RANGELANDS

Impact of ENSO events on the Kruger National Park's vegetation

Konrad J. Wessels
Patrick C. Dwyer

The El Niño Southern Oscillation (ENSO) is a global coupled ocean-atmosphere phenomenon that is a primary driver of inter-annual variability in the rainfall and consequently the vegetation production of southern African rangelands. Evidence from the Kruger National Park shows the strong relationship between the ENSO episodes (droughts during El Niño and high rainfall during La Niña episodes), rainfall, grass production and satellite time-series data of vegetation activity. El Niño conditions have lead to the devastating droughts in 1991-92, 1997-98 and 2002-2003 while La Niña conditions lead to very high vegetation production (1995-96 and 1998-99), but also flooding (1999-2000). This chapter briefly discusses the management implication for the park and neighbouring communal areas.

Introduction

The El Niño Southern Oscillation (ENSO) is a global coupled ocean-atmosphere phenomenon that refers to temperature fluctuations in surface waters of the tropical Eastern Pacific Ocean. When sea surface temperature anomalies of greater than 0,5 °C persist for more than five months it is known as an El Niño (warm anomaly) or a La Niña (cold anomaly) episode. Droughts in South Africa are closely linked to warm ENSO (El Niño episodes) and the past twenty years have seen some of the strongest ENSO events in recorded history [1, 2]. ENSO is an important driver of inter-annual variability in the rainfall and consequently the vegetation production of southern African rangelands [2]. These droughts have caused huge livestock losses (especially in 1991-92) and thus pose significant challenges to communal and commercial livestock farmers, as well as wildlife managers. In addition, the 1999-2000 La Niña caused disastrous flooding in southern Africa.

Daily, coarse resolution satellite data (250 m to 1 km pixel size) are routinely used to estimate the photosynthetic activity of vegetation over vast areas. Vegetation indices, such as the Normalised Difference Vegetation Index (NDVI), use the contrast in the reflectance between the visible and infrared wavelengths to measure photosynthetic activity of vegetation. By tracking these vegetation indices throughout an entire growing season, the total amount of vegetation production can be estimated.

Time series of satellite vegetation index data allows us to monitor vegetation production and thus the impacts of droughts over multiple years. It is essential to quantify the impact of natural, inter-annual, climate variability (driven by ENSO events) on the ecosystem services, such as rangeland production, so that the impacts of human-induced land degradation and long-term climate change can be viewed against this background variability. This paper will demonstrate how the impacts of ENSO episodes on vegetation production in the Kruger National Park and surrounding areas can be monitored using long-term satellite time-series data and field measurements.

Satellite data

Daily Advanced Very High Resolution Radiometer (AVHRR) data have been recorded by the CSIR Satellite Application Centre since 1985 and is one of the most complete 1 km AVHRR data sets in the world. The data were consistently processed and calibrated by the Agricultural Research Council – Institute for Soil, Climate and Water (ARC-ISCW). The NDVI is calculated from the visible and infrared channels of the data and clouds are masked out. The impact of clouds and other atmospheric effects are removed from the data calculating ten-day maximum NDVI value composites. The NDVI values are summed over the growth season (October to April) to estimate total grass biomass production (Figure 3.24) [3].

The Moderate Resolution Image Spectroradiometer (MODIS) is a vast improvement on the AVHRR sensor and became available in 2000. The 16-day Enhanced Vegetation Index (EVI) (an improvement on the NDVI) composite data is available at 250 m resolution (pixel size) on the Internet. The growth season sum EVI was calculated after automatically detecting the start and end of the growth season as the 10% threshold of the individual annual amplitude. The growth season was therefore not fixed as in the case with the AVHRR data, but variable in timing and length.

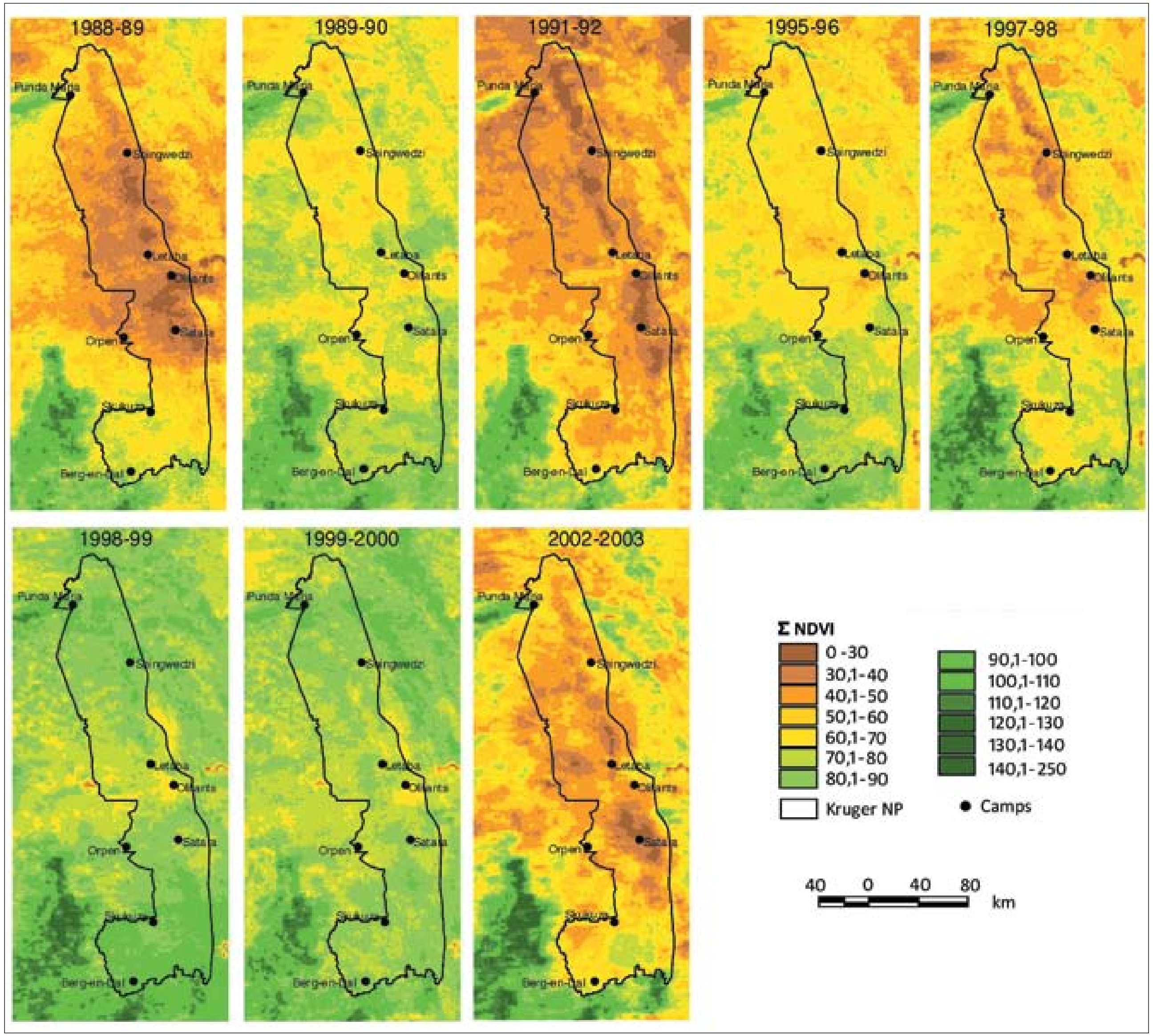

Figure 3.24 Growth season sum (October to April) of the NDVI of AVHRR satellite data illustrating the influence of the low rainfall El Niño (1991-92, 1997-98 and 2002-2003) and high rainfall La Niña (1996-96, 1998-99 and 1999-2000) episodes on vegetation production of the Kruger National Park and surrounding areas. [3]

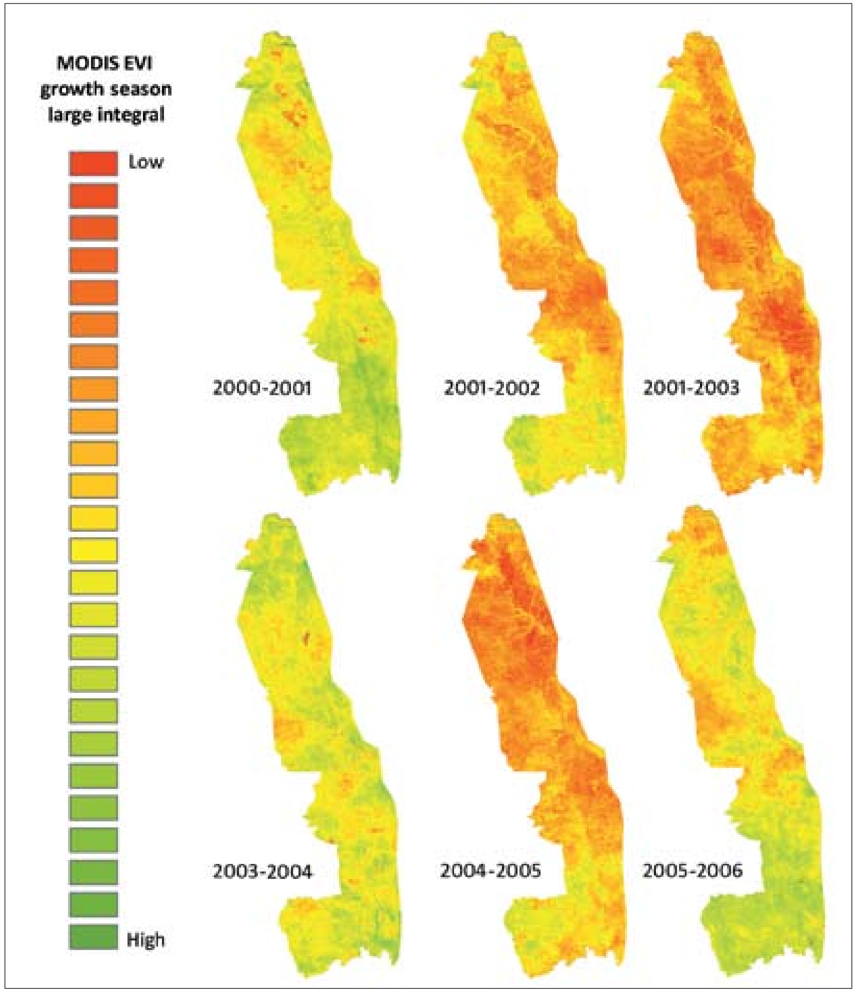

Figure 3.25 Growth season total (large integral of seasonal EVI curve varying between October to April) EVI of MODIS satellite data illustrating the influence of the low rainfall El Niño episodes (2002-2003 and 2004-2005) and above average rainfall (2000-2001) on vegetation production of the Kruger National Park.

Field measurements for 'ground truthing'

Satellite data are not of much use without field measurements of vegetation parameters, which are necessary for developing predictive models and testing the accuracy predictions of vegetation production. End-of-season standing grass biomass are recorded annually (since 1989) at more than 500 sites (called vegetation condition assessment or VCA sites) in the Kruger National Park. The remotely-sensed estimates of vegetation production (growth season sum NDVI and EVI) are strongly correlated with these field measurements (Figure 3.26) [3]. Although these VCA sites were not initially designed to be compared with coarse resolution satellite data, they turned out to be very useful. The VCA sites are only 50 × 60 m in size, which is significantly smaller than the 1 km AVHRR or 250 m MODIS pixels. Without these field data it would have been impossible to ground-truth the satellite data and demonstrate its value.

Figure 3.26 Annual grass biomass measurements taken with a disk pasture meter at one of 533 VCA sites in the Kruger National Park. [Konrad J. Wessels]

The impact of ENSO events on rainfall and vegetation production

The ENSO phenomenon is monitored from sea surface temperatures in the Eastern Pacific Ocean. The Oceanic Niño Index (ONI) is based on the three-monthly mean sea surface temperatures and expresses severity of the ENSO phenomenon on an ongoing basis [1, 2]. Figure 3.27 graphs the strong relationship between the ENSO (ONI index), rainfall, growth season sum NDVI (AVHRR) and grass biomass measured at Skukuza in the Kruger National Park. Given the diverse nature of the measurements involved (from sea surface temperatures in the Pacific, ONI to grass biomass in field plots) this strong relationship is truly remarkable.

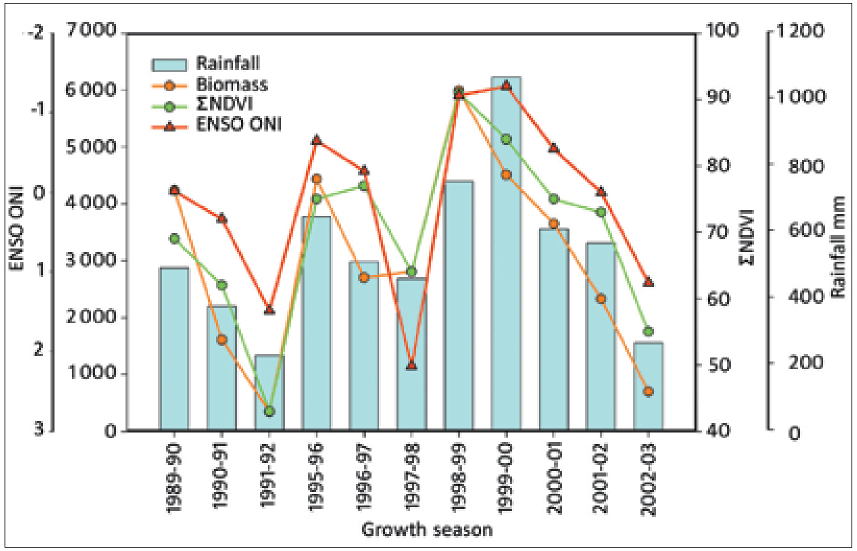

Figure 3.27 Graph showing the strong relationship between the Oceanic Niño Index (inverse scale, high + values indicate El Niño, high – values indicate La Niña episodes), rainfall, grass biomass and AVHRR satellite's growth season sum NDVI for Skukuza in the Kruger National Park.

During the 1991-92 El Niño, just over 200 mm rain fell in Skukuza with the result that less than 400 kg/ha grass was produced. In contrast, a very strong La Niña episode persisted over the 1998-99 and 1999-2000 seasons resulting in very high rainfall (750 and 1 050 mm respectively) and very high grass production, close to 6 000 kg/ha in 1998-99. All the rain that fell during the 1999-2000 flooding could clearly not be utilised by the vegetation (Figure 3.27). This illustrates the huge influence that ENSO has on rainfall and vegetation production.

The impact of the droughts caused by El Niño episodes on the vegetation production of the Kruger National Park is evident in the AVHRR satellite data for 1991-92 (one of the driest years on record), 1997-98 and 2002-2003 (Figure 3.24). The very high vegetation production as a result of the high rainfall during 1996-96, 1998-99 and 1999-2000 La Niña event is very clear in the AVHRR growth season sum NDVI (Figure 3.24).

The impacts of the 1999-2000 La Niña event was still evident in the high vegetation production in the 2000-2001 growth season, as indicated by the MODIS satellite data (Figure 3.25). This was followed by the droughts caused by the 2002-2003 and 2004-2005 El Niño episodes. The historical satellite time-series data can therefore provide essential spatial information on ecosystem variability and resilience in the context of ENSO episodes.

Responses to ENSO – management and adaptations

Drought driven by ENSO is a natural part of this highly variable ecosystem and SANParks policies and management do not attempt to override the impacts of this process [4]. In fact, droughts may be beneficial to the national park's conservation objective of maintaining natural patterns and processes in order to maximise the maintenance of biodiversity through time. For example, although herbivores may suffer during extreme and extended drought periods, other species such as predators (for example, wild dogs) may flourish. The reverse is true during extreme wet periods when the herbivores are widely distributed and generally in good condition. Although the provision of artificial water holes might appear to be a solution to the general public, research has shown that this merely exacerbates starvation-induced mortality of game [5] and may severely degrade the vegetation over large areas around the watering hole [6].

ENSO episodes also have a very large impact on fire in the Kruger National Park and fire is a major driver of vegetation structure, such as the balance between grass and trees in the savanna. In the winter season following an El Niño summer, only a very small portion of the park burns naturally (less than 5%) because there is very little grass to fuel the fire. Conversely, as much as 30-50% of the park can burn following a high rainfall La Niña summer season when grass fuel is abundant [7]. In order to avoid disastrous runaway fires following a high rainfall growth season (for example, 1996-97) the park applies prescribed burning early in the fire season (April to June) to reduce the amount of grass fuel and break up the landscape into a mosaic of burnt and unburned areas with low intensity fires. The park thus has to perform many prescribed burns in a La Niña year and very few, if any, in an El Niño year.

In contrast with the Kruger National Park, livestock and game farmers find themselves in a precarious position, where their livelihoods are often at the mercy of ENSO. The 1991-92 El Niño caused massive cattle deaths in the neighbouring communal areas when households lost more than half of their herds [8]. The cattle numbers are only now recovering to pre-1991 levels, although fewer households now hold any cattle. Interestingly, an adaptation to El Niño in the communal areas appears to be a switch from cattle to goats, which are cheaper, less vulnerable to drought and reproduce faster. The negative impact of drought on cattle ownership might force families to turn to new alternative livelihood activities not pursued before, such as the sale of fuel wood [8].

It is clear that ENSO has a very large impact on the rainfall, vegetation and fire in the Kruger National Park and surrounding areas. In fact, ENSO has a significant impact across southern and eastern Africa as well as the rest of the globe [2]. Long-term satellite data sets, climate data and field measurements are indispensable in monitoring these impacts, but need to be appropriately employed to reduce the vulnerability of rural livelihoods to ENSO episodes [9].

Acknowledgements

Philip Frost and Dawie van Zyl processed the AVHRR data. We thank SANParks for access to the VCA data.