation alternative states. In many regions, excessive biomass removal (e.g. by wood harvesting, or overgrazing) has resulted in depletion of vegetation biomass and soil erosion. These changes are very difficult to reverse due to the positive feedbacks that stabilize the degraded situation. Here I briefly present a restoration hypothesis suggesting that climatic oscillations such as El Niño Southern Oscillation (ENSO) could be used in combination with controlled grazing to restore degraded arid ecosystems. This idea is currently being tested in Latin America (www.biouls.cl/enso/).

Key words: Land degradation, desertification, ecosystem restoration, ENSO, El Niño.

Land degradation is a major problem in drylands around the world. Original forests and shrublands have been transformed into degraded savannas and deserts. Return to the more lush original vegetation is extremely difficult. Establishment of new trees is crucial for the restoration of many degraded arid and semi-arid ecosystems. However, tree regeneration often fails due to a combination of excessive grazing and lack of water. Both constraints are often so serious that amelioration of only one of them is often not enough.

The usually dry conditions of many drylands around the world are periodically interrupted by dramatic increases in rainfall associated with the El Niño Southern Oscillation (ENSO) phenomenon. During an El Niño episode, rainfall increases in certain areas of the world, while severe droughts occur in other regions. These increases in rainfall can be four to ten times that of a 'normal' year. The phenomenon lasts approximately one year before the climate conditions reverse. The next phase, known as La Niña, produces roughly the opposite climate patterns as found during an El Niño episode. The oscillation between El Niño and La Niña is irregular, but typically occurs once every three to six years (Allan *et al.*, 1996).

A Restoration Hypothesis

Increased rainfall during an ENSO event is crucial for plant establishment, productivity and diversity in many arid and semi-arid ecosystems (Holmgren *et al.*, 2001).

One may imagine that an ecosystem essentially just tracks fluctuations in environmental conditions. However, a fundamentally different thing may happen in ecosystems that have alternative stable states. This implies that under the same environmental conditions (e.g., rainfall) an ecosystem may be in either of two (or more) distinct states. Positive feedbacks in the ecosystem may cause such multiple stability. In this case, a rare extreme event such as

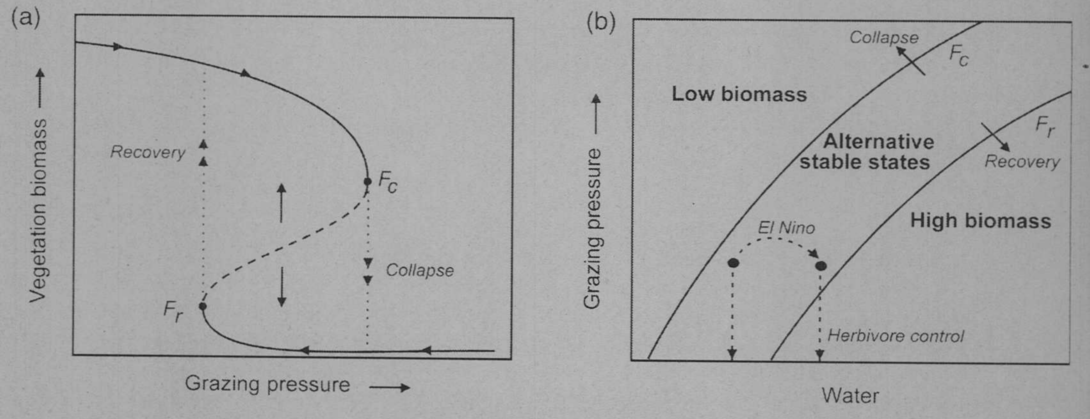

Fig. 1. *Panel (a): Equilibrium biomass of vegetation in semi-arid regions as a function of grazing pressure. The inflection points (dots) of the curve are fold bifurcations that mark critical biomass removal rates. At grazing pressures higher than F_c the vegetation can only be in a state with low biomass. At grazing pressure lower than F_r a high biomass condition is the only stable state. At intermediate grazing pressure (between F_c and F_r) a high biomass state and a low biomass state are alternative equilibria (solid lines) of the system. Here, the dashed middle section of the sigmoidal curve represents an unstable equilibrium that marks the border of the basins of attraction of these two stable branches. Panel (b): Critical thresholds of biomass removal as a function of water availability. Under wetter conditions, equilibrium biomass and the critical grazing pressure for collapse (F_c) or recovery (F_r) are higher. A certain reduction of biomass removal rate (e.g., herbivory control) indicated by the vertical arrows may be sufficient to induce woodland recovery in a wet ('El Niño') year, but not in a dry year (Reproduced with permission from Holmgren and Scheffer, 2001).*

high rainfall, may trigger structural shifts to a different ecosystem state that remains present even after the environmental conditions revert (Scheffer *et al.*, 2001). There is clear evidence that semi-arid ecosystems have alternative vegetation states (e.g., 'woody', 'herbaceous', and 'bare soil') depending on the extent of grazing and water availability (Westoby *et al.*, 1989; Rietkerk and van de Koppel, 1997; van de Koppel *et al.*, 1997).

The existence of alternative states in semi-arid ecosystems has strong implications for the response of these ecosystems to climatic variability such as El Niño Southern Oscillation. Holmgren and Scheffer (2001) hypothesized that ENSO episodes of increased rainfall can be used together with controlled grazing to enhance plant establishment and produce permanent shifts in ecosystem state.

Using a graphical model, Holmgren and Scheffer (2001) inferred the expected combined effects of altered biomass removal levels and changes in rainfall conditions during El Niño. Where woodlands have been lost they can recover if water availability increases and/or biomass removal decreases sufficiently to cross the critical line F_r (Fig. 1b). In regions where El Niño years are wetter than intermittent periods, a rainy El Niño event will shift the system to the moister right hand side in the graph. In some cases, this could be sufficient to allow regeneration of some key-species, triggering a recovery of the woodland. However, in other cases the increased precipitation during El Niño alone will not be sufficient and a reduction of the grazing intensity (lower biomass removal, in general) would be needed to meet the critical requirements (F_r) for regeneration. Note that there can be situations in which a complete exclusion of grazing is sufficient to allow regeneration during rainy El Niño years, but has no effect during normal conditions (Fig. 1b). Thus, in cases where neither herbivore control nor rainy El Niño events alone are sufficient to trigger woodland recovery, tuning herbivore control to rainy El Niño events may result in vegetation regeneration. Note that the idea applies to rainy events in general. As mentioned in the introduction, in various regions of the world La Niña events are wet and El Niño episodes dry.

Importantly, although the pulse of rainfall associated to an ENSO event is a temporal condition, a resulting recovery may be permanent due to the resilience of woodland (an alternative stable state). As long as drought is not so severe and biomass removal is moderate enough to remain below the critical line (F_c) even in dry years, a woodland will remain once it is well established. This is due to the nursing effect of adult trees and shrubs on seedlings, and to the relative tolerance of grown individuals to grazing. This potentially long-lasting effect of a brief regeneration episode makes it worthwhile to invest in making the most out of rainy years such as the ones correlated to the ENSO events (Holmgren and Scheffer, 2001).

Most likely, grazing control is crucial to allow woodland regeneration during rainy years even if the grazing intensity at the start of the year would allow initial seedling establishment. This is because not only plants, but also herbivores respond to the increases in rainfall associated with El Niño. Farmers tend to increase the cattle stock in view of the lush growth of herbs and grasses, and also populations of natural herbivores increase following the productivity peak in plants (Meserve *et al.*, 2003). Obviously, this may lead to the elimination of the establishing seedlings, and potentially even leave the final condition of the vegetation deteriorated rather than improved after a good rainfall year.

Indeed we know that El Niño episodes have triggered structural and long lasting changes in arid and semi-arid ecosystems in the past. For example, recoupment of woodlands in semi-arid Australia (Austin and Williams, 1988) and large increases in shrub cover in the Chihuahuan desert have been linked to extreme rainy episodes related to the ENSO climatic oscillation. Also, several interesting experiences in north Perú have tried to use the rainy

El Niño years for reforestation purposes (Albán *et al.*, 2003). These efforts were initially inspired by the spectacular natural regeneration of several tree species in severe conservation status during the very strong El Niño of 1983. One of the main messages from the Peruvian experiences has been the recognition that herbivore control (against goats and lizards) is fundamental to warranty long-term seedling survival.

Although the idea of using climatic oscillations such as El Niño for dryland restoration seems plausible, it is awaiting a more formal experimental proof. At present the idea is being tested in semi-arid ecosystems of Chile and Perú (www.biouls.cl/enso/).

From Theory to Management

The potential use of climatic fluctuations for restoration face difficult climatic, ecological and social challenges. Forecasting the ENSO events in advance is crucial. At present, forecasting is possible a few months in advance and our understanding of this climatic phenomenon is improving. We need to understand in which ecological conditions ENSO rainfall can enhance vegetation recovery, especially under different grazing scenarios. Since ENSO events vary in intensity, we also need to know how much water availability would probably be needed to pass the threshold for vegetation recovery. The ecological success of the El Niño approach depends largely on both the socio-economic and the local climatic conditions. Clearly, many social factors are involved in determining whether or not this new approach to the restoration of degraded drylands will become embraced on a larger scale as a management practice. Among others, it will need a change of habit from managers and landowners that are now used to plan reforestation actions regardless of fluctuating climatic conditions and often herbivores conditions. It is possible that few individuals will initially accept this new idea until a tipping point may be reached at which a positive feedback mechanism creates a rapid increase of the percentage of 'believers' until it stabilizes at a high level of recognition (Scheffer *et al.*, 2002).

Adapting to Global Climate Change

The origin of the variability in the strength and frequency of the ENSO events is still unknown. El Niño has been occurring for millennia, but several studies have noticed an intensification of the ENSO signal during the 20th century (Tudhope *et al.*, 2001). Since the late 70's there has been a tendency for more El Niño and fewer La Niña events, indicated by a long period of negative Southern Oscillation Index (SOI) (Trenberth and Hoar, 1997). Also, the two strongest ENSO events of the century took place in the second half of the century (1982 and 1997).

This pattern is considered highly unusual and very unlikely to be the result of natural variability alone (Trenberth and Hoar, 1997). There is still great uncertainty on the effects of global climate warming on ENSO dynamics (Collins, 2000), but recent high resolution climatic models suggest that the frequency of El Niño like conditions should be expected to increase over the coming decades (Timmermann *et al.*, 1999). Changes in the frequency and intensity of the ENSO oscillations will likely have profound ecological consequences. Therefore research on ENSO long-term ecological effects and potential ways of adaptation to this climatic variability will be of crucial importance in the coming decades.

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