ECOLOGY, CONSERVATION AND CLIMATE–FIRE CHALLENGES ON ULUGURU MOUNTAIN BIODIVERSITY HOTSPOT, TANZANIA

A DISSERTATION

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BY

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Dedication

I dedicate this work to my loving family; you encourage me to reach out for my dreams.

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Chapter 1: Introduction

The government of Tanzania established the Uluguru Nature Forest Reserve (UNFR) in 2008 (Box 1) (URT, 2002). The UNFR is located in the Uluguru Mountains, part of the Eastern Arc Mountains of Tanzania and Kenya that are rich in unique fauna and flora that are of both local and global conservation value. Humans started settling and farming on the slopes of the Uluguru Mountains in the 1800s, and the evidence of fire on the Eastern Arc Mountains, of which UNFR is part, dates back ten thousand years (Mumbi *et al.* 2008). Fire in the UNFR has been a concern for more than a century and efforts to suppress fire in the UNFR (formerly known as Uluguru Territorial Forest Reserve [UTFR]) were institutionalized but have never been successful. In 1909, German colonial rule (1880s-1918) institutionalized a management plan for the UTFR, which included fire suppression. Later the British (1919-1961) and Tanzanian government (1961-present) continued with the plan to suppress fire in the UTFR, all in failure. Colonial governments put in place regulations and laws to stop local people from using fire as a farm management tool. Often fire suppression regulations and laws were enforced based on the assumption that local people did not know the importance of the forests around them so they just let them burn. Laws and regulations for suppressing fire put strict controls on the activities of local people. Colonial administrators and foresters accused local people of starting these fires and the local people were at the center of the fire issue in the UTFR. Accusations led to conflicts between local people and the colonial administrators and foresters, so much so that in the 1950s the local people around the UTFR torched the forest in protest against a forced land use scheme in their area

Box 1 Government Notice for Uluguru Nature Reserve (UNFR)

Forest Act (Uluguru Nature Forest Reserve) Declaration

GOVERNMENT NOTICE No. 296 PUBLISHED ON 7/11/2008

FOREST ACT, 2002

(CAP. 323 R.E. 2002)

ORDER

(Made under section 29(1))

THE FOREST ACT (ULUGURU NATURE FOREST RESERVE) DECLARATION ORDER, 2008

1. This Order may be cited as the Forests (Uluguru Nature Forest Reserve) Declaration Order, 2008 and shall come into operation on the date of publication.

2. The area of reserved land within the limits defined in the Schedule to this Order formerly declared to be Uluguru North Territorial Forest Reserve and Uluguru South Territorial Forest Reserve under Government Notice No. 578 of 1963 and Bunduki Territorial Forest Reserve under Government Notice No. 44 of 1946 are hereby altered to be Uluguru Nature Forest Reserve.

3. The Government Notices No. 578 of 1963 and 44 of 1946 are hereby revoked.

SCHEDULE

MOROGORO AND MVOMERO DISTRICTS ULUGURU NATURE RESERVE

Approximate area: 24115.09 hectares (241.15 sq. kilometres)

Situation and Boundaries: All that area of reserved land formerly under Uluguru North, Uluguru South, and Bunduki Territorial Forest Reserves, including the land namely Bunduki corridor that links the former Uluguru North and Uluguru South Territorial Forest Reserves and the piece of land that links the former Uluguru Territorial Forest Reserve and former Bunduki Territorial Forest Reserve. The Boundaries marked by beacons and directional trenches enriched with border trees, located on latitude $7^{0}02^{'}00^{''}$South and longitude $37^{0}39^{'}30^{''}$ East as delineated and described on Forestry and Beekeeping Division Plan No. JB 2541a Deposited with the Director of Surveys and Mapping Division of the Ministry of Lands, Human Settlement Development, Dar Es Salaam.

Dar Es Salaam SHAMSA S. MWANGUNGA

25th October, 2008 *Minister of Natural Resources and Tourism*

(Temple, 1972). During colonial rule, efforts to suppress fire in the UTFR failed and, fifty years after independence, fire continues to burn in the UNFR and conflicts persist between local people and forest officers. Currently, there is a poor understanding of fire in the UNFR. To that end, this research explores the ecology, climate-fire synergy, and conservation challenges in the UNFR.

Fire suppression in natural forests and nature reserves has been highly contested. The contestation hinges on two schools of thought regarding fire in natural forests. One line of argument is that fire has been part of the ecosystem and is an unavoidable ecological process: fire regulates vegetation competition, supplies nutrients to the soil, controls pests in forests, and in general sustains the forest ecosystem (Sugihara, *et al*., 2006, Shlisky, *et al*. 2009). However, other scholars and conservation agencies argue that fire threatens biodiversity, particularly when these fires are human-induced (Burgess et al., 2007). Because the fires in UNFR are anthropogenic in origin (Lyamuya *et al*., 1994), the fires do not conform to the interannual variations common in natural fire regimes (Kull and Laris, 2009). Even low intensity fires often kill a large percentage of the evergreen tropical forest canopies, which makes these anthropogenic fires detrimental in tropical forests (Barlow et al., 2003) because they may occur at the time when forests are experiencing extreme moisture deficits and have accumulated abundant fuel.

Variations in climate (especially precipitation) determine the amount of available moisture in tropical forests, which is a component that further complicates the fire issue. Extreme moisture stress in forests increases the vulnerability of forests to fires. Therefore, climate and fire are related.

The change in status from UTFR to UNFR is fundamental for the management of fauna and flora and other environmental, social, cultural, economic services the nature reserve offers locally and beyond local boundaries. Local and international nature conservation agencies, environmental activists, foresters, donors, and the government of Tanzania are happy with the achievement. However, the conundrum remains how to manage fires and fire-related conflicts in the UNFR. Changes in the way the Reserve will be managed are currently under consideration by the Office of the Chief Conservation Officer in Morogoro. Management of the UNFR involves managing two key aspects: the reserve itself ("nature") and the local people surrounding the reserve ("society"). At the center of the management plan is the idea that nature and people must be managed separately in order to sustain both nature and society. However, nature and society are intertwined so that without a thorough understanding of the interrelationships, management for both may fail.

In order to address the overarching objective of this research - to understand the conservation and climate-fire interactions that pose challenges in managing the UNFR - I have divided the core theme into subthemes. In the second chapter, I investigate the conflicts between the forest officers in charge of managing the UNFR and local people around the UNFR. In this chapter I tackle the question: Why do conflicts between forest officers and local people persist? What forms do these conflicts take and how are these conflicts mediated?

In the third chapter I address the interaction between fire and climate. I focus on the interaction between local precipitation and local factors such as topography and altitude and also teleconnections (the Indian Ocean Dipole and the El Niño-Southern Oscillation). In addition, I use data for the 1985-2007 period to underscore how the interaction between local rainfall and teleconnections affects local fire regimes in the UNFR.

In the fourth chapter, I focus on the effect of fire on trees in the northwestern UNFR. I look at how fire has or has not affected tree species diversity in this area. First, I address how tree species diversity in unburned areas compares with burned areas of the UNFR. Second, I inquire whether burned and unburned stands depict any sere development that provides evidence of the impacts of fire.

I conclude in the fifth chapter by highlighting the key findings of this dissertation research and some proposals for the way forward. I wrote Chapters 2, 3 and 4 as independent journal manuscripts so that each manuscript has its own references, figures, tables and formatting.

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Chapter 2: Unpacking Conflicts Between Forest Officers and Local people Over Fire Incidences in Uluguru Nature Forest Reserve (UNFR), Tanzania.

In this study, I focus on the factors that drive conflicts between local people and foresters over fire events in the UNFR. Combining archival fire-events data with the findings from in-depth interviews with researchers, foresters, conservationists, and local people, I discern four types of fire-related conflicts between foresters and residents near the UNFR: *Interest, Structural, Relationship* and *Information Vacuum*. Most fires in the reserve are accidental. Therefore, viewing the local people as ‘the problem’ and their livelihoods as ‘the threat’ to the reserve is an overly simplistic assessment of the situation, which does not take into account the complexities of the social situation and the interests of the individuals involved. Indeed, people are not the focus of the current model of managing the reserve. Because the local people and the Reserve are inseparable, the Tanzanian government must involve local people in the management of the UNFR to ameliorate fire-related conflicts.

Introduction

“I think the fines that local people pay for being arrested for starting fires are too little to stop them from repeating the act….” Forest Officer, Morogoro, July 2009.

“Traditional laws [from the 18th Century through the mid-19th Century] were not that punitive, the traditional government would not let, say, jail a person or cane people.

There were high conduct standards and respect amongst people, they were fearful of something forbidden (*Mwiko*), nobody questioned forbidden things…so people never did forbidden things, it was just that, which served forests." Local leader, Morogoro, January 2009.

The two viewpoints illustrated in these quotations about the management of the UNFR (Uluguru Nature Forest Reserve,[1] formerly known as Uluguru North Territorial Forest Reserve and Uluguru South Territorial Forest Reserve) contradict one another. The viewpoints illustrate the ways in which trained forest managers, acting through the central government, and local people,[2] acting through their traditional administrative system, would act to abate fires in the UNFR, and indicate how widely views on fire incidence in the UNFR can vary. This ideological divergence stems from, I argue, two sources. The first source is the way each narrative frames individual feelings and how these feelings shape *trust* in a forest management paradigm. The second source is how the ideologies challenge the efficacy of either modern or traditional knowledge systems in forest management, including fire suppression. At the center of each narrative is a human agent interacting with the forests and shaping the observable characteristics that define forest degradation or forest health. Managerial excellence involving a particular forest management model is essential for the success of addressing anthropogenic drivers of forest degradation (including stopping incidents of fire).

[1] The UNFR is located on the North and South ranges of mountains called the Uluguru. I use UNFR and Uluguru interchangeably.

[2] I use the term "local people" as a general term for people who live[d] on the slopes of the UNFR on Uluguru Mountain, regardless of their ethnic identity, class, gender, education or occupation.

Neither traditional nor modern model of forest management is necessarily better; however, area-specific forest management success stories demonstrate the effectiveness of a particular model in the area over time. I identify two conflicting institutions that affect the care of the forest: the first is the local or traditional institution, while the second is the state or modern institution. While the traditional institution is rooted in local space, the state or modern institution exists in three spatial dimensions: grassroots (Village, *Kata* and Division), regional (District, Region), and national (Ministry/State).

The management of the UNFR today is a legacy of colonial nature management. The German (1880s-1919) and British (1919-1961) colonial governments used a protectionist approach to restrict local people's access to the Uluguru forests through various laws and regulations. From 1929-1955, the colonial government established and enforced stringent requirements, such as obtaining permits to burn one's own land, mandatory use of fire breaks around each farm, regulations to prevent large-scale burning, and an organized survey of forest boundaries (Temple, 1972,1973; Lundgren, 1978). However, conservation policies during the colonial era were not locally tailored (Temple, 1972) and excluded the role of the local people in forest management. After Tanzania's independence in 1961, a protectionist approach continued to characterize forest policies. For example, from1963-1996 it has been unlawful to enter the forest without a forest officer's permit (Bhatia and Ringia, 1996). Despite these efforts, fires persist in the UNFR (Frontier-Tanzania, 2005).

To understand the conflicts related to human-induced fires in the UNFR, I recast the current explanatory trajectory to provide alternative interpretation and understanding of the root cause of fires. The accusation that individuals, in this case people who live in the area, start fires is a one-sided characterization of a fire phenomenon; its advocates assume that local people are the problem and that there is something inherent in this area or the local people that explains the high fire incidence in the UNFR. A thorough understanding of fires in the area requires approaching the issue as complex and informed not only by multiple levels of spatial context and their interactions, but also by history (Robbins, 2004). To explicate the phenomenon of fire in the UNFR over time and space, I draw from social construction theory, rooted in the work of 19th Century radical philosopher Immanuel Kant, who proposed the constructed nature of observed phenomena (Robbin, 2004). The overarching questions for this study are: (1) Why do fires persist in the UNFR, in spite of all the efforts in place to suppress them? (2) What forms do conflicts over fires take? and (3) How are these conflicts mediated?

Drawing from the literature on constructivism, especially what Robbins (2004) called soft constructivism (a focus on people's misperceptions of objective facts or the social inclinations that infiltrate scientific endeavors), does not mean ignoring the physical processes that affect the UNFR, such as fire or variations in climate. While the effects of fire on forest vegetation is a *physical* output of fire interacting with the vegetation, some of the processes that lead to fire occurrences reveal temporal and spatial processes of *power* that culminate in conflicts over fire incidence between the local people and UNFR managers. Power and conflict point to the literature on conflict theory, originated by philosophers such as Marx (1818-1883), and later extended by Weber and many other scholars in nature-related conflict studies today (e.g., Skutsch, 2000, Nygen, 2000, Tropp, 2003, Sangiga et al., 2007). I do not address claims of power relations and the production of capital because they are not related directly to this study; however, I concur with the idea that conflicts involve two groups or two perspectives and result from those who have power trying to perpetuate that power. Struggle begins as a response to the unjust practices that those with power impose on those without power.

Schroeder (1999) noted that the government of Tanzania, local and international nature conservation organizations, and private entities that benefit from conservation activities have asserted dominion over nature, denying local people the rights to access the same. The state, private institutions, and local and international conservation agencies share interests and interpretations of what nature should be, specifically, that nature conservation areas must be devoid of people. This environmental imagery (Nygren, 2000) is a social representation that affects the formulation and management of nature reserves and local people near nature reserves. The involvement of dichotomous parties, which are asymmetrical in power and interests, results in a conflict of interest. At the micro-level, the struggles and resultant conflicts may stem from an individual in response to effects that other conservation stakeholders cause him/her. Investigating the past and current power relationships that involve different processes and entities in the management of the UNFR will lead to improved fire management and fewer fires.

This study comes at a crucial turning point: the Tanzanian Ministry of Natural Resources and Tourism is currently revising the command-and-control approach in forest management and implementing Participatory Forest Management (PFM) in Tanzania (United Republic of Tanzania, 2002). This study will benefit the Uluguru Nature

Reserve Conservator Office as its officers draft a management plan for the UNFR. The benefits of this study for the local and international biodiversity conservation community, who wish to see peace and biodiversity sustained in the UNFR for generations to come, are invaluable.

In the next section, I describe the study area and the methods of data collection and analysis. In the results section, I describe the context of the conflicts, the types of conflicts, and the current model of fire suppression in the UNFR. A discussion of the key findings follows. I conclude by reiterating the salient findings of this study.

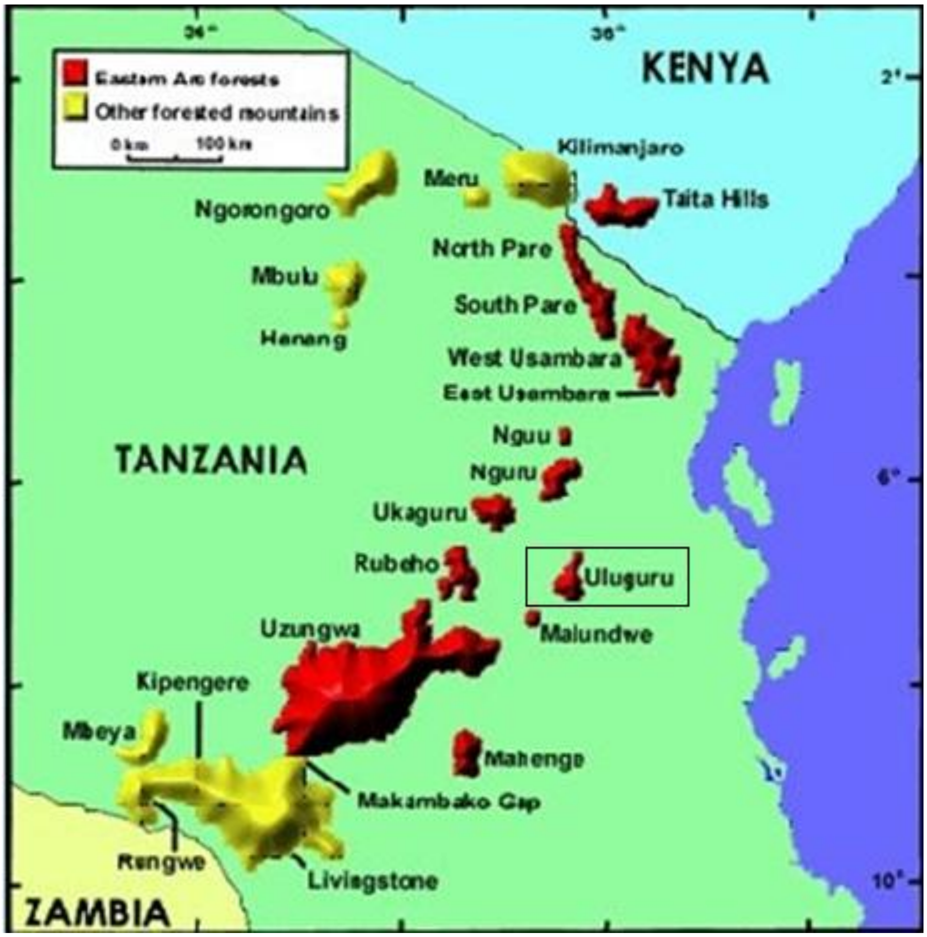
Methods

Description of the Study Area

The government of the United Republic of Tanzania, through Government Notice Number 296 of July 11, 2008, declared the former North and South Uluguru Territorial Forest Reserve as Uluguru Nature Forest Reserve (UNFR) (Figure 2A). The Uluguru Nature Forest Reserve lies south of the equator $06^{o}51'$–$07^{o}12'$S and $37^{o}36'$–$37^{o}45'$E and includes 291 square kilometers of forest area (Burgess and Mhagama, 2001). The UNFR is one of a chain of 12 mountain blocks of the Eastern Arc Mountains (Figure 1), stretching 900 km from Makambako (in southern Tanzania) to the Taita Hills (in South Coastal Kenya) (Critical Ecosystems Partnership Fund, 2003). The main soil types are acidic lithosols and ferralitic red, yellow and brown latosols that developed on

Precambian granulite, gneiss and migmatite rocks (Frontier-Tanzania, 2005). The terrain is steep, although sometimes forests thrive on 50^0-70^0 slopes.

Figure 1. UNFR and the Eastern Arc Mountains (red color)

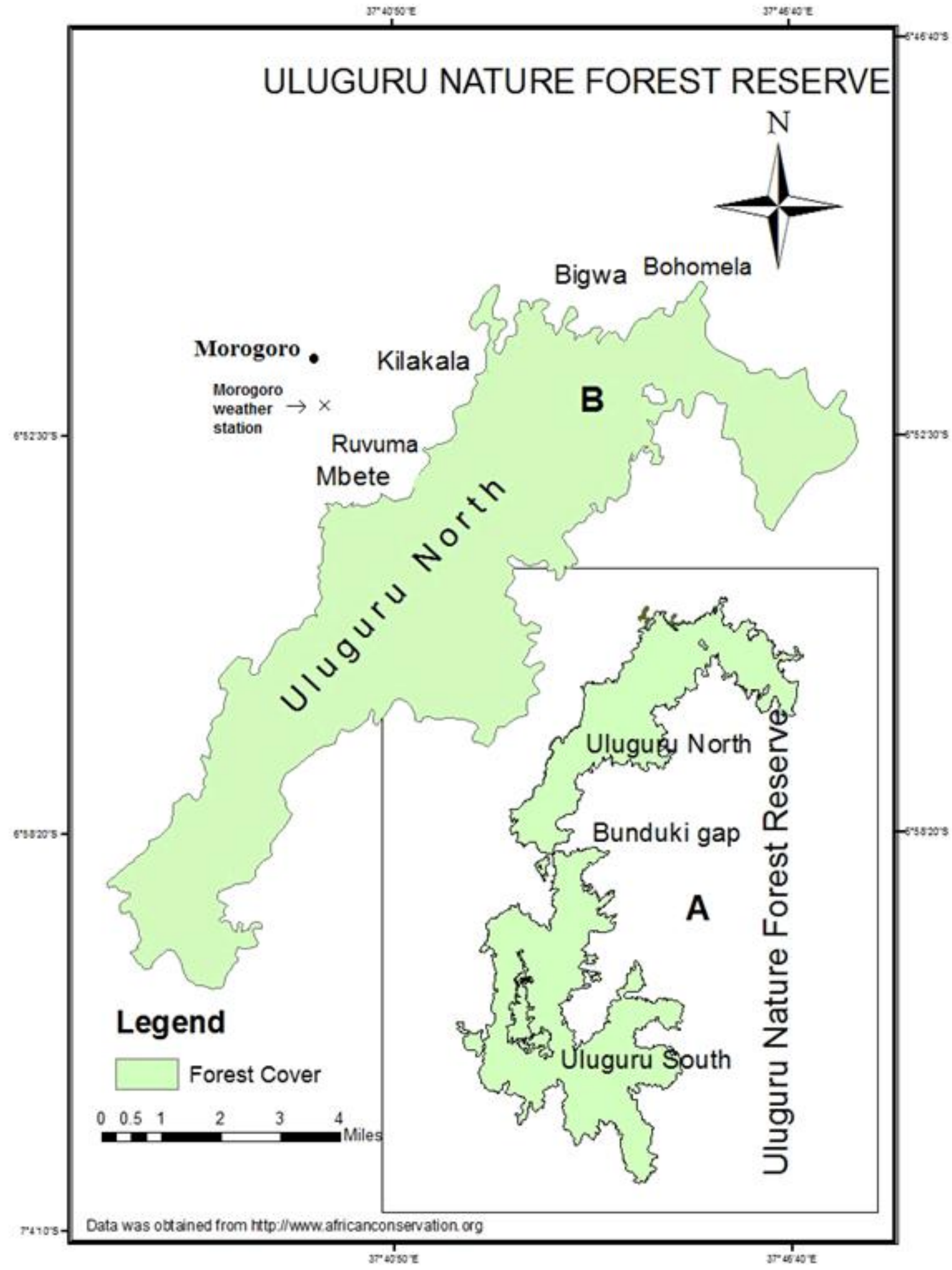


Source: www.easternarc.or.tz/eastarc

In this study, I focus on the northwest section of the UNFR (Bigwa to Mbete, a north-south transect, Figure 2B), in particular on the forest ecotone bordered by a wooded grassland under the control of the Morogoro Municipal Council. The Bigwa-Mbete stretch has the most fires of the UNFR sections (personal observation, 2008). This area is on the leeward side of winds from the Indian Ocean and receives less rainfall (1200-3100mm/year) than the eastern area (3000-4000mm/year) (Burgess and Mhagama, 2001).

The UNFR supports more than 135 strictly endemic plant species, as well as hundreds of plants endemic to the Eastern Arc Mountains (EAM); 26 EAM endemic tree species grow in the UNFR (Burgess, 2001, Burgess et al., 2001). In addition, the UNFR sustains 16 strictly endemic vertebrate species, 45 EAM endemic and 82 near-endemic vertebrate species (Burgess, 2001, Burgess et al., 2001, Doggart et al., 2001), and 169 invertebrate species, most of which depend on the forest (Burgess et al. 2001). Moreover, the UNFR supports several red-listed species, including 8 birds, 17 reptiles, 20 amphibians and an undocumented number of invertebrate species (Baker, 2002, Svendsen et al., 1995).

Figure 2. Uluguru Nature Forest Reserve (UNFR), showing Uluguru North



Data Collection

I obtained data on arrests and fire incidence from the Catchment Forestry Office (CFO) in Morogoro, Tanzania. The CFO started documenting fire incidents in the 1980s, so the archival data in the study represents the incidents of fire in the UNFR from the 1985 through 2007. Data on fire occurrences included information on the cause of the fire, whether foresters made any arrests, and if so, whether they took to court the arrested person. In addition, I conducted in-depth interviews with scientists (researchers, foresters, and conservators) who work or have worked in the Uluguru Nature Forest Reserve to record their views on fire incidents and the underlying reasons for fire occurrences. I also questioned respondents about their experiences with actions that forest officers took on arrested people accused of starting fires in the UNFR. I inquired about their opinions of the justice of the approach conservators use in managing the UNFR and whether the model was a sustainable one for the maintenance of biodiversity and peace and harmony between conservators and the local people. I obtained scientists' recommendations for increasing peace and tranquility by decreasing the incidence of fire and the concomitant arrest of local people who started fires.

Data Analyses

I transcribed all audio file information from the in-depth interviews into text format. From the transcribed text, I grouped the similar ideas into specific themes (Emerson, 1995). I read the themes as a text that represented the ideas and feelings of the interviewees and the reasons for those ideas and feelings. Understanding each theme in this way helped me interpret the ideas that arose during the in-depth interviews. I also went through 91 fire reports I obtained from the Catchment Forestry Office, Morogoro. Because fire reports were hard copies, I read the documents and identified similar themes. As with the interviews, I read the fire reports as a picture of the day of the fire event, but also considered other factors that affected the content of the reports. Next, I synthesized the information from the fire reports and the in-depth interviews to interpret the meaning of the information provided (Bernard, 2000). Most fire reports were in Kiswahili; I conducted most interviews in Kiswahili and later translated them into English.

Results

The context of conflicts. On the night of January 25, 2009 there was a fire event in the Uluguru Nature Reserve. The fire started in an area I had visited with a forest officer during the day to assess plant species diversity in fire-prone areas. On the morning of the 26th, government officials, foresters, and a few individuals from the municipal fire department went to the area to extinguish the burning fire. Although I had originally planned to go to Bohomela, the fire was easily visible, and I decided to go to the fire site. On the way to the UNFR, we met a local male in his mid-forties or early fifties returning from the forest with dead wood for fuel. One of the government officials asked him, "Don't you see fire burning up there?" The man replied, "So what can an individual like me do?" The statement irritated the government official who ordered his immediate arrest and placement under police custody.

This confrontation, involving individuals with an asymmetrical power relationship, illustrates two different views of UNFR management and responsibility: the view of the government and the view of the local people. The local person may have been reflecting on the difficulties of hiking to the burning area and the impossibility of extinguishing a fire that had started to crown (burn the tops of trees). However, the government officer not only believed that the local person had an obligation to help extinguish the fire, but also understood that the local person did not have the right to argue or question authority. The government officer was enforcing Forest Act No.7 (2002), which requires local people to extinguish fires burning in any forest in their proximity (United Republic of Tanzania, 2002). Few officials were able to hike the steep terrain to the burning area. In fact, no one would attempt to extinguish the fire at its current altitude, even if the person could reach the point where the fire was burning. The fire had started crowning and was impossible to extinguish by beating out the fire with tree branches. Although the fire burned out of control, later that day it rained and the fire died out. This interaction between the government officer and the local man is a good illustration of the power asymmetry between government UNFR officers and the local people living on the slopes of the UNFR. The concept of power is critical in this context. In the discussion that follows, I underscore how the concept of power relates to and leads to different conflicts, and how it defines access to and control of resources in the UNFR.

In the case of the UNFR, the state wants to remain in control of the local people and the nature reserve these people surround. Strong state control and the authoritative characteristics of nature reserve management have a long history, as I discuss later in this section. While this authoritative approach to the management of natural resources seems necessary in the eyes of the foresters, government bureaucrats, and local and international organizations interested in the conservation of biodiversity, it may have unjust consequences for local people. The potential unjustness arises because local individuals and the state have conflicting beliefs about access to and control of forest-based resources in the UNFR. These conceptual differences shed light on the types of conflicts that exist in the study area.

Types of conflicts. I classify nature-related conflicts based on four approaches. Some authors suggest classifying conflicts based on *Actors* (Skutsch, 2000, Sangiga et al., 2007) and *Structure* (Skutsch, 2000). In addition, I suggest classifying conflicts based on *Harmonious* and *Shared Information* approaches. I identified four categories of conflicts that relate to fire events and the forest officers' accusations of the local people: conflicting interests, structural conflict, antagonistic relations, and an information vacuum. Next, I describe each of the conflict categories.

Interest Conflict. Forest officers within the Ministry of Natural Resources and Tourism (MNRT), and members of the local and international conservation community would like to see the UNFR managed in a way that prevents human encroachment for any extractive use. Members of these groups prefer to eliminate fire through fire suppression. This nature conservancy perspective assumes that fire is a threat to the species in the reserve and that the biodiversity (fauna and flora) cannot be sustained if fire is present (Burgess et al., 2001). To achieve conservancy goals, the MNRT declared the UNFR a nature reserve on July 11, 2008. The declaration is in line with the conservation priority of a nature reserve based on endemism, the magnitude of threat (Mittermeier et al., 1998), and IUCN category I (nature reserve) status (Weeks and Mehta, 2004). Therefore, the interest of the MNRT hinges on a non-utilitarian principle, mainly the non-extraction of forest resources and the suppression of human activities that would in any way affect the flora and fauna in the UNFR. Fire suppression was among the major goals of the UTFR, and is now a primary goal of the UNFR.

Declaring the area the UNFR changed its status from the Uluguru Territorial Forest Reserve (UTFR) to a nature reserve. This status change led to restricted access to the forest. A nature reserve is set aside for preservation (Mittermeir et al., 1998), research, and monitoring (Weeks and Mehta, 2004). Although in earlier times, local people had partial access to the UTFR for forest products like dead fuel wood, wild fruits and mushrooms (management based on partial-utilitarian principle), current regulations strictly prohibit local people' access to the UNFR.

The local people's interest in the forest centers on the use of forest resources (dead wood, medicine, fruits), regardless of the forest's status based on the utilitarian principle. Local people have derived their livelihood from these forest resources. Members of the Waluguru, the major tribe on the slopes of the Uluguru Mountain, have lived around the UNFR area for over a century. These residents have benefited from forest products (Hamisy et al., 2000), as well as non-forest products and ecosystem services, such as water catchment, microclimate regulation, and a place for rituals and worship. It would be impractical to assume a separation between local people and the forest resources around them (DeFries et al., 2007), because these individuals interact with and are part of the forest ecosystem.

The interests of conservation managers clash with those of the local people because their perspectives on the UNFR are so different. Clashes between the two groups have occurred for over a century, and are ongoing. Arrests for starting fires continue, but the incidence of fire does not decline. A conflict of interest between local people and conservation managers is just one of the many types of conflict in the area.

Structural conflict. Another type of conflict between conservation managers and the local people, which is closely related to the first type, is *Structural Conflict*. Structural conflict results from the imbalance of power between the entire state apparatus including the Ministry of Natural Resources and Tourism and the local people. Operating through a top-down approach, the ministry officers instruct the conservation managers about how to achieve the goals of managing the UNFR. The following excerpt from a ministry letter addressed to local forest officials illustrates this management approach. A letter, dated September 2003, from the permanent secretary of the Ministry of Natural Resource and Tourism to the Project Manager (Region) overseeing the management of the Uluguru Territorial Forest Reserve read:

> In addition to the taken actions, it is crucial that you look for those who started the fires and bring them to justice. Almost every year fires that torch Uluguru Mountain start from the same areas. Those who start the fires see we do not make follow-ups, which means we do not care, therefore they also do not care, so they

> perpetuate their sabotage. Please collaborate with the responsible authorities to hunt down who started the fires so you take them to the court of law [and] then send me a progress report.

The ministry's exercise of power and control through the apparatus of the state, such as the police, prisons, and the courts, targets the local people. An organizational structure has to be in place to control local people (Weeks and Mehta, 2004). The underlying assumption of the system is that the culprits are members of the local population. While the government has power, the local people are powerless and at the receiving end of orders from the state (Schroeder, 1999)—the local people have no choice but to respond to government orders. The Forest Act (2002) part IX section 71-3 addresses local people receiving orders from the state. The Forest Act's clause on local people' obligation to extinguishing fire is an example of how local people must comply. The Act states that:

> Any person in the vicinity of a fire has the obligation whether called upon do so or not, to attempt or assist in extinguishing such fire which he has reasonable cause to believe is not under control or may become dangerous to life or property but no person shall be obliged to take any action which a reasonable person or firm disposition would consider likely to endanger his life or cause him injury.

Local people have an organizational structure that binds them together (Fairhead and Leach, 1995, Sangiga et al., 2007). Since the reign of the first chief of the Waluguru, leadership based on majority votes, the majority voted Chief Mbega or Kingalu into office. The chief had three subordinates (*Gungulugwa, Zegema* and *Kijoka*) and 176 sub-chiefs. The local people vote for the leaders. The local sub-chiefs address the needs of the local people in their jurisdiction. The sub-chiefs were responsible to the chief and their respective communities. There was a strong sense of loyalty and obedience to customary regulations. For example, prior to praying for rain the whole chiefdom must fulfill some prerequisites. The local leader described how obedient and loyal the local people were to the chief and his administration:

> …the day we pray for rain I inform all sub-chiefs that no person is allowed to light fire in his/her home until the prayer and the ceremony associated with the prayer is finished….nobody is allowed to burn because we believe that the rising smoke confronts clouds so it will not rain; we call this *Virangi*.

The preceding narrative, however, contradicts the forest officers' accounts. One of the fire reports sent to the Ministry's Head Office in 2000 read:

> The year 2000 has been the worst in fire incidents, unlike the past two years (1998 and 1999). Extreme drought and the late onset of short rains have largely contributed to the situation. In addition, other contributors to fire incidents include the local people's myth that setting fire induces rain and the use of fire in preparing farms and hunting of wildlife. Experience shows that most fires start from public lands or local people' farms and torch the Uluguru Nature Forest reserve.

I argue that the local people, or *Waluguru*, still value local or traditional leadership because it has existed for about 168 years (early 1800s-1968). However, the governance structure in place has obscured that local leadership. The government abolished the position of chief in 1968 (Hartley and Kaare, 2001). The chief seems powerless, indicative of the slow decay of the traditional system (Fairhead and Leach, 1995). This illustrates the conflicts and the uneven power and authority between the two institutional controls of the local people: the state and the traditional administrative system. Although efforts to suppress fires have been in place for years, these efforts have not had much success. Indeed, the structural conflict highlights a third type of conflict between the local people and the foresters: a *Relationship* conflict.

A *Relationship* conflict is firmly rooted in the attitude of one group of people toward another. The roots of this attitude may stem from the negative stereotypes that one or both groups develop about the other, due to the observed behavioral practices that define the groups. When one of the groups does not understand or accept the practices of the other, these practices become a ground for defining the other group who, in the minds of the first group, are unreasonably pursuing a particular practice. UNFR managers, having been trained in the management of natural resources, tend to prejudge the local people (Skutsch, 2000) as culprits in all the fire events taking place in the nature reserve. Similarly, the local people perceive UNFR managers as *the arm of the state* whose job is to discipline people (Week and Mehta, 2004) so the nature reserve will remain in its pristine condition. This prejudice is an indication that a conflict exists but nobody is aware of it (Skutsch, 2000) or people are aware of it but feel that it is inevitable.

After Tanzanian independence in 1961, the Ministry of Natural Resources and Tourism adopted colonial policies when developing national-level forest management plans (including fire control) for all forest areas and unique areas with rare species, like the UNFR. Subsequent policies and Acts have all been in favor of the preservation of nature, regardless of any settlement around these natural landscapes (Weeks and Mehta 2004, Saginga et al., 2007). Although it has been unlawful to enter the forest without a forest officer's permit (Bhatia and Ringia, 1996), obtaining permission before accessing the forest is not realistic for the local people as there are few foresters relative to the size of the Uluguru Nature Forest Reserve.

In July 2008, the Government of Tanzania established the UNFR, which means no local people may access the reserve. The government, through the conservator's office in Morogoro, is in the early stages of preparing a management plan for the UNFR. Until the new management plan is completed, the practical management of the UNFR is based on the guidelines and regulations developed for the UTFR.

The management of the UTFR, and now the UNFR, with respect to restricting anthropogenic pressure on the forest resources, has focused narrowly on the local people being the problem and foresters being the managers. The contentious relationship between the foresters and the local people indicates a relationship conflict between the two sects. The fact that the government does not assist local people who are hurt while fighting fires aggravates this conflict. One forester described the situation in this way:

> In 1987 there was a fire event in the UNFR; we went to put it out. The local people also joined the foresters to fight fire, it was windy and the fire was big. In the course of fire fighting unfortunately one villager was badly burnt… the state was not responsible whatsoever for his treatment in hospital, his family and relatives had to bear all the burden of cost for taking care of him while in hospital. It was so disappointing!

Some degree of compassion must arise between the state and the local people for a good relationship to develop. The state must demonstrate that it cares for its people. The state claims that its involvement in conservation benefits the local people and the nation in general, and trusts that this shared interest will translate into a close relationship between the state and the local people. However, a close relationship requires that each party be well informed about the inception, development, implementation and evaluation of the management plan, which is not the case in the example of the UNFR. The state can develop a relationship with local people by involving them in the decision-making (governance) process during the inception, development, implementation and evaluation of UNFR management plans. When every stage of UNFR management plan development is transparent, the local people will feel valued (increasing the legitimacy of the process), develop a sense of ownership (accountability) of the management plan, and cooperate (be ready to learn systematically through the process).

There is currently an *Information Vacuum* conflict between the local people and the foresters or UNFR managers. The local people are unaware of the necessary forest-management-related information, such as their responsibility to help extinguish fires in the UNFR. In addition, local people are unaware of the penalties stipulated in the 2000 Forest Act for accidentally causing a fire in the UNFR or deliberately accessing the UNFR for forest and non-forest products. In a fire event in September 2009, a forester's observation of the local people's sluggishness in helping extinguish the fire illustrates their lack of knowledge about their legal obligations. The forester remarked:

> In September 2009, a fire event burned the UNFR near Bigwa and Lukuyu area. To my surprise, few people showed up to help put out fire in the UNFR on that day. Most people seemed to mind their own business, which upset me. I think the laws governing fire must be strictly enforced and the local people must be educated about their responsibility whenever there is a fire event in their proximity.

The local people acknowledge the importance of having forests, and know the environment they interact with everyday, including the UNFR. The following narrative by an elderly local leader challenges foresters' homogenization of local people as ignorant of the ecosystem services provided by the UNFR:

> Forests are our survival, we get water for domestic use from the forests around us, the weather is good because we have forests around…We pray for rain, and use our own technology to bring rain…but this works because we have forests in our area.

A lack of shared knowledge between the UNFR managers and the local people, or at least learning from each other, leads each side to act out of ignorance. Their actions, such as local people refraining from helping extinguish fires in the UNFR or foresters asserting that the local traditions hinder compliance with laws governing the management of the UNFR, are detrimental to the successful management of UNFR. While local people assume the UNFR managers are against their communities, the UNFR managers assume the local people are against conservation efforts. Because of the inconsistent background information, local people and UNFR managers clash over forest management. The following statements exemplify the disparate understandings of the two groups. A forester described the local beliefs in the following way:

> The local people believe the forests belong to the government, the government is responsible for taking care of it. Therefore, whatever happens to it is none of their business. In June 2005 there was a fire incidence in Mbete area…people were not motivated at all to help putting fire out, they do not see how this endangers their own survival by affecting water sources, the environment and ultimately their poverty. Forester, June 2009

However, an elderly local woman provided a completely different reason for the actions of local people:

> When there is a fire incident, they [the state] come and start harassing people…all of them come, the people from the office of the regional and district commissioner, municipal officials, the Municipal militia (*Mgambo* in Swahili). You may show up to help only to end up harassed! Who wants to fall victim of

> harassment…you would not either, would you? So we shy away because it is their forest, [it] is under the government.

The types of conflicts between local people and UNFR managers are diverse. I have identified at least four types of conflict: conflicts related to interests, structure, relationships and lack of information. The categories are not mutually exclusive; rather, they interact and reinforce one another.

The current model for addressing fire issues in the UNFR

Currently, the model for addressing fire issues reflects a top-down or hierarchical command-and-control approach. The Ministry of Natural Resources and Tourism, through the Department of Forestry and Bee Division and the Chief Conservator's office in Morogoro, is responsible for the management of the UNFR, including fire suppression. Policing is the main strategy used to prevent the local people from accessing the UNFR and ensure that there are not any human-induced fire incidents. Every day forest officers patrol the borders of the forest and sometimes the interior of the UNFR. The forest officers usually perform random checks so the local people do not think there is a regular schedule for patrols. Because local people are unsure when they will encounter a patrolling forest officer, they refrain from encroaching the UNFR.

The management of the UNFR reflects forest policy. This policy, defined as a set of ideally rational and consensual intentions implemented for a particular achievable output, has excluded some voices completely. Since 1909, when the German colonialists introduced a management plan for the UTFR, local people's voices have been ignored in the conception, negotiation, and agreement of the common platform of implementing the policy. The Germans imposed a new administrative structure through headmen (*Akida*) and the management strategy of the UTFR on local people. In this case, the colonial bureaucrats, who assumed knowledge about the status of the forests, the people around the forests, the local people's interactions with the forests around them, what causes the degradation of the forests, and ways government could halt the degradation of the forests, created the forest management policy.

The British, having taken over from the Germans, imposed the *Mndewa* local administrative system in 1919, but continued the German legacy of managing the UTFR. During both German and later British rule, bureaucrats imposed rules and regulations of land management on local people. Over time, the interactions between the local people and colonial rulers became increasingly strained. Tired of the ill-conceived policies, in the 1950s the local people protested a British agriculture project by setting a fire in the UTFR. This reaction reaffirms that, "voices that are not heard (or are disregarded) in the policy process must be a central concern" (Blaikie and Oliver 2007:61).

After the Tanzanian government took control of the forest, the restrictive approaches implemented during the colonial rule persisted. The exclusion of the local people has continued in the current forest policy, despite the change from UTFR to UNFR. This continuity is partially due to preparatory transitional logistics, such as the preparation of UNFR management plan. In the following sections, I describe and explain the processes of managing the UNFR and the management practices UNFR has inherited from the UTFR.

Under the UTFR status, the state allowed the local people minimal access to the forest because local people needed certain forest products that, when harvested, would not affect the forest health. Local people were allowed access to gather dead wood, fruits, mushrooms, and for rituals or worship. The government strictly prohibited any destructive activity inside the reserve, such as farming, lumbering, cutting of trees for any other use (carving, charcoal kernelling, and construction), debarking trees for ropes and medicines, uprooting trees, and capture of wildlife. After the UNFR declaration in July 2008, the local people were not allowed to access the forest at all.

The conservator's office is responsible for establishing firebreaks at the UNFR's boundary with public land. The chief conservator's office employs local people to create firebreaks. The employed local people create firebreaks using hand hoes and machetes because this method is cheap and feasible given the rugged and dissected steep terrain. Firebreaks are usually three meters wide and are supposed to surround the UNFR. However, during my fieldwork only a few areas had firebreaks. When I asked the forest officer about other parts of the UNFR lacking firebreaks, the officer told me their office had inadequate funds so they created firebreaks in the most fire-prone areas.

At the village level, there are community environmental committees, mostly comprised of leaders and a few individuals who are non-leaders. These committees are responsible for any environmental-related issues, such as harvesting of privately owned trees. Harvesting a privately owned tree requires not only a permit from a forest officer, but also notifying the village environment committee. The permit assures the person who harvests the tree that he or she will not be accused of having harvested trees from the UNFR.

There is a coordinated effort between the central government (through the Regional Commissioner Office and the District Commissioner Office) and the Municipality of Morogoro to fight fires collaboratively. This massive effort may seem adequate to suppress fire in a 291 square kilometer forest, but the area most prone to fire is the northwest part of the UNFR, which is characterized by steep and dissected terrain. No road network reaches the forest boundary, nor is the firebreak continuous in this area. The UNFR boundary is only accessible on foot. Aerial firefighting equipment and mechanisms are not in place and are not an option given the current government budget, which is largely donor dependent.

Discussion

The brief history outlined above indicates how relationship conflict has developed over time and space. German colonialists established restrictive management of the UNFR in 1909. The German (1880s-1918) and later British (1919-1961) colonial governments adopted a protectionist approach to restrict local people's access to the Uluguru forests through various laws and regulations. Between 1929 and 1955, the colonial government established and enforced stringent laws and regulations to suppress fire in the UTFR (Temple, 1972, 1973; Lundgren, 1978). Although these policies may have maintained biodiversity in the UTFR, they did not account for local situations (Temple, 1972), and were not participatory.

This study reveals three key points. First, is the nature of the creation or production of nature conservation areas like the Uluguru Nature Forest Reserve (UNFR) based on a western conceptualization of a nature reserve. Second, is the interplay of local and global forces over time and space in shaping the management of UNFR. Finally, sustaining the biodiversity and the people's livelihoods in the study area requires recasting the thinking behind the current management model. I discuss each of these findings in turn.

The colonists produced a social construction of the UTFR within the western framework of creating pristine landscapes exclusive of human interactions. This conceptualization of the production of nature started in the western world (Neumann, 2003, Weeks and Mehta, 2004) and was institutionalized in Africa (Schroeder, 1999, Brockington and Igoe, 2006) including Tanzania. The legacy of the western imposition of nature conservation is deeply engrained in the policies that govern the management of the Uluguru Nature Forest Reserve today. Conservationists are not completely ignorant of the lost values, conservation traditions, and knowledge of the local people; however, conservationists practice in response to western standards of nature conservation or preservation (Mittermeier et al., 1998, Schroeder, 1999) in order to attract the interest of local, regional, and international conservation agencies and donors. While this approach may seem ideal in the broader sense of biodiversity conservation in nature reserves such as the UNFR, it leads to an inherent rift between the interests of local people and those of the government or state and the conservation community. Because the state has power and control, and gains support from the regional and international forces that have a stake in biodiversity conservation, it must manage people living near nature reserves (Weeks and Mehta, 2004). The traditional administrative structure is crumbling (Fairhead and Leach, 1995), the local people remain passive observers, their interest in forest management continues to decline, and their trust of forest officers dwindles daily.

The state must underscore the role of the local people in the management of the UNFR; otherwise, local people's rapport to the state's effort to manage the UNFR sustainably is likely to fail. The state must understand that the deteriorating traditional leadership structure and local traditions contain valuable aspects, and that if these can be merged carefully with the government's strategies the result is likely to yield a successful management plan for the UNFR.

The Ministry of Natural Resources and Tourism is solely responsible for managing the UNFR. As an institution of the state, the ministry works with local conservation institutions, regional and global conservation agencies, and international donors interested in the conservation of biodiversity. There is, however, a clear link between the German and British colonial management of the UTFR and the state's practices for forty-nine years after independence (1961 to the present). Quoting from correspondence between British colonial officials in 1931, Neumann (2003) highlighted the exclusionary ideology that informed the colonialists' emphasis on creating perpetually pristine lands and ignoring the interests of the local people of these areas.

The Tanzanian government introduced its first forest policy in 1953. However, the government did not consider people living adjacent to forest reserves as stakeholders in forest management until 1998, when the government reviewed the forest policy. The 1998 National Forest Policy states:

> To enable participation of all stakeholders in forest management and conservation, joint forest management agreements, with appropriate user rights and benefits, will be established. The agreement will be between the central government, specialized executive agencies, private sector or local governments, as appropriate in each case, and organized local communities or other organizations of people living adjacent to the forest.

The Forest Act of 2002 emphasized the idea of local people participating in the management of forests adjacent to their communities. In section 3(d) of the objectives of the Forest Act of 2002, the government promises to “delegate responsibilities for management of forest resources to the lowest possible level of local management consistent with the furtherance of national policies.” The administration of Amani Forest Nature Reserve (established in 1997) is an example of Joint Forest Management (JFM) involving both the state and the local community. While there are other examples of JFM in the country, these examples involve forest reserves that do not have a nature-reserve status.

The National Forest Policy (1998) and the Forest Act (2002) both emphasize the involvement of local people in forest management; however, there is a gap between policy and practice. Forest officers lack an understanding of the micro-scale functioning of local (traditional) institutions and local communities' motivations to support conservation; that lack of understanding creates a mismatch between forest management policies and their implementation (Kajembe and Kessy, 2000). Foresters assume they know how to manage both forest reserves and the local people; this assumption indicates that the state, while moving toward delegating forest management responsibility to local people, is not ready to surrender its power.

The state is not ready to devolve some of its decision making process to the local level in managing nature reserves like the UNFR, which shows that while the forest management paradigm has changed in theory, it has not yet changed in practice. In fact, the Forest Act still maintains that areas rich in biodiversity are "sensitive" areas, and that the state "owns all biological resources." Hence, the government has the "right to determine and regulate access to genetic resources…in accordance with the provisions of this Act [Act 2002] and any other written law on biological resources." (URT, 2002). I argue that the state asserts the authority to decide how to manage any forest reserve and thus local people are likely to be passive observers and recipients of state orders. However, ignoring the role of the local people in managing forest resources is a source of conflict between foresters and local people. Whether or not local people are involved in the management of the nature reserve, whenever the state adjusts management policies, it should clarify how local people will benefit from the new management structure. Providing local people with incentives to manage the UNFR can ease current and future conflicts between local people and foresters, and may increase local people' motivation to assist with fire suppression in the UNFR.

In 1980, the International Union for Conservation of Nature (IUCN), United Nations Environmental Program (UNEP), produced a World Conservation Strategy (WCS) document. UNEP in collaboration with World Wildlife Fund (WWF), commissioned the WCS by funding the preparation and inception of its core themes and structure. The WCS did not thoroughly address the social and political issues of conservation (Boyd, 1984) and contained a weak argument for ingenuity in traditional conservation strategies. These shortcomings are not surprising because the creation of biodiversity hotspots such as the UNFR is based on plant endemism and the degree of threat (Mittermeier et al., 1998, Burgess et al., 2001), not on how local people might benefit and improve their standards of living. In addition, the nature reserve is a scientific reserve, which means the status dictates not allowing any human activity in the reserve (Weeks and Mehta, 2004).

The government of Tanzania has ratified a number of international conventions, including the Convention on Biological Diversity (March 8, 1996); the United Nations Framework Convention on Climate Change (April, 1996); and the Convention for the Protection, Management, and Development of the Marine and Coastal Environment of the Eastern African Region and Related Protocols (March 1, 1996). In response to international biodiversity conservation needs, the state has also developed the National Biodiversity Strategy and Action Plan, 2000. The conventions and the National Biodiversity Strategy and Action Plan marginalize the voices of the local people. The governance of both nature and the people around nature reserves is featured more prominently in these documents (Weeks and Mehta, 2004). Assuming that local people must be disconnected from the natural environment around them in order to preserve nature (DeFries et al., 2007) is a serious mistake, because the two are, in practice, inseparable. The management of biodiversity must address this connection. The marginalization of local people in management policies and practices engenders a weaker attachment to forest resources, which erodes local people' belief that they have a stake in management.

The current UNFR management model and the draft management plan reflect the legacy of excluding local people from forest management. The management focus is biodiversity only, not biodiversity and people. Bureaucrats, assume they know what is required to effectively control the UNFR, initiate, develop, and execute plans. Inherent in this process is the silencing of local voices, a key to overseeing (Fairhead and Leach, 1995, DeFries et al., 2007) the UNFR. The current process, therefore, is a command-and-control approach.

The characterization of the local people as the problem and their traditional lifestyle as inherently dangerous to the survival of the UNFR is an overgeneralization and a fallacy that requires rethinking. Reconsidering this erroneous characterization will enable the state to identify key incentives for local people to get involved in running the UNFR, and can serve as a way to bridge policy and practice based on strong traits of the local community. Isolated incidents involving a few individuals are behind the fires in the Ulunguru, not the entire local community. Therefore, a collective accusation of the local people is unjust. Further, this collective accusation seems to hinder efforts to keep fire out of the UNFR.

The state must address the root causes of extant and potential conflicts in order to manage the UNFR successfully. The local people are the key to sustainable management and the state must not ignore their role in the management plan, especially because the population of the area surrounding the UNFR has a high density (78+ people per km^2) (Cincotta et al., 2000). During my fieldwork, I observed that most fire events in the UNFR were accidental. Rarely did fires involve arson or fire used as hunting tool. The attitude of the local people toward management lies at the core of the success or failure of biodiversity conservation. Successful management is not a matter of controlling the actions of the local people. Rather, addressing the fire issue in the UNFR requires a thorough understanding of the underlying factors that lead to fire events. Why do fires that seem manageable in farms accidentally burn out of control and torch the UNFR? This topic requires further investigation to illuminate the micro- and macro-scale factors that explain fire incidents. I explore this question in the next chapter, in which I discuss climate-fire synergy in the UNFR.

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Chapter 3: Climate-Fire Synergy in the Uluguru Nature Forest Reserve in Tanzania

I investigate the relationship between short-term climate variability and the fire ecology of the Uluguru Nature Forest Reserve (UNFR). I investigate the influence of relief, altitude, the Indian Ocean Dipole or Dipole Mode Index (DMI), and Niño 3.4 on short (November-December) and long rains (March, April, May) in the UNFR. Fire events correlate weakly with amount of annual local rainfall, suggesting that fire occurrence in the UNFR results from a combination of factors, such as rainfall anomalies, topography, type of vegetation (fuel), timing and use of fire by local people as a farm preparation tool, and teleconnections. A thorough understanding of fire behavior across time and space is necessary to design a successful UNFR management plan; the resulting plan must address both anthropogenic and climatic drivers of fire.

Introduction

In this study, I investigate the relationship between short-term climatic variation and forest fires in the Uluguru Nature Forest Reserve (UNFR) in Tanzania. The UNFR, part of the Eastern Arc Mountains, contains 108 plant species, 6 species of amphibians, 4 reptile species, and shrews and birds not found elsewhere in the world. Fires in the Uluguru pose an urgent threat to the conservation of the unique plant and animal species (Myers et al., 2000, Burgess et al., 2001; Frontier-Tanzania, 2005; Burgess et al., 2007). Fire disturbance in the Uluguru and the Eastern Arc Mountains in general was partly responsible for the extinction of some plant species about 10,000 years ago (Mumbi et al., 2008).

Weather determines the timing, spatial extent, and size of fires (Johnson and Miyanishi, 2001). Over the past four decades, the UNFR has experienced frequent droughts. Maack (1996) and Lyamuya et al. (1994) argued that in the past 40 years fires have become more frequent in the UNFR. Possible future increases in temperature and decreases in dry-season precipitation in Tanzania (Christensen et al., 2007) might worsen the effects of fire on forest ecosystems (Bhatia and Ringia, 1996; Lyamuya et al., 1994). Currently, however, the relationship between weather patterns and fire patterns in the Ulugurus is unknown. In this study, I examine the relationship by seeking to answer the question: *Do annual and dekad*[3] *variations in weather influence fire occurrences in the UNFR?* To address the central question, I seek to answer two sub-questions: (1) *What was the relationship between fire events and weather in the Uluguru Nature Forest Reserve from 1971 to 2007?* and (2) *What were the fire regimes in the Uluguru Nature Forest Reserve from 1971 to 2007?* I hypothesize that large fires occur during long periods without rainfall or with very little rainfall.

Particular weather conditions, such as precipitation, relative humidity, air temperature, and wind, determine the possibility of forest fires (Weber and Flannigan, 1997). In East Africa, these weather conditions are part of large-scale atmospheric dynamics, such as the El Niño/Southern Oscillation (ENSO) (Indeje et al., 2000, Anyamba et al., 2002; Mchugh, 2006) and the Tropical Indian Ocean Dipole (IOD) (Ummenhofer et al., 2009). In fact, the East Africa October-December (OND) short rains correlate positively with (ENSO) (Mutai and Ward, 2000). Topography, the presence of

[3] Dekad refers to ten days of recorded rainfall data, unlike the term decade, which refers to ten years of recorded data.

the Indian Ocean, and variation in vegetation type influence the variability of rainfall in Tanzania and the Uluguru area (Ogallo, 1989). At a coarser spatial level, variability in climate is linked to wildfire incidence in East Africa (Indeje et al., 2000). In general, Clark et al. (2002) argue, when a drought (less-than-normal rainfall) interrupts an extended period of more-than-normal rainfall (which influences fuel accumulation in forests) fires tend to be severe. At a fine spatial scale, understanding the ecology of fire in the UNFR requires a thorough examination of the linkage between fire and weather at the local level.

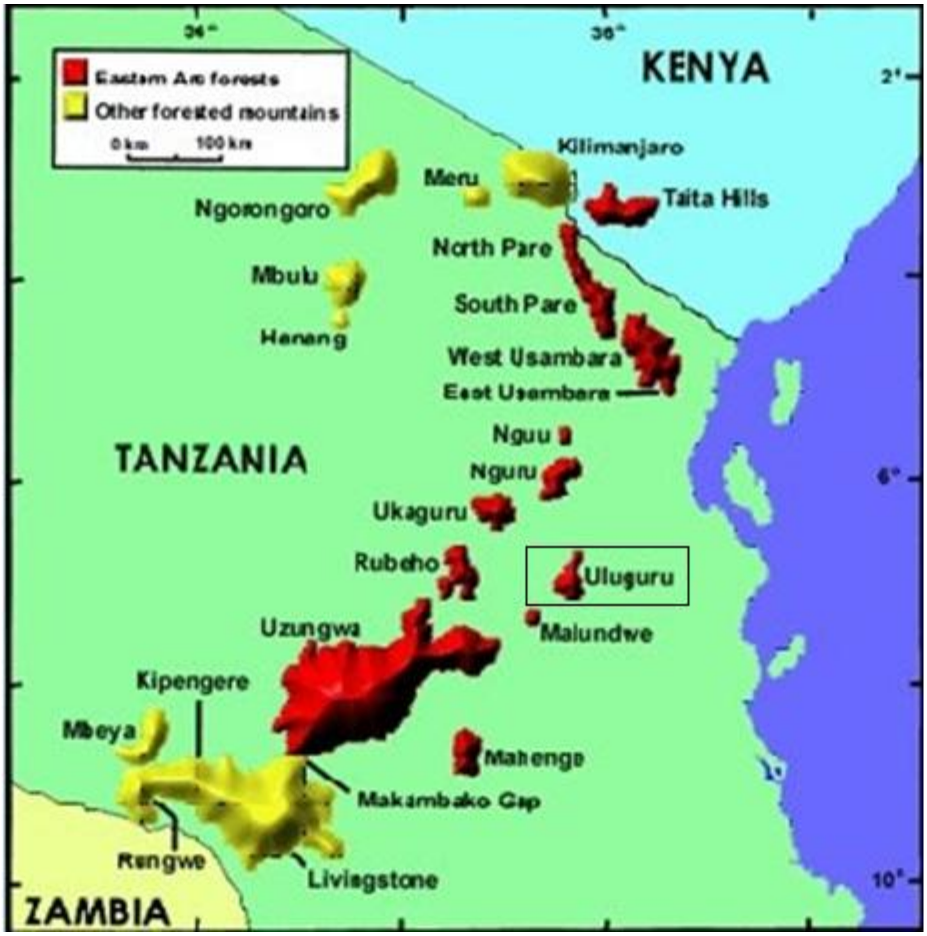
In North American forests, fires may result from lightning and human activity (Stephens, 2005), and are rarely a yearly occurrence (Johnson and Heathcott, 1990). In contrast, fires in the UNFR are almost entirely human-caused (Lyamuya et al., 1994) and occur almost every year. On the slopes of the Uluguru the local people practice agriculture and commonly use fire to manage weeds; fires often burn out of control and ignite the Uluguru forest (Bhatia and Ringia, 1996; Critical Ecosystems Partnership Fund, 2005). The Tanzanian Ministry of Natural Resources and Tourism adopted fire suppression plans for the region based on the assumption that local people were the sole source of fires. The ministry implemented a set of strict regulations on forest use by local people, including requiring anyone entering the forest to have a forest officer's permit (Bhatia and Ringia, 1996). Because there are few forest officers relative to the size of the UNFR, it is impractical for each person entering the forest to acquire a permit, and non-permitted incursions into the forest occur frequently.

Fires continued in the Ulugurus and, fueled by the foresters' assumption that local people's non-permitted use of the forest caused the fires, clashes between forest officers and local people have increased. However, humans have lived in the Ulugurus for centuries (Young and Fosbrooke, 1960) and it is unclear whether recent human activity on the mountain is the only factor contributing to fire occurrence. By combining precipitation data from the Morogoro weather station for 1971-2007 with fire events data from 1985-2007, I explore the possible relationships between fire and climate that may affect the frequency of human-caused fires in the UNFR.

Description of the Study Area

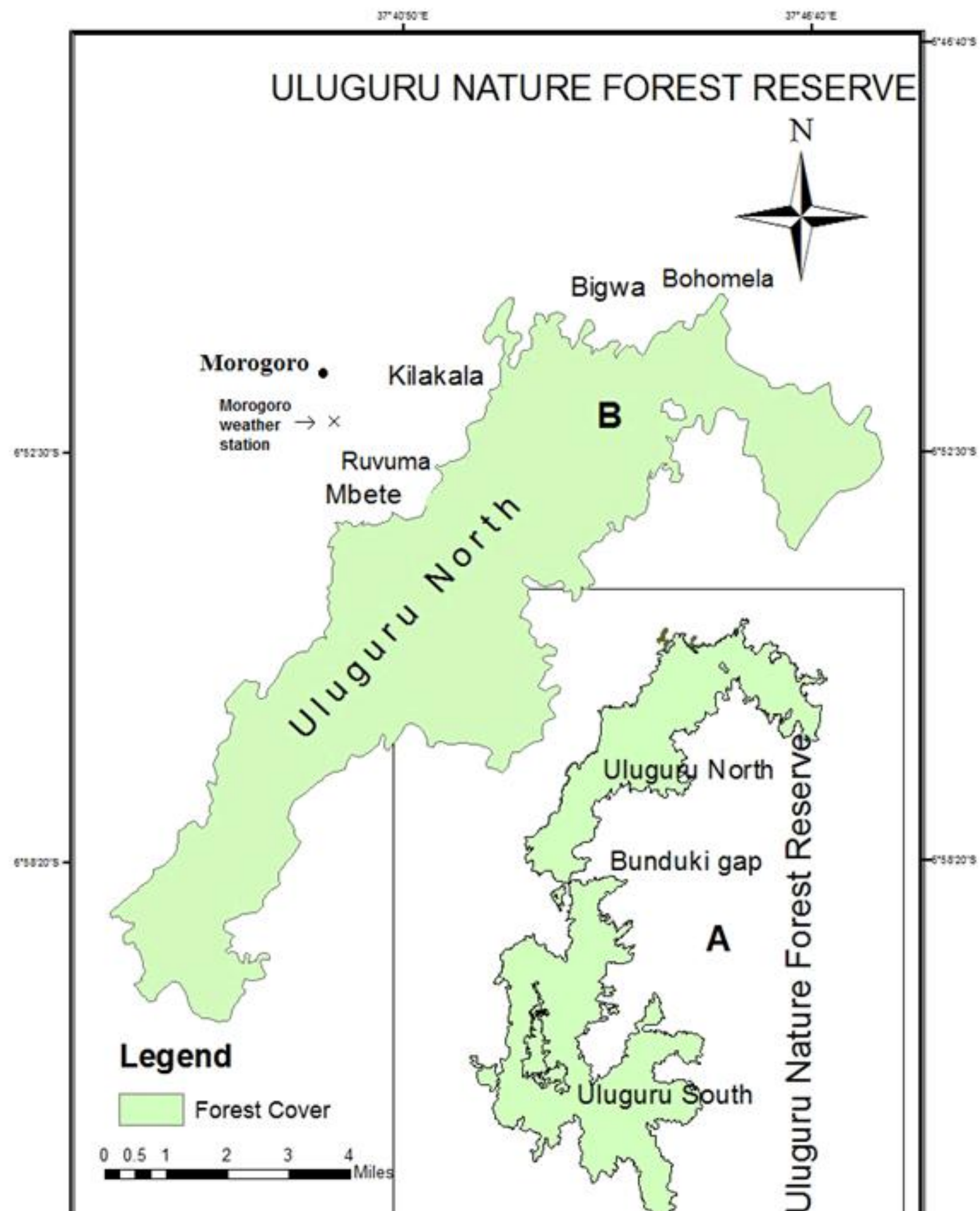
The UNFR is part of a chain of 12 mountain blocks in the Eastern Arc Mountains, which stretch 900 km from Makambako (in southern Tanzania) to the Taita Hills in south coastal Kenya (Figure 1) (Critical Ecosystems Partnership Fund, 2003). The UNFR lies south of the equator between 06^{o}51'–07^{o}12'S and 37^{o}36'–37^{o}45'E (Figure 2a) and includes 291 square kilometers of forest area (Burgess and Mhagama, 2001). On 11 July 2008, Government Notice Number 296 of The United Republic of Tanzania combined the former North and South Uluguru Territorial Forest Reserves and formed the Uluguru Nature Forest Reserve (UNFR) because of its local and global biodiversity conservation value (Burgess et al., 2001; Frontier-Tanzania, 2005; Burgess et al., 2007).

Figure 1 Map of Tanzania showing Uluguru and the Eastern Arc Mountains (red color)



Source: www.easternarc.or.tz/eastarc

Figure 2 Uluguru Nature Forest Reserve (UNFR) showing Uluguru North



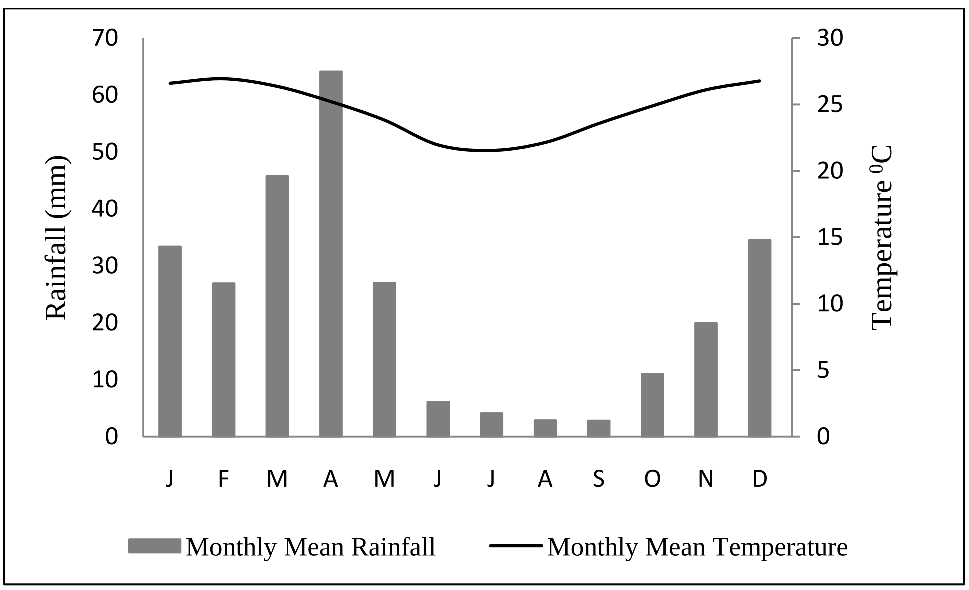
The UNFR lies on a 45.5 km-long faulted block mountain with very rugged and continuous ridge topography that rises steeply from 150 m to 2,638 m above sea level. At the Bunduki gap this continuous ridge divides into Northern Uluguru (20.5 km long and 8 km wide) and Southern Uluguru (25 km long and15.5 km wide) (Figure 2A). Rainfall estimates range from 1,200 to 3,100 mm/year on the western slopes, and 2,900 to 4,000 mm/year on the eastern slopes. The western side of the mountain experiences a rain shadow effect from the moist southeasterlies from the Indian Ocean (Mumbi et al., 2008). Lovett and Pocs (1993) identified no dry season in the area, probably because they used mean monthly precipitation, which may have obscured variations within a month.

In this study, I divide the year into four types of climatic seasons: short rains in November and December (ND);[4] a short dry spell in January and February (JF); long rains in March, April, and May (MAM); the early dry season between June and July (JJ), and the late dry season in August, September, October (ASO). Both JF and ASO fall under the dry season category. Temperatures are highest (22°C) in December and lowest (17°C) in July (Lovett and Pocs, 1993). Based on calculations using 1971-2007 data, the mean temperature was 27°C in December and 22°C in July (Figure 2). The main soil types are acidic lithosols and ferralitic red, yellow, and brown latosols that have developed on Precambian granulite, gneiss, and migmatite rocks (Frontier-Tanzania, 2005). The terrain is steep, although sometimes forests thrive on 50^{o}-70^{o} slopes.

[4] I base the analysis on ND as the short rain season because JF is a transitional season that may include a few weeks of dry season.

This study was conducted in the northwest part of the UNFR, on a north-south transect from Bigwa to Mbete (Figure 2B), and along the edge of the forested-wooded grass area. The study area is on the leeward (western) side of the UNFR, which receives less rainfall and thus is more affected by fire than the windward (eastern) side of the UNFR (Burgess and Mhagama, 2001).

Figure 3 Monthly mean rainfall and temperature (1971-2007) at Morogoro Station (526 m or 1725 ft above sea level)



Data Sources

Monthly precipitation and temperature data were available from the Morogoro weather station, located adjacent to the UNFR at 6°50'S, 37°39'E. Rainfall and temperature data were available through the Tanzania Meteorological Agency (TMA)

Headquarters in Dar Es Salaam. I obtained the Dipole Mode Index (also referred to as the Indian Ocean Dipole Mode) from the National Aeronautics and Space Administration (NASA) website.[5] El Niño Sea Surface Temperature (SST) Index data for the Niño 3.4 region was obtained from the Climate and Global Dynamics Division (CGD) of the National Center for Atmospheric Research (NCAR).[6] According to the NCAR website, the Niño 3.4 region is one of many El Niño/Southern Oscillation indicators based on SST. Niño 3.4 is the average SST anomaly in the region centered at 5^0N-5^0S and 170^0W-120^0W. I included DMI and Niño 3.4 indices in this study because they have been shown to affect precipitation in East Africa (Behera *et al*., 2005; Indeje *et al*., 2000).

I obtained fire records from the Catchment Forestry Office (CFO) in Morogoro, Tanzania, which has documented fire incidents since 1985. The officials at CFO confirmed that fire records were complete because all forest guards recorded any fire incidents in their areas of patrol on a daily basis and provided the reports to their supervisors at the CFO. Forest guards patrol the UNFR daily. The fire records consisted of the date and place of occurrence, cause, damage, how long the fire burned, and efforts taken to extinguish the fire. However, the data did not include a description of the size of the fire. Similarly, information on the size of the area burned was missing in some reports, which made comparison of areas burned over time impractical.

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[5] http://gcmd.nasa.gov/records/GCMD_Indian_Ocean_Dipole.html
[6] http://www.cgd.ucar.edu/cas/catalog/climind/Niño334_data.html

Data Analyses

To identify precipitation anomalies based on rainfall data from the Morogoro weather station, I created a rainfall index (RI) for each month. For each month, I computed the mean rainfall from 1971 to 2007 (e.g., the mean rainfall for all Aprils from 1971 through 2007). Next I calculated (normalized by standard deviation) the extent to which each individual month deviated from the mean (e.g., how much did the April 1980 rainfall deviate from mean April rainfall) to identify extreme (non-normal) weather patterns during the 1971-2007 timeframe. Because I normalized the data the value of, for example, 1.5 rainfall index (means that the rainfall index in that period was 1.5 standard deviation above the mean for that period). I identified extreme dry periods or runs of months with little or no rain prior to a fire event because they help explain fire patterns (Beverly and Martell, 2005). Then, the separate anomalies for each month were interpreted in relation to data for prior months, which explain a monthly or seasonal rainfall condition in a particular year. Using the calculated rainfall index, I was able to correlate the index with DMI and Niño 3.4 indices to explain the relationship between local rainfall and teleconnections[7]. The relationship between local rainfall and teleconnections helps explain yearly and seasonal variations in rainfall, which in turn help explain fire regimes in the UNFR.

I analyzed the overall precipitation trend from 1971-2007 to understand spatial and temporal anomalous (positive or negative) rainfall conditions that existed in the study area. In order to understand whether anomalous rainfall conditions explain observed

[7] Distant regional weather conditions (e.g. IOD and Niño 3.4) that affect rainfall in UNFR.

patterns of fire in the UNFR, I analyzed rainfall data from the Morogoro weather station from 1971 through 2007. Later, when I analyzed the relationship between rainfall and fire, I used a 1985-2007 timeframe because the catchment office in Morogoro began keeping records of fire events in 1985. The records represent all fire events that occurred in the UNFR from 1985 through 2007.

To test the hypothesis that large fires occur during long periods without rainfall or with very little rainfall. I calculated a Pearson Correlation. For each year from 1985 through 2007, I grouped the amount of precipitation in each season: January and February (JF); March April and May (MAM); June and July (JJ); August, September and October (ASO); and November, December (ND). Daily fire events data were converted into monthly fire frequencies. Next, I calculated the Pearson Correlation ($\rho<0.05$ two tailed). In addition, I correlated the DMI and Niño 3.4 with RI (seasonal) for periods with/without fires. Correlating DMI and Niño 3.4 with RI helped explain the drivers of rainfall variability at Morogoro.

Results

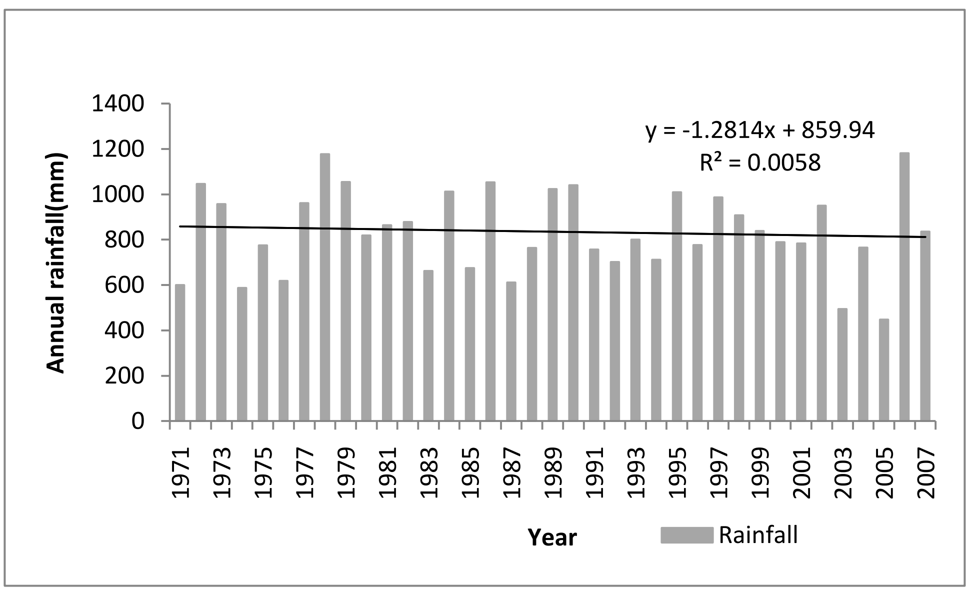
The relationship between local rainfall and fire

In this section, I present: the results of the correlation analyses and a graphical representation of the total annual rainfall in Morogoro (1971-2007), the annual fire frequency (1985-2007), the relationship between total annual rainfall and fire (1985-

2007), fire and rainfall distribution over seasons, and the relationship between rainfall and DMI and Niño 3.4 indices.

Figure 4 reveals almost no trend in rainfall over the 1971-2007 time period. Figure 5 shows annual fire events in the UNFR between 1985 and 2007. Fifty-four fire events were recorded during this time. The Mean Fire Interval[8] (MFI) was 1.69 over the same period. In addition, the results in Figure 5 reveal that the number of fire events was higher in 1995 and 2005 than any of the other years. When I removed the extreme value of fire events in 2005 (assuming it was skewing the data) from the dataset, the overall trend during the 1985-2007 period showed a very small decline in fire events that was not statistically significant (P=0.0528 one-tailed) (Figure 6).

Figure 4 Annual rainfall at Morogoro station (1971-2007)



[8] Arithmetic average of the interval, in years, between two successive fire events

Figure 5 Fire frequency in the UNFR (1985-2007)

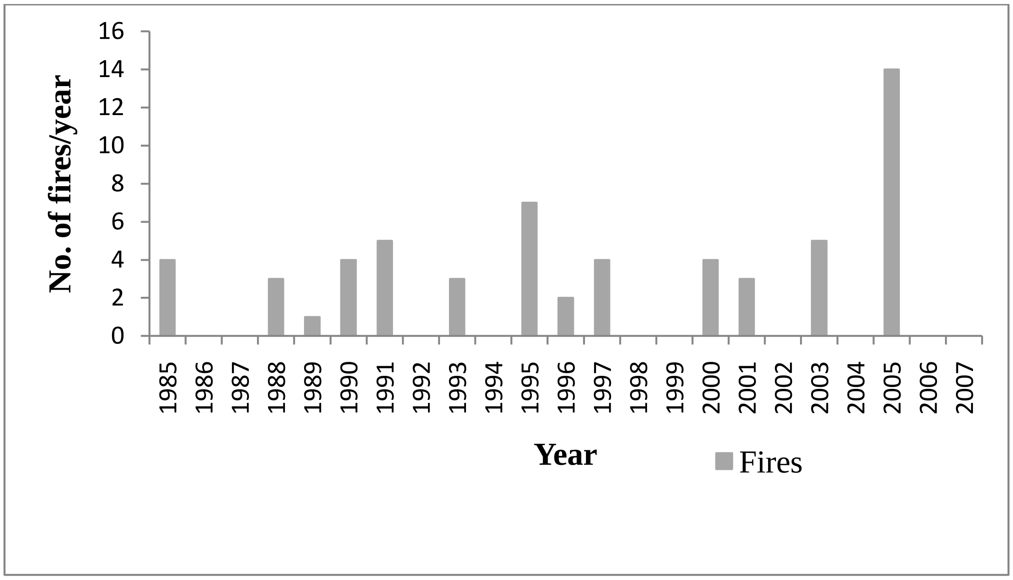


Figure 6 Trend of fire frequency in the UNFR (1985-2004; 2005 fires removed)

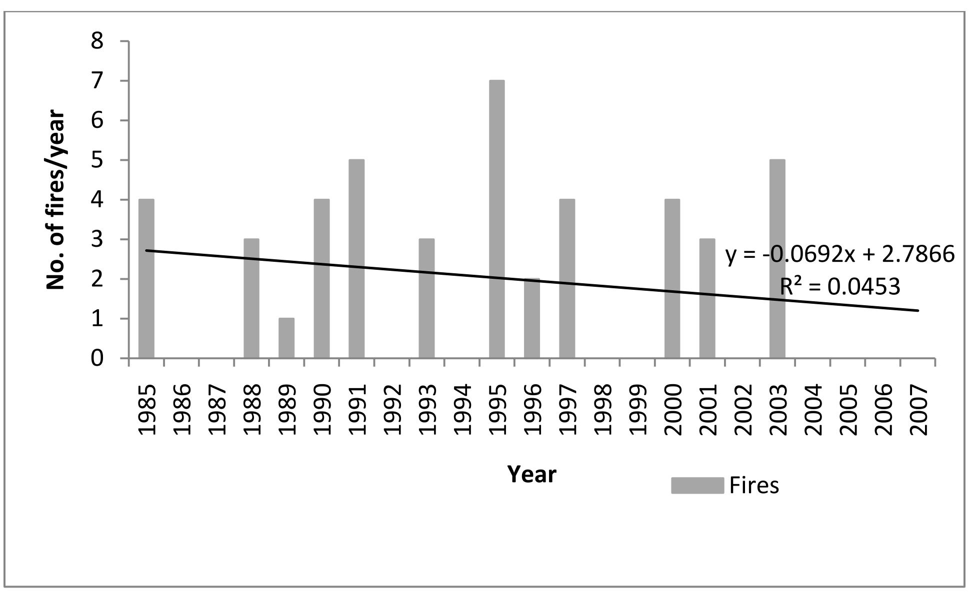


Figure 7 illustrates the relationship between rainfall and fire events between 1985 and 2007. More fire events in 1995 coincide with a high total annual rainfall (1009.6 mm), but when fire events spiked in 2005, total annual rainfall (447.2 mm) was quite low. Figure 8 shows that most fires occur in August, September, and October (ASO). A few fires occurred during wet seasons in March, April and May (MAM), and November, December (ND), and during the short dry spell in January and February (JF). Figure 9 depicts anomalous rainfall at the Morogoro station in 1995 and 2005, respectively. In 1995, the Morogoro station received more-than-normal rainfall in JF, MAM and ASO. In the same year, less-than-normal rainfall fell in JJ and ND. In 2005, all seasons throughout the year received less-than-normal rainfall.

Figure 7 Annual rainfall and fire events (1985-2007)

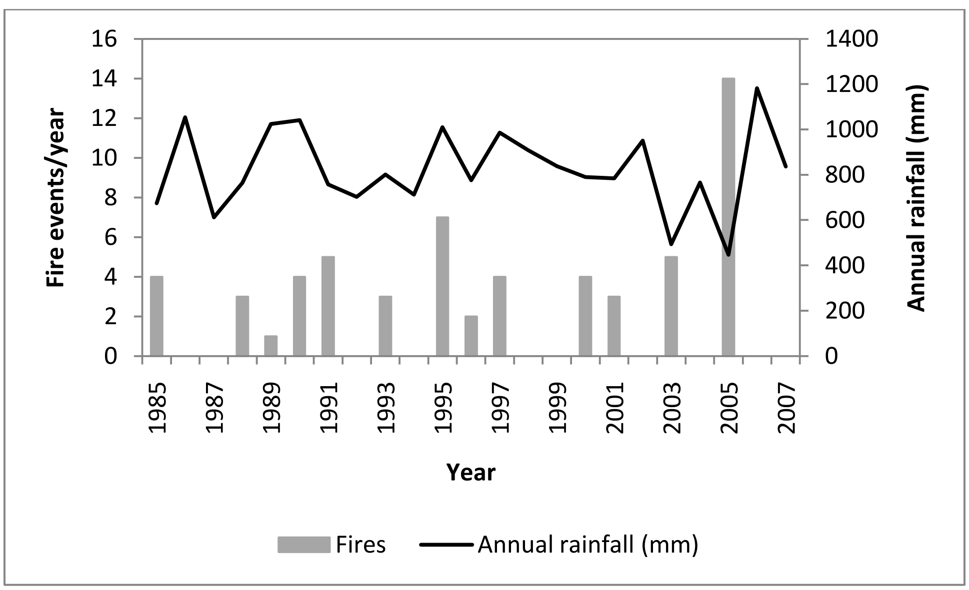


Figure 8 Annual fire pattern (1985-2007)

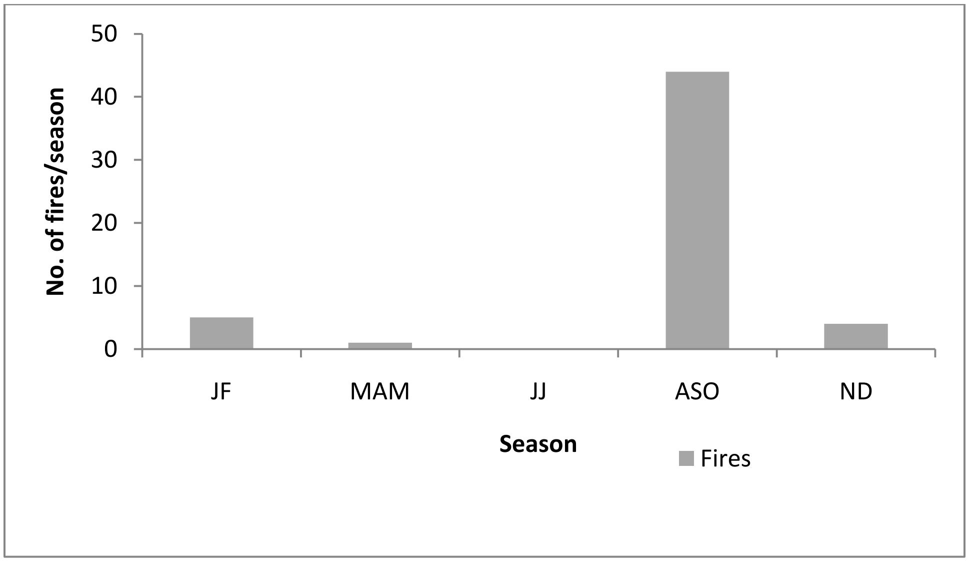
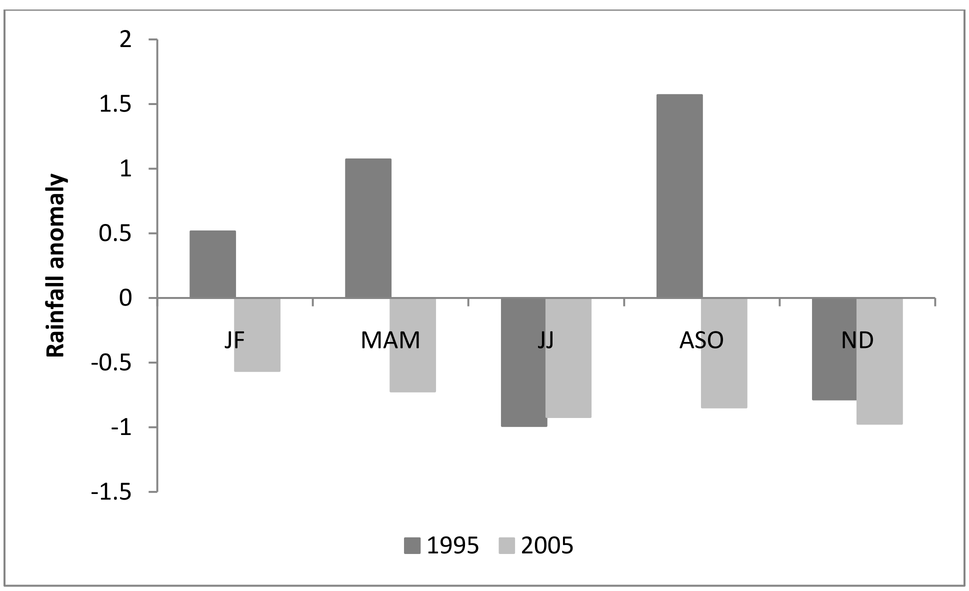


Figure 9 Rainfall anomalies for 1995 and 2005 (values are in standard deviations from normal)



Seasonality plays a significant role in the observed fire pattern in the UNFR. There are four main seasons in a year. The short rain season (*Vuli*) is in November and December (ND); long rains (*Masika*) fall in March, April, and May (MAM); the early dry season arrives in June and July; the late dry season occurs in August, September, and October (ASO); and a short dry spell occurs January and February (JF). These seasons result from the migration of the Inter-Tropical Convergence Zone (ITCZ) from south of the Equator to north of the Equator and vice versa. In addition, topographic relief modulates rainfall formation in the UNFR because of its higher elevation. The Uluguru Mountains orographically uplift warm and moist near-surface Indian Ocean air, which cools as it rises over the mountain and produces precipitation. Topography explains the disparity in precipitation between the eastern side of the UNFR, which faces the Indian Ocean easterly winds, and the leeward side of the UNFR, which lies in the rain shadow.

The frequency of fire in a particular season relates to the weather condition of the season, particularly precipitation. This pattern occurs because fuel must be able to accumulate, must be dry enough to ignite, and there must be a source of ignition (in the case of Uluguru, mainly humans). Fuel igniting in the UNFR depends on the moisture condition of the available fuel, which in turn depends on the amount of rainfall in a season or the preceding season. The moisture condition, among other factors, determines the frequency of fires in a particular year. The Pearson Correlation (r) between precipitation data for the entire year (all seasons) and the annual number of fire events was r = -0.23348 at P=0.0899 (two-tailed), which was statistically significant (Figure 10). Therefore, I suggest that there is a weak relationship between annual precipitation and annual fire events. The results show that precipitation and fire events are weakly negatively correlated, which implies that wetter (more precipitation) conditions do not explain completely lower fire frequencies and that the opposite may be true when there is low precipitation.

Figure 10 Scatter plot of the correlation between annual precipitation and annual number of fires for the 1985-2007 period.

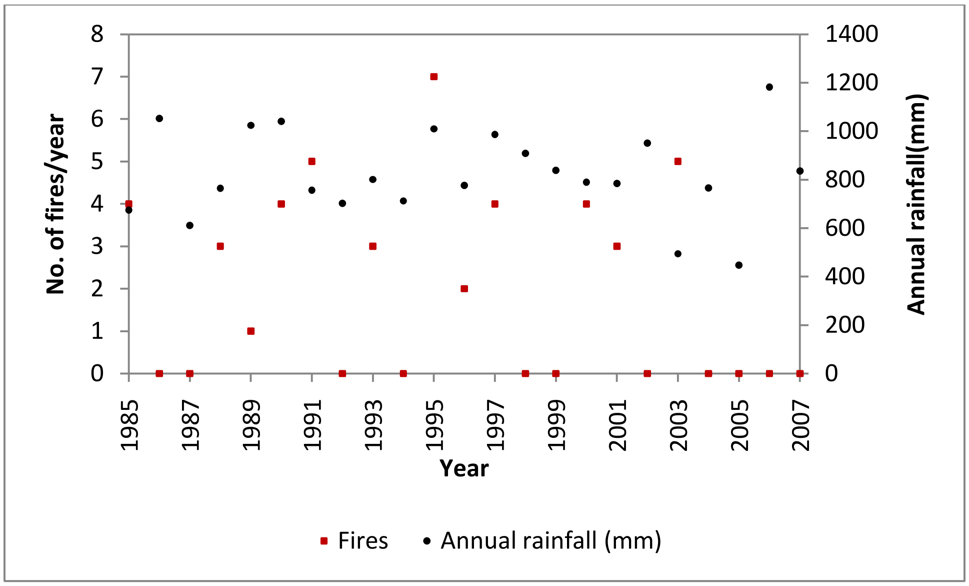


Figure 8 depicts the seasonal distribution of fire frequency over the 1985-2007 period. The figure reveals that 81.5% of fires burned between August and October, 7.4% of fires occurred in November and December, 9.2% of fires burned in January and February , and 1.9% of fires were recorded in March, April, and May. Fires in the short and long rain seasons occur when there is less-than-normal rainfall during those seasons.

Rainfall amount (less or more-than-normal) depends on both local and regional drivers of precipitation. In the following section, I explore how Niño 3.4 region and Dipole Mode Index Sea Surface Temperatures (SST) affect rainfall in the UNFR.

The Relationship between local rainfall and teleconnections (Dipole Mode Index and Niño 3.4)

Seasonal cooler-than-normal (negative DMI) SST in the western Indian Ocean was associated with less-than-normal rainfall in the UNFR in 1995 and 2005, with few seasonal rainfall exceptions (Figure 11 A). Seasonal cooler-than-normal (negative Niño 3.4) SST in the western Pacific Ocean was related to less-than-normal rainfall in the UNFR (Figure 11 B), particularly during the late dry and short rain seasons in both years. Seasons (10-20 days without rainfall) with less-than-normal rainfall in the UNFR in 1995 and 2005 explain fire incidents in those years. More fires occurred in 1995 and 2005 than in other years (Table 1). More precipitation in October (78.7 mm) 1995 was responsible for the spike of rainfall in the ASO season. The 1995 June, July season received 0.6 mm of rainfall, with the same amount of rainfall falling in November. The erratic rainfall in the early dry and short rain seasons accounted for higher fire incidents in 1995. For example, in 1995, four fires burned the UNFR in the third dekad in August (weak positive rainfall anomaly), and three fires occurred in the first dekad in September (negative rainfall anomaly) because both dekads were dry (Appendix II b).

A correlation between DMI (SON) and rainfall (SON) at Morogoro station was positive (r= 0.4713). DMI (DJF) was positively correlated with rainfall (DJF) (r=0.4536) and DMI (JJA) was positively correlated with precipitation (JJA) (r=0.4614). Similarly, a correlation between Niño 3.4 (SON) was positively correlated with rainfall (SON) (r=0.4367). The correlation between Niño 3.4 (DJF) with rainfall (DJF) was 0.3625, and Niño 3.4 (JJA) with rainfall (JJA) was negatively correlated (r= -0.0696). In 2005, the Niño 3.4 SST correlations with RI (all seasons) were significant (r=0.603), but a weak correlation (r=0.246) was observed in 1995. These results suggest that warm/cool DMI and Niño 3.4 affect seasonal rainfall amounts in the UNFR, which in turn affect fire incidents.

Table 1 Fire events in the UNFR (1985-2007)

Year	No. of fire events	Year	No. of fire events	Year	No. of fire events
1985	4	1993	3	2001	3
1986	0	1994	0	2002	0
1987	0	1995	7	2003	5
1988	3	1996	2	2004	0
1989	1	1997	4	2005	14
1990	4	1998	0	2006	0
1991	5	1999	0	2007	0
1992	0	2000	4	2008	2

Figure 11 (A-E) indicates seasonal DMI and rainfall (RI) anomalies, and correlations between seasonal DMI and RI at the Morogoro station when few fires (1-5 fire events) occurred in the UNFR. Figure 11 (A-E) and Table 2 show that a cooler-than-

normal SST in the western Indian Ocean was connected with less-than-normal rainfall in the early dry season, with few exceptions. Warmer-than-normal SST in the western Indian Ocean was connected with above-normal rainfall in the early dry and long rain seasons, respectively. The results suggest that during years with fewer fires, the DMI is in its warm phase with the UNFR receiving more-than-normal rainfall. The UNFR received less-than-normal annual rainfall in 1996 and more-than-normal annual rainfall in 1997, during which the DMI SST was cooler/warmer-than-normal, respectively.

Figure 11 (A) Dipole Mode Index relationship with Morogoro Rainfall Index (1995 and 2005). The units are in standard deviations from normal.

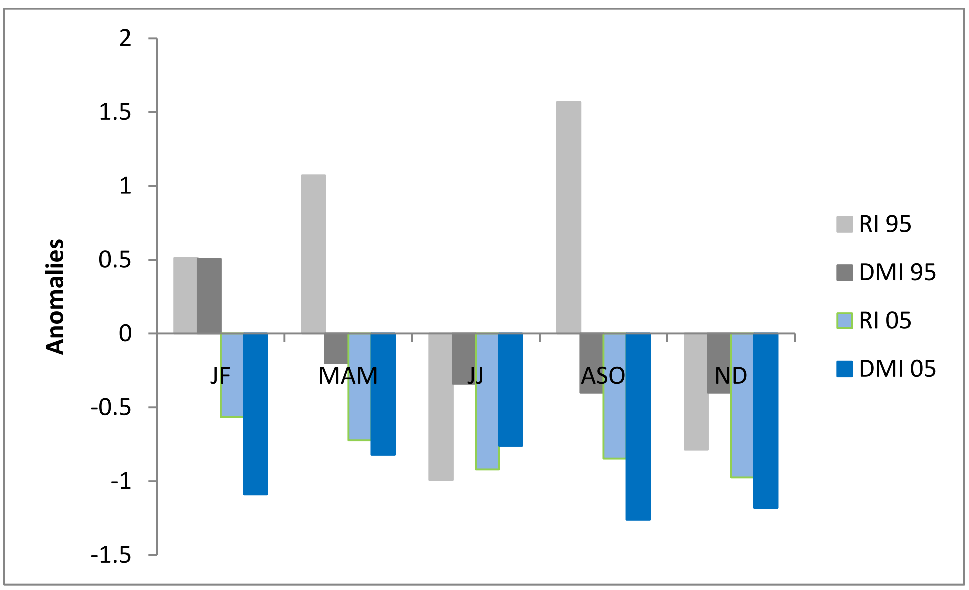


Figure 11 (B) Niño 3.4 Index relationship with Morogoro Rainfall Index (1995 and 2005). The units are in standard deviations from normal.

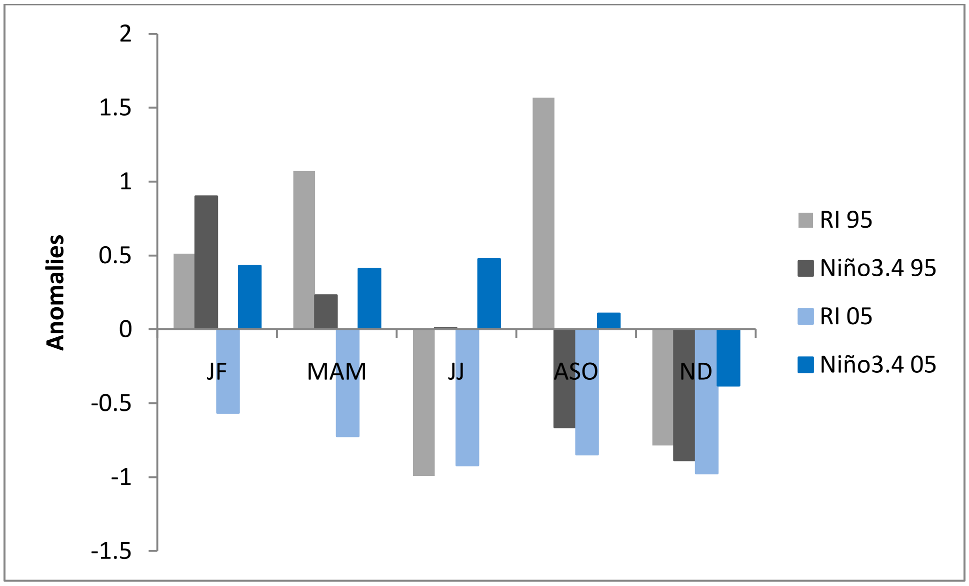
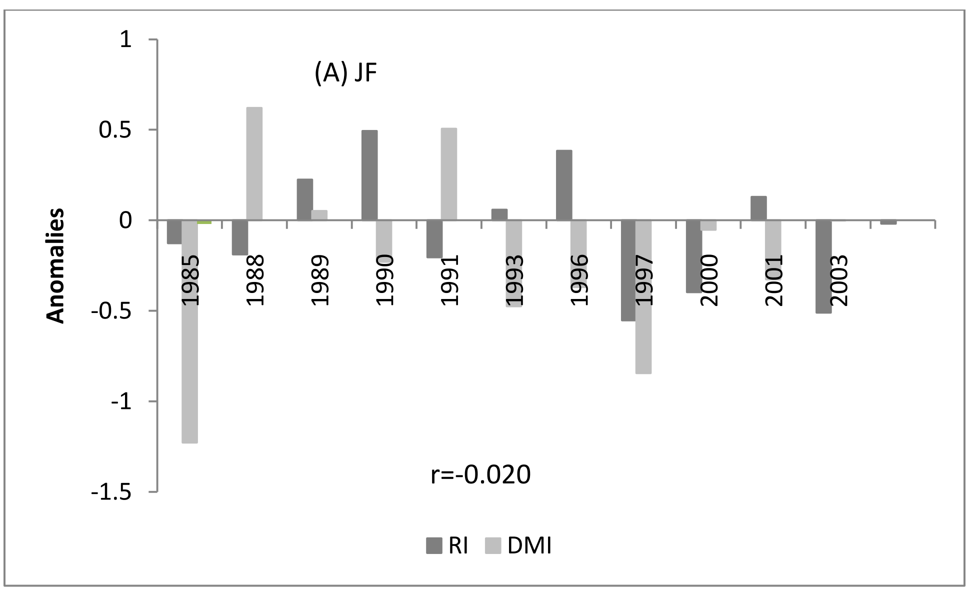
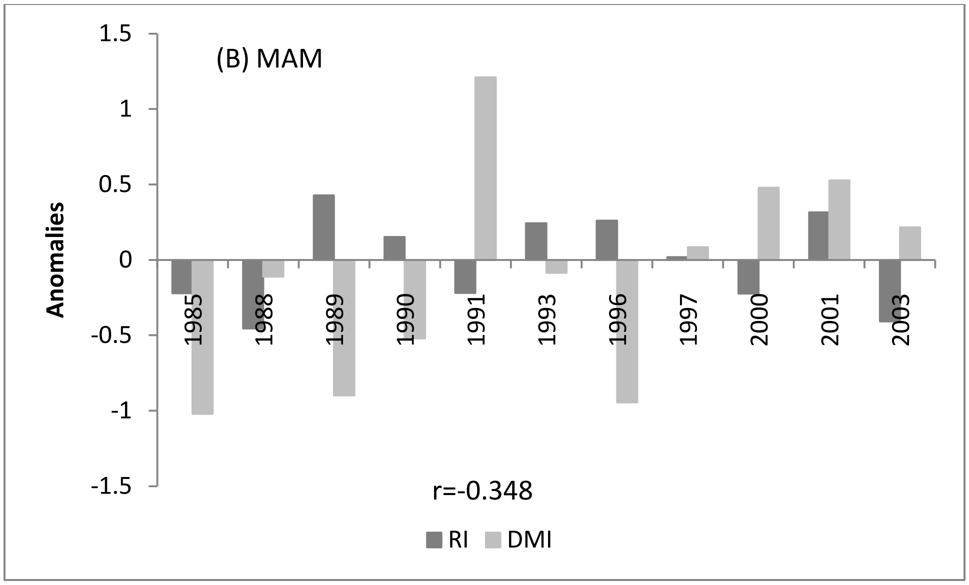
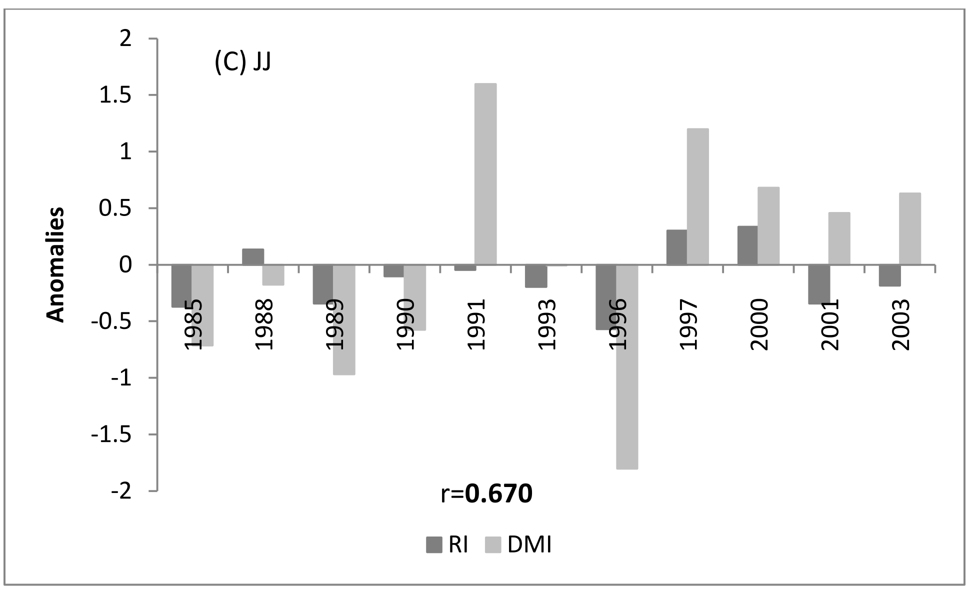


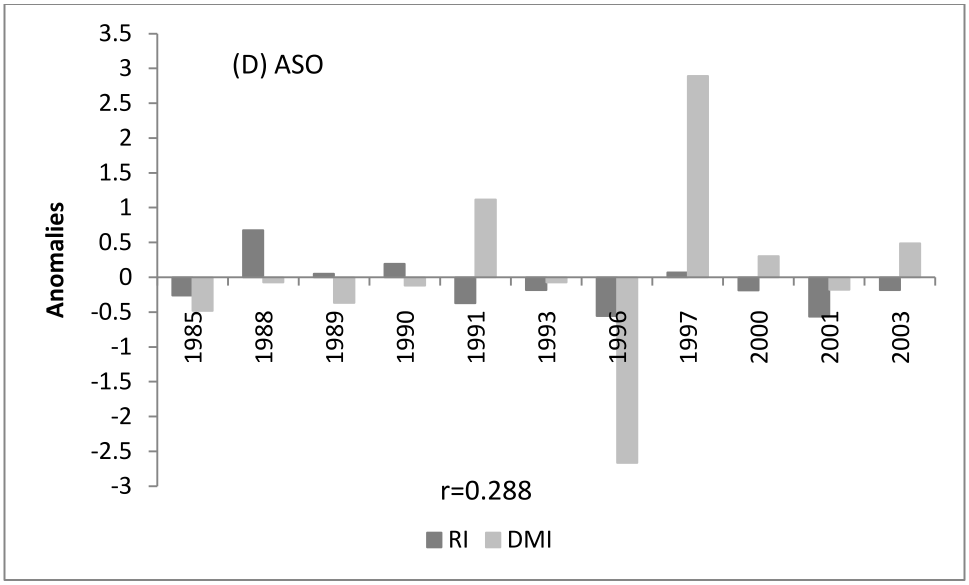
Figure 11A-E Seasonal anomalous rainfall relationships with Dipole Mode Index for years with few (1-5) fires and correlation between DMI and RI. The units are in standard deviations from normal.

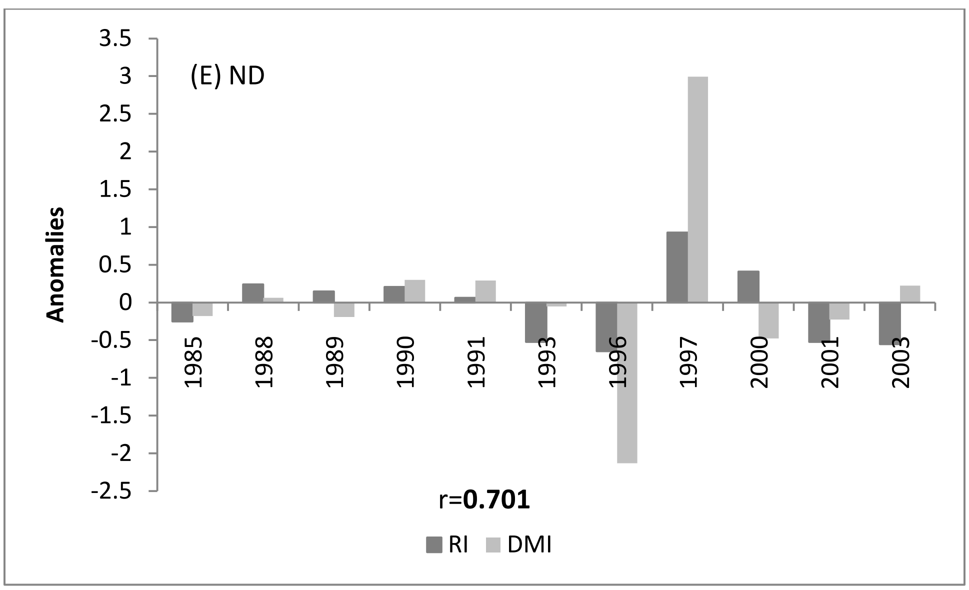






Values in bold indicate significant correlations





Values in bold indicate significant correlations

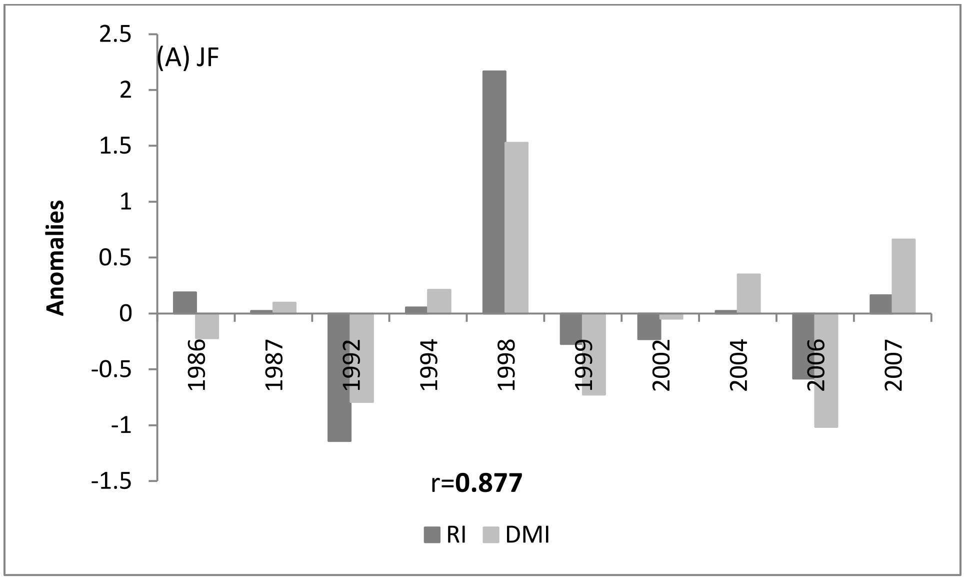
Table 2 Correlations between monthly DMI and monthly local rainfall for years with few (1-5) fires

Year	Zero lag
1985	**-0.52**
1988	-0.27
1989	0.3
1990	**0.41**
1991	-0.29
1993	-0.4
1996	**0.9**
1997	**0.78**
2000	-0.15
2001	0.36
2003	**0.89**

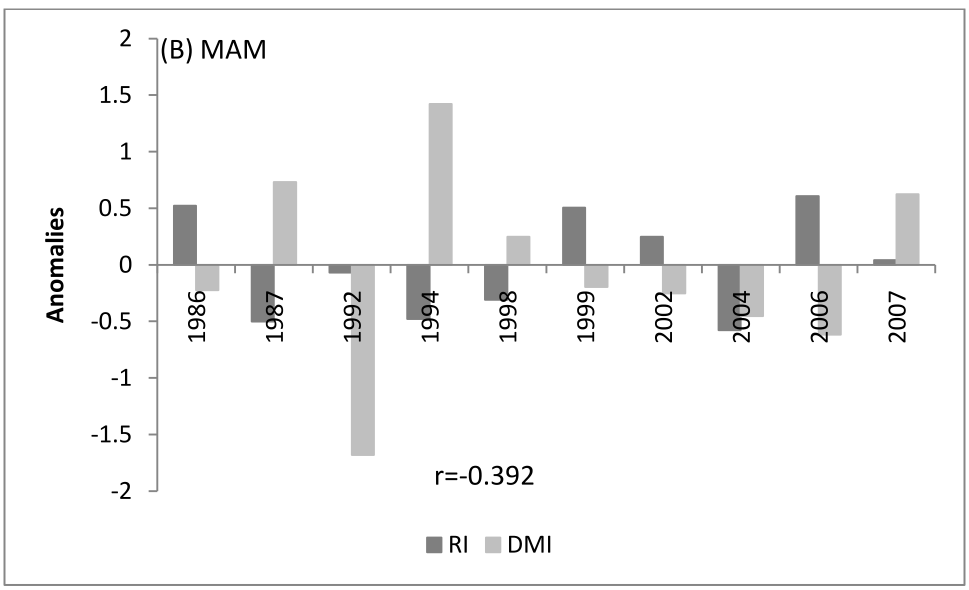
Values in bold indicate significant correlations

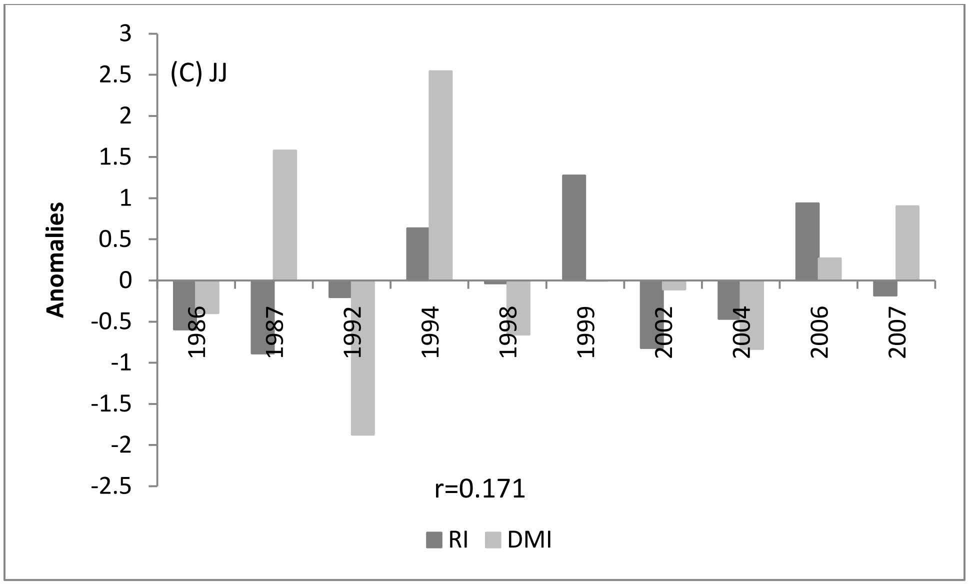
For years in which no fire events were recorded in the UNFR (Figure 12 A-E), a positive DMI correlates strongly with above-normal rainfall (Table 3). The January-February and ASO rainfall seasons correlate strongly with a positive DMI in those months. A negative DMI in 1992 was associated with less-than-normal rainfall in all seasons of the year except ND. In 1998, the UNFR received more JF season rainfall than in any other year in the time period considered. In addition, the short rain (ND) season in 2006 received a higher amount of precipitation than other years over the same period. The more-than-normal precipitation that fell in the 2006 ND season was associated with a positive DMI during the same season.

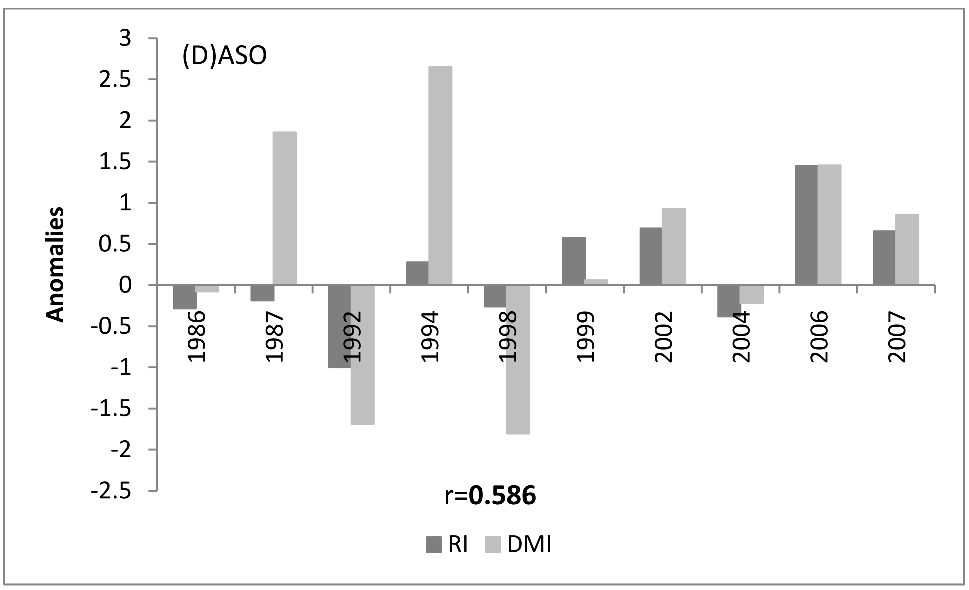
Figure 12 A-E Seasonal anomalous rainfall relationships with Dipole Mode Index for years without any fire and correlations between DMI and RI. The units are in standard deviations from normal.



Values in bold indicate significant correlations







Values in bold indicate significant correlations

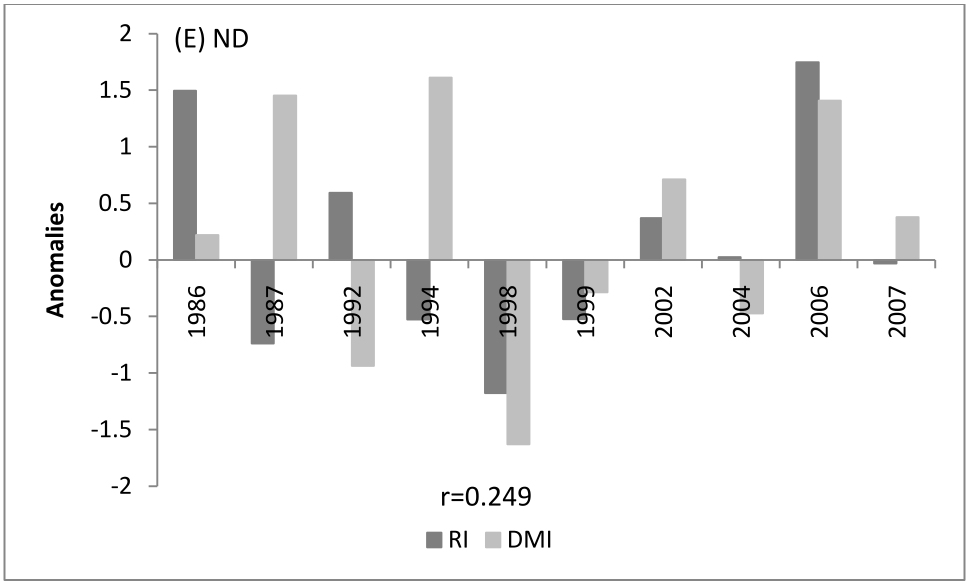


Table 3 Correlations between monthly DMI and local rainfall (all seasons) for years without any fire

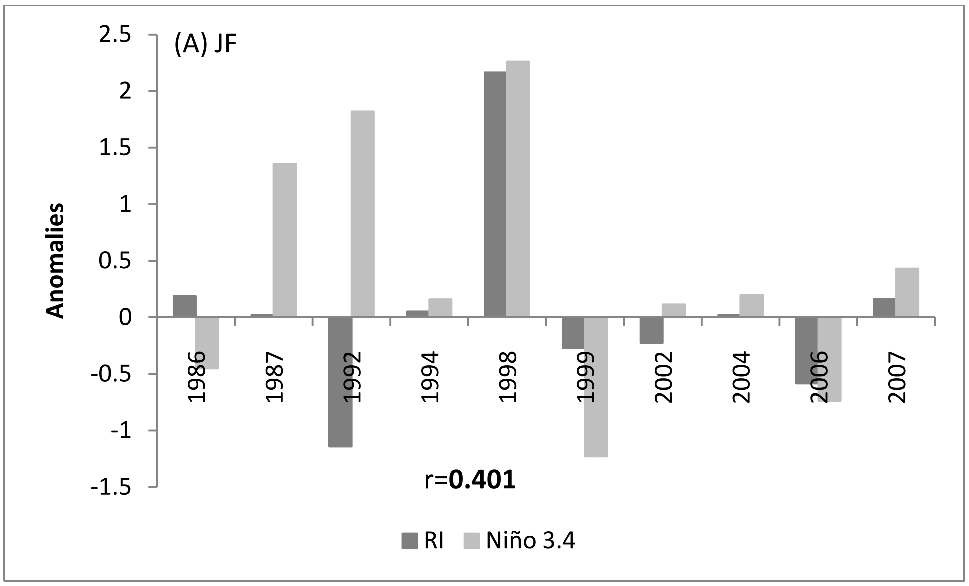
Year	Zero lag
1986	**0.82**
1987	**-0.52**
1992	-0.003
1994	**0.45**
1998	**0.84**
1999	**0.71**
2002	**0.69**
2004	**0.57**
2006	**0.92**
2007	0.28

Values in bold indicate significant correlations

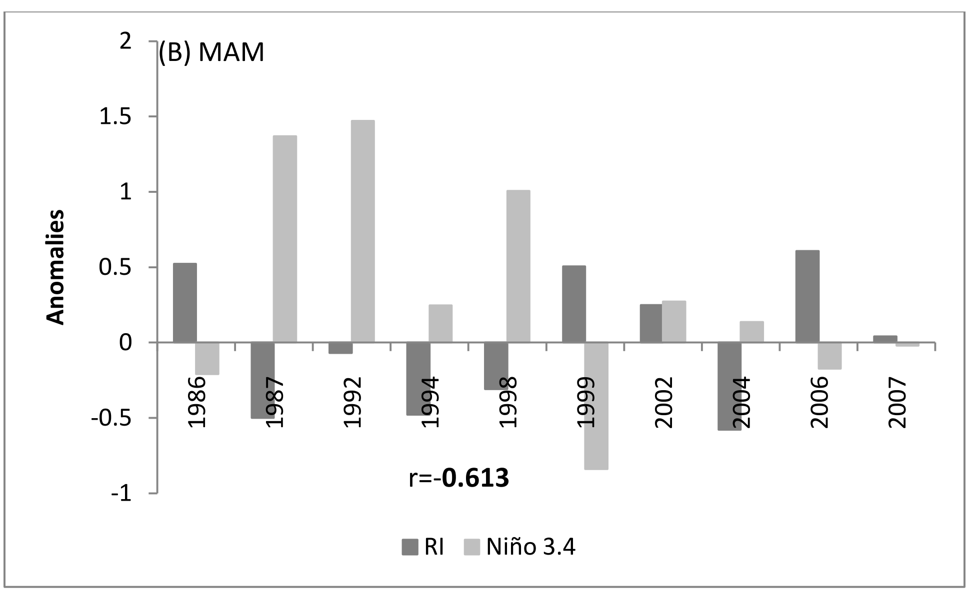
The DMI relationship with RI suggests that a positive/negative DMI is associated with more/less-than-normal rainfall in the UNFR. However, the DMI does not explain RI anomalies in all years. In the next section, I present the relationship between seasonal Niño 3.4 Index (Sea Surface Temperature in the western Pacific Ocean) and the Rainfall Index (RI) at Morogoro from 1985 to 2007.

Figure 13 shows the relationship between the Niño 3.4 Index and rainfall at Morogoro (RI) for years that did not experience any fire over the 1985-2007 period. The overall relationship is not as strong as was observed between RI and DMI, but on average a positive Niño 3.4 was associated with more-than-normal rainfall at Morogoro (Table 4). Warmer-than-normal SST in the western Pacific Ocean and corresponding more-than-normal rainfall years experienced no fires. The strength of the seasonal correlations between Niño 3.4 and RI suggest that Niño 3.4 affects seasonal precipitation throughout the year. Niño 3.4 was strongly correlated with the amount of rainfall the UNFR received in 1998, 1999 and 2006.

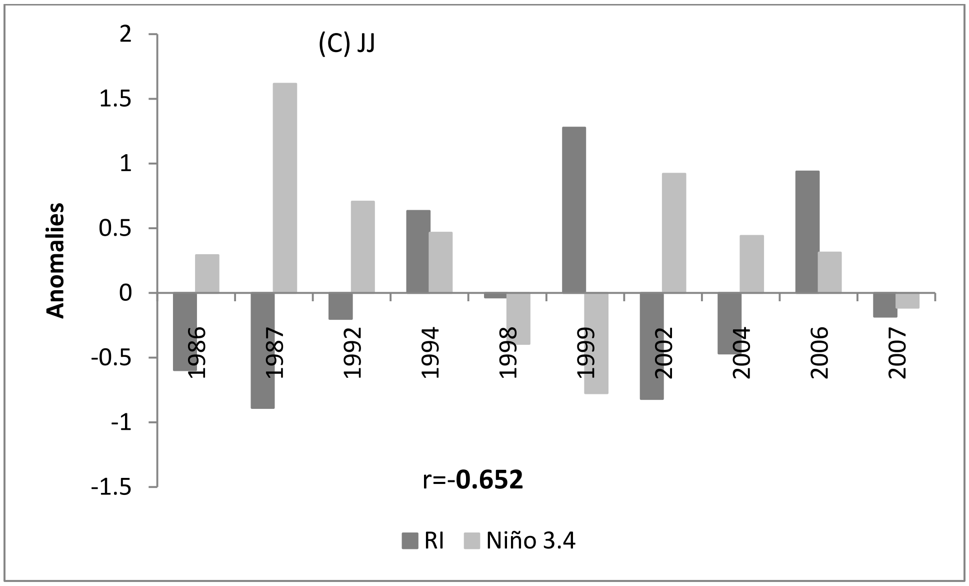
Figure 13 A-E Seasonal anomalous rainfall relationships with Niño 3.4 index for years without fires and correlations between Niño 3.4 and RI. The units are in standard deviations from normal.



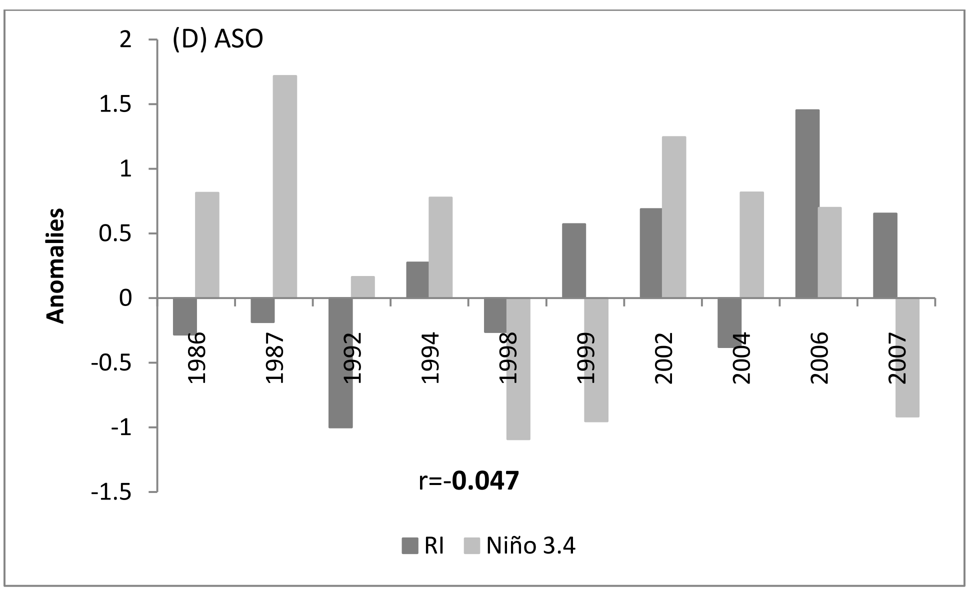
Values in bold indicate significant correlations

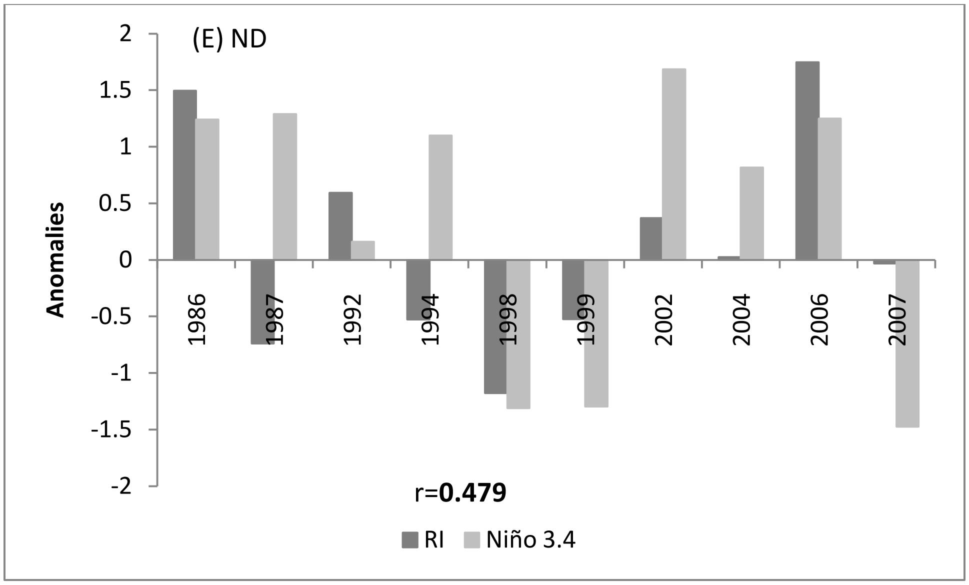


Values in bold indicate significant correlations



Values in bold indicate significant correlations





Values in bold indicate significant correlations

Table 4 Correlations between monthly Niño3.4 and local rainfall (all seasons) for years without any fire

Year	Zero lag
1986	0.356
1987	0.015
1992	-0.379
1994	-0.203
1998	**0.848**
1999	**0.956**
2002	0.354
2004	0.256
2006	**0.967**
2007	-0.198

Values in bold indicate significant correlations

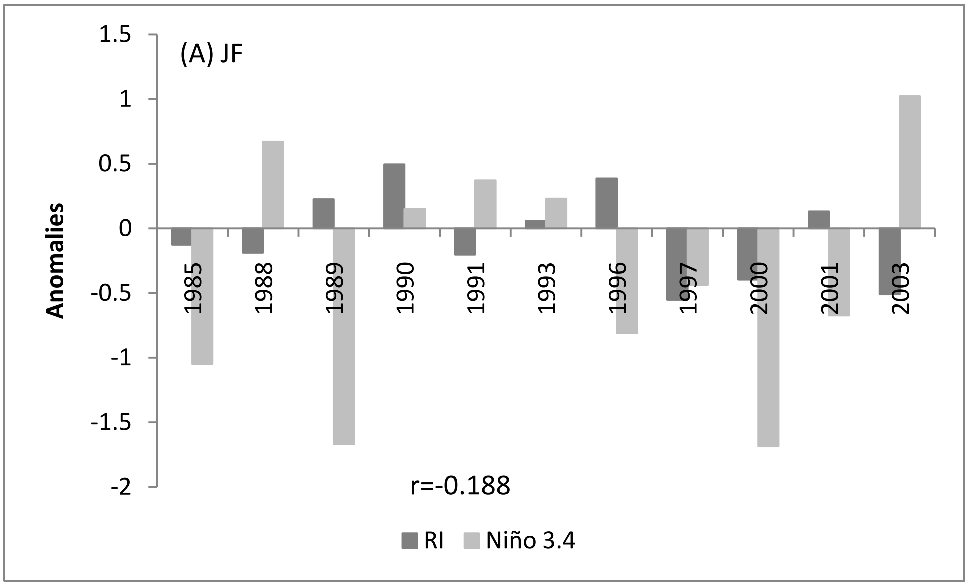
Figure 14 (A-E) and Table 5 indicate that during years with few (1-5) fire events a negative Niño 3.4 often was associated with more-than-normal annual rainfall, although the seasonal Niño 3.4 correlation with RI was weak. No extreme rainfall fell during the years with few fire incidents. Fewer fires burned in the UNFR during more-than-normal rainfall. The relationship between Niño 3.4 and RI suggests that a negative Niño 3.4 results in more-than-normal rainfall in the UNFR. Few fires burned in the UNFR during years with more-than-normal rainfall, while overall fires did not burn during years with abundant rainfall, with a few exceptions.

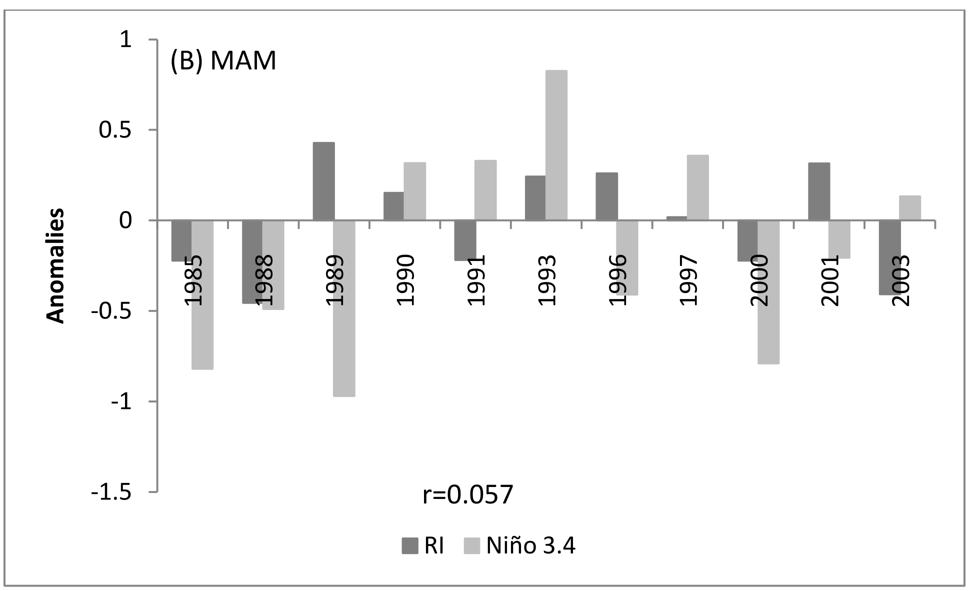
Table 5 Correlations between monthly Niño 3.4 and rainfall for years with few (1-5) fires

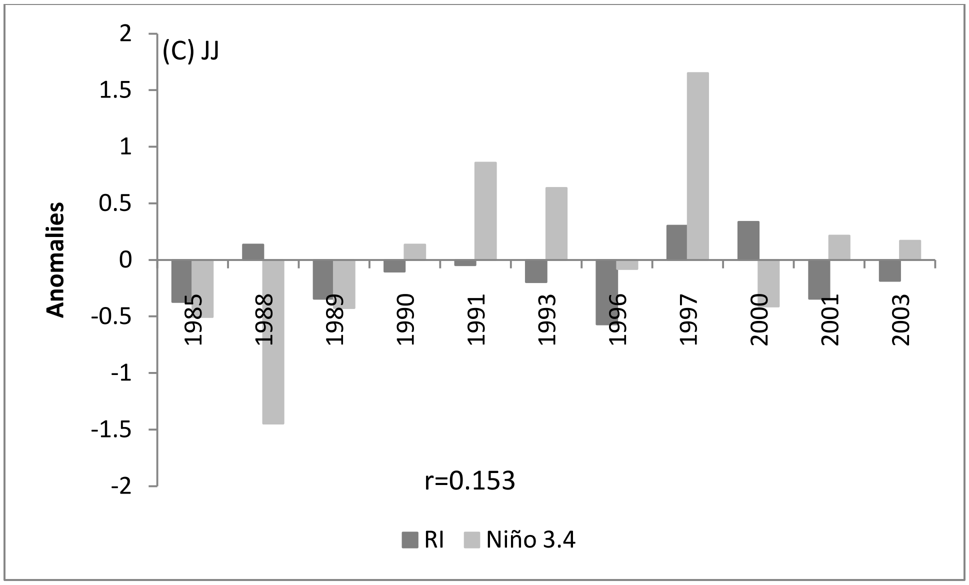
Year	Zero lag
1985	**-0.698**
1988	**-0.658**
1989	**-0.471**
1990	0.026
1991	**0.715**
1993	**0.460**
1996	**-0.769**
1997	**0.851**
2000	**0.546**
2001	**-0.580**
2003	**-0.562**

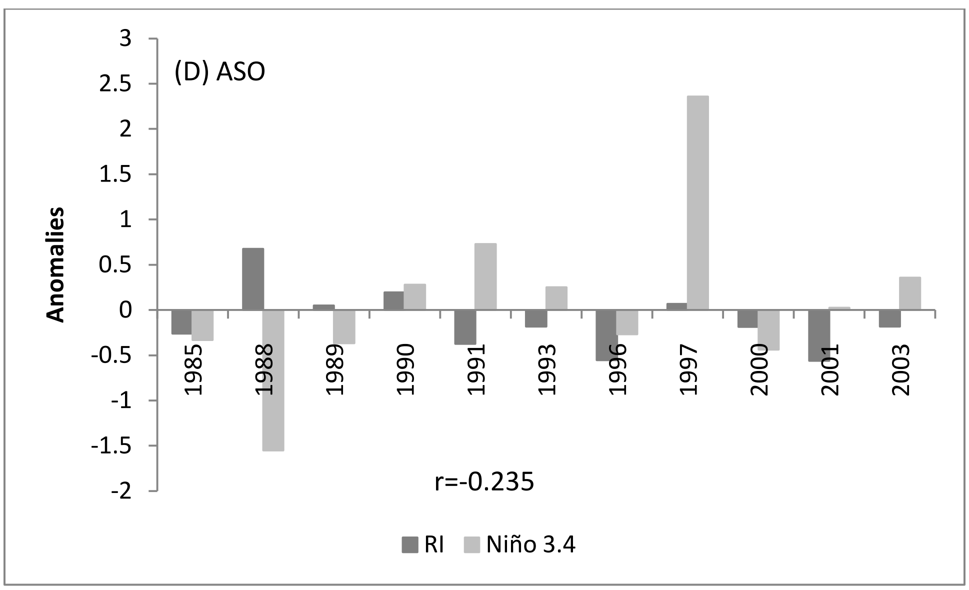
Values in bold indicate significant correlations

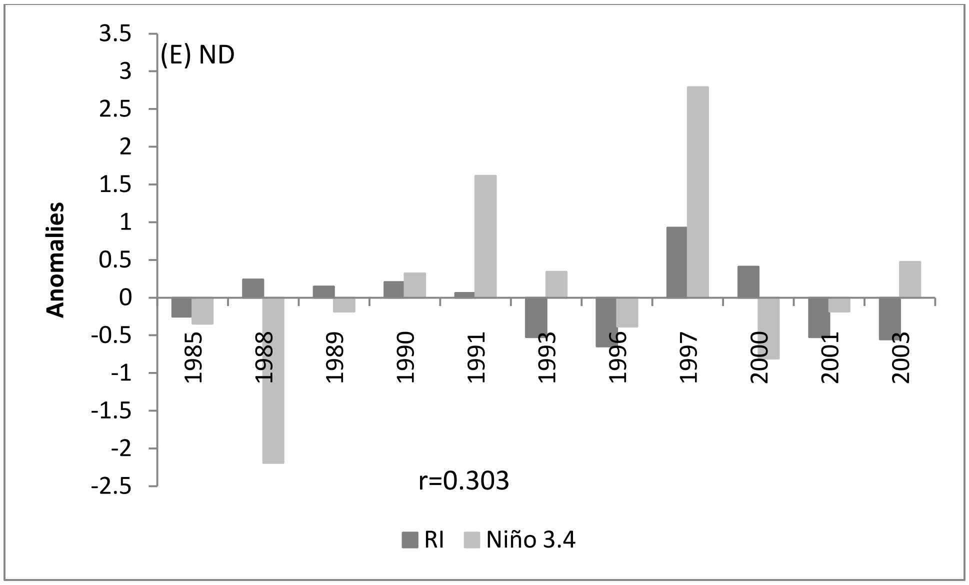
Figure 14 A-E Relationship between Niño 3.4 and rainfall during years of fewer fires (all seasons) and correlations between Niño 3.4 and RI. The units are in standard deviations from normal.






(C) JJ
Anomalies
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1985
1988
1989
1990
1991
1993
1996
1997
2000
2001
2003
r=0.153
RI
Niño 3.4


(D) ASO
Anomalies
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1985
1988
1989
1990
1991
1993
1996
1997
2000
2001
2003
r=-0.235
RI
Niño 3.4



Discussion

The Relationship between Climate and Fire Events

The results obtained in this study reveal seasonal and annual variability in rainfall throughout the 37-year period studied (1971-2007). Between 1985 and 2007 the seasonal variability in rainfall was associated with the number of fire events in the UNFR. Less-than-normal annual rainfall was associated with fire events, but occasional fires occurred in years with more-than-normal annual rainfall. The fire records show that fire events occurred either in the early or late dry season before the more-than-normal rainfall started. Local factors such as relief, maritime influence of the Indian Ocean, and variability in vegetation influence rainfall in East Africa (Ogallo, 1989), and in the UNFR in particular. Aside from local factors, teleconnections such as the DMI (or Indian Ocean Dipole Index) and Niño 3.4 (Sea Surface Temperature in the western Pacific Ocean) affect rainfall. Details on the association between Niño 3.4 and DMI or IOD are well documented (Allan et al., 2001; Annamalai et al., 2004; Kug and Kang, 2005). In addition, Indeje et al. (2000) and Behera et al. (2005), discuss the influence of DMI and Niño 3.4 on East African rainfall levels.

The results of correlating the Dipole Mode Index (DMI) and Niño 3.4 with Rainfall Index (RI) at the Morogoro station demonstrate that teleconnections affect local precipitation at Morogoro and UNFR. Negative correlations indicate that a warmer (El Niño)/cooler (La Niña) (positive/negative Niño 3.4, respectively) is associated with below/above average precipitation in the short-rain and long-rain seasons. This finding contradicts the claim that El Niño/La Niña is always associated with more-than-normal/less-than-normal short (OND) and long (MAM) rainfall in central and southern Tanzania (Conway, 2002, Indeje et al., 2000). My results reveal that not all seasons at the Morogoro station experience more/less-than-normal rainfall in response to positive/negative phases of Niño 3.4.

My results show that the average Dipole Mode Index (DMI) (or Indian Ocean Dipole) in March, April, May (MAM) was negatively correlated with MAM rainfall. The UNFR experienced more-than-normal rainfall in MAM during a cool (negative) DMI phase. These results are similar to a previous study by Behera et al. (2005). In that study, the authors argued that the relationship between a cool DMI and more-than-normal rainfall in East Africa occurs because of a persistent cold-sea surface temperature in the western Indian Ocean in MAM after the boreal summer monsoon causes an active coastal upwelling. At this time, Behera et al. (2005) argued, easterly surface winds that originate south of the equator in the eastern and central Indian Ocean change their course and shift northeastward toward East Africa. These veering regional winds coincide with the development and retreat of the boreal summer monsoon, leading to moisture convergence over East Africa, which results in more-than-normal rainfall in MAM.

A strong negative correlation between DMI and rainfall in the UNFR during years with few fire events indicates a strong influence of DMI on local rainfall levels. This strong influence was significant in 1985, 1990, 1993, 1996, 1997, and 2003. Again, the negative correlation in 1985 illustrates that cool sea-surface temperature (SST) in the western Indian Ocean resulted in less-than-normal rainfall at Morogoro in the same year. Warmer SST in the western Indian Ocean was associated with more-than-normal rainfall in the UNFR. However, exceptions to this phenomenon include, for example, 1987 when a warmer SST in the Indian Ocean was associated with less-than-normal rainfall in the UNFR.

The most fire-prone season is August, September, and October (ASO). During positively anomalous precipitation years such as 1995, 1997 and 2002 very little rainfall falls in August and September, with the most rainfall occurring in October (Appendix I and II). In 1996, Niño 3.4 was negatively correlated with rainfall, indicating that cooler SST resulted in less-than-normal rainfall in the UNFR. This pattern is in line with the work of Camberlin and Philippon (2002), who observed that the 1996-97 period was characterized by La Niña episodes, which depressed the amount of rainfall in East Africa and the state of vegetation biomass (Anyamba et al., 2002). Less-than-normal rainfall in the UNFR led to moisture stress in the forest vegetation, increasing its flammability.

Fires in the second dekad of December would be uncommon because of the expected abundant moisture in the fuel. However, because of the strong positive correlation between DMI and rainfall (MAM) in 2003, which led to more-than-normal rainfall in the UNFR, fires occurred later in December 2003. When November and December (ND) are negatively anomalous (Appendix I, figures b and c), these dry conditions have a devastating effect on soil moisture (Indeje et al., 2000), and soil moisture stress in turn induces vegetation stress. Even when it rains prior to November, as in the first dekad of October 1989, an intervening dry dekad is enough to enable the forest to burn (Appendix II a) as long as there is an ignition source. Dry spells, even in rainy seasons, have a significant impact on the moisture available for plants (Pohl and Camberlin, 2006).

For years that the UNFR did not burn, the correlations in all seasons between DMI and RI were very strong, except in 1992 and 2007. A negative DMI (cool western Indian Ocean SST) in 1992 was associated with less-than-normal rainfall in all seasons except ND. Similarly in 1992, the impact of positive DMI on rainfall was significant for the ASO season only. The Niño 3.4 correlation with rainfall was significant in 1998 and 1999. I cannot attribute the absence of fire events exclusively to more-than-normal rainfall because no fires also occurred in years with less-than-normal rainfall. Based on the available data, it is difficult to establish the extent that patrols around the UNFR prevented fires from burning. Nevertheless, I expect that the strict policing of the UNFR was responsible for reducing the number of fires, particularly in years with less-than-normal rainfall.

Fire events correspond strongly with the timing of regional atmospheric conditions such as changes in the DMI and Niño 3.4. Generally, less-than-normal rainfall provides suitable conditions for flammability. Low rainfall levels deprive the vegetation and soil of moisture, creating stress on the vegetation (Indeje et al., 2000) and making it more flammable. The rest of the fires correspond with the 1988/1989, 1999/2000 and 2001/2002 La Niña conditions; a negative anomaly characterizes these years (Indeje et al., 2000; Mutai and Ward, 2000; McHugh, 2006).

The results illustrated a weak negative correlation between fire events and precipitation, which suggests that rainfall partially explains fire incidence in the UNFR. This finding indicates that other factors also influence the occurrence of fires. In the next section, I discuss the multi-causal nature of fire in UNFR.

The multi-causal nature of fire occurrences

Forest fire is an ecological process that responds strongly to climatic drivers (Le Page et al., 2007). Precipitation is one of the dominant climate factors that explains ignition in a forest (Payne et al., 1996). Lack of moisture and flammability of forests are related (Camberlin and Philippon, 2002; Le Page et al., 2007); in the case of the UNFR, severe moisture deficits during periods of less-than-normal rainfall increased the amount of flammable forest fuel. Therefore, rainfall variability provides one explanation of fire events in the UNFR.

I base the second explanation on local people's use of fire as a farm management tool. The use of fire on farmland is a source of ignition to the already moisture-deficient fuel in the UNFR. This relationship does not suggest that fire occurrence in the UNFR has only one cause. Other factors that affected fire occurrence include the timing of agricultural activities, especially annual farmland preparation in August, September, and October (ASO). My interviews with over 200 farmers in the study area in 1999 indicated that 48.8% of farmers prefer preparing their farms in September, 18.8% favored late August, and 31.25 % and 1.4% prepare their farms in early October and early November, respectively, because they perceive that should fire escape from the farms to the UNFR, the forest is too wet to ignite. The reasons given for later preparation was that October was most favorable for burning. Because it is close to the start of the short rain season, there has been little rainfall already, and therefore the vegetation will not be extremely dry. It is safe to burn then, because fires are not likely to escape from their farms. What farmers may not know was that because they cultivated on steep slopes and fire travels faster upslope (Mark, 2009), they could not put out some fires before the flames escaped. The results of this study, however, showed that ASO months are characterized by dry weather that increased the possibility of what Lulandala (1998), Newmark (1998) and Lyamuya et al. (1994) call dry season fires. Dry weather conditions might carry over from a rainfall deficit year to the following year, worsening drought conditions.

In conclusion, the results reveal that short-term climate variability is partly responsible for the frequency of fire events. Precipitation and fire events are negatively correlated. Years with higher levels of wetness experienced few to no fire incidents, in contrast to years with very low rainfall levels or many dry spells. However, not all years with less-than-normal rainfall experienced fire; policing of the UNFR boundaries may help to deter fires in these moisture-stress years. Although I cannot pinpoint the relative contributions of each factor with the current data, short-term climatic variability and land use (especially the use of fires in farm preparation) help explain fire occurrence and frequency in the UNFR. Fires burn almost annually and are most frequent in ASO. Fire events in the UNFR are complex phenomena because of the synergistic nature of the local climate and teleconnections, anthropogenic activities, and the nature of vegetation in the UNFR ecotone. Any UNFR fire management plan requires a thorough understanding and incorporation of factors that affect fire in the region. In addition, UNFR management practices should consider disparities in the effects of climate-fire interrelationship on the distribution of tree species. I discuss this topic in the next chapter, in which I explore patterns of plant species diversity between burned and unburned areas of northwest UNFR.

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Chapter 4: Patterns of Plant Species Diversity in Northwest Uluguru Nature Forest Reserve (UNFR), Tanzania.

I examined the implication of fire on tree species diversity in the northwest Uluguru Nature Forest Reserve (UNFR). I compared tree species diversity between burned and unburned areas, and determined whether burned and unburned areas depict any variation in stages of succession. I sampled tree species in eighteen stands, and I ordinated tree species data using Nonmetric Multidimensional Scaling (NMS or NMDS) (PC-ORD version 5.10) to describe relationships (similarity and dissimilarities) between tree species, forest succession, and the effect of fire on tree species. Species richness did not vary significantly between burned and unburned plots. However, species composition was high in burned stands, which contributed to a high basal area in burned stands. Unburned stands had low species composition and low basal area. Fire intolerant tree species dominated unburned areas while species in the burned areas were fire adapted. A few species existed in both burned and unburned stands. Trees in burned areas are still at a young successional stage while in unburned stands vegetation development has reached a successional stage that the vegetation is stable with hardwood forest formation. A sustainable management plan for the UNFR must be based on empirical data describing how and why the fire regime varies over space and time.

Introduction

This study investigates the implications of the relationship between climate and fire regime on tree species diversity in the Uluguru Nature Forest Reserve (UNFR). I compare burned and unburned areas of the UNFR along a Bohomela-Mbete transect (North-South orientation) (Figure 1). The UNFR, part of the Eastern Arc Mountains (EAM), contains 108 endemic plant species (Myers *et al.* 2000, Burgess *et al*. 2001). Fire is a natural phenomenon that can transform forest ecosystems (Dale *et al.*, 2000) because it may lead to the loss of seed bank, mortality of mature trees and plants that are not fire resistant, shifts in succession direction, and ultimately habitat loss, particularly when plants fail to recover after a fire event (Whelan, 1995). Fires on the UNFR and the EAM as a whole are known to have caused some plant species to go extinct about 10,000 years ago (Mumbi *et al*., 2008). Over the past four decades, the UNFR has experienced frequent drought (Maack, 1996), and this period has experienced more frequent fires than in prior decades (Lyamuya *et al.*, 1994). Every year humans cause fire in the UNFR, particularly in the sub-montane zone (Lyamuya, *et al.*, 1994).

Climate models predict future drought and warming in this area of about 1-4^{0}C by 2100 (IPCC, 2007), which may worsen the effects of fire on forest ecosystems (Bhatia and Ringia, 1996, Lyamuya *et al*., 1994). Studies in North America have indicated that weather determines the timing, spatial extent and size of fires (Johnson and Miyanishi, 2001). Weather conditions determine ignition, and winds affect the rate of spread of fire (Johnson *et al*., 1990). Similar factors apply to the UNFR although the UNFR topography and wind patterns may affect the location of fire and fire patterns. During my field visit to the UNFR in August 2008, I noted that the forests near Bigwa, Kilakala and Mbete villages are the most affected by fire, which is in line with observation by Lyamuya *et al*., (1994). Fire poses an urgent threat to conservation of forest plant species in the UNFR (Burgess *et al*., 2007; Frontier-Tanzania, 2005). However, how fire affects forest tree diversity is undocumented. I study this phenomenon by using tree species data from sample plots in the Northwest part of the UNFR along a North-South transect in the sub-montane ecotone. I seek to answer the following questions: 1) How does species diversity in frequently burned areas compare with species diversity in unburned areas of the UNFR? and 2) Do burned and unburned stands depict any sere[9] development that is evidence of the impact of fire? A thorough understanding of these questions will contribute to developing a sustainable management plan for the UNFR that is based on empirical data.

Methodology

Study area

This research was conducted in the UNFR near Morogoro, Tanzania (Figure 1). The UNFR extends from 06^{0}51’–07^{0}12’S and from 37^{0}36’–37^{0}45’E and has 291 km^2 of forest area (Burgess *et al*., 2001). The Uluguru Mountains are one of a chain of 12 mountain blocks of the Eastern Arc Mountains (Figure 2), a 900-km stretch from Makambako (southern Tanzania) to the Taita Hills (South Coastal Kenya) (Critical Ecosystems Partnership Fund, 2003). The Tanzanian Ministry of Natural Resources and Tourism, through the Forestry and Bee Division’s Catchment Forestry Office in Morogoro, manages the UNFR. The study site was on the northwest part of the Uluguru (Bohomela to Mbete, a north-south transect, Figure 1) at the forest ecotone. The UNFR in this region is bordered by a wooded grassland (governed by the Morogoro Municipal Council), private woodlots, settlements, and small scale farms. Evergreen montane forests cover Bohomela and Ruvuma while the Bigwa-Kilakala area consists of

[9] The series of stages of vegetation succession from pioneer to climax.

deciduous woodland forest (Burgess et al., 2007). The Bigwa-Kilakala stretch is the most fire affected (personal observation, 2008, Lyamuya *et al*., 1994). Fire records from the Morogoro Catchment Forest office support this observation, and show that Bohomela (part of Bigwa ward) in the north, and Ruvuma in the south do not burn. The study area is on the leeward (western) side of the EAM and receives less rainfall than the eastern EAM (Burgess, *et al*., 2001).   Annual precipitation at Morogoro station (just west of the UNFR) averages 835 mm, with a distinct dry season from June through September. Main soil types are acidic lithosols and ferralitic red, yellow and brown latosols that have developed on Precambian granulite, gneiss and migmatite rocks (Frontier-Tanzania, 2005).

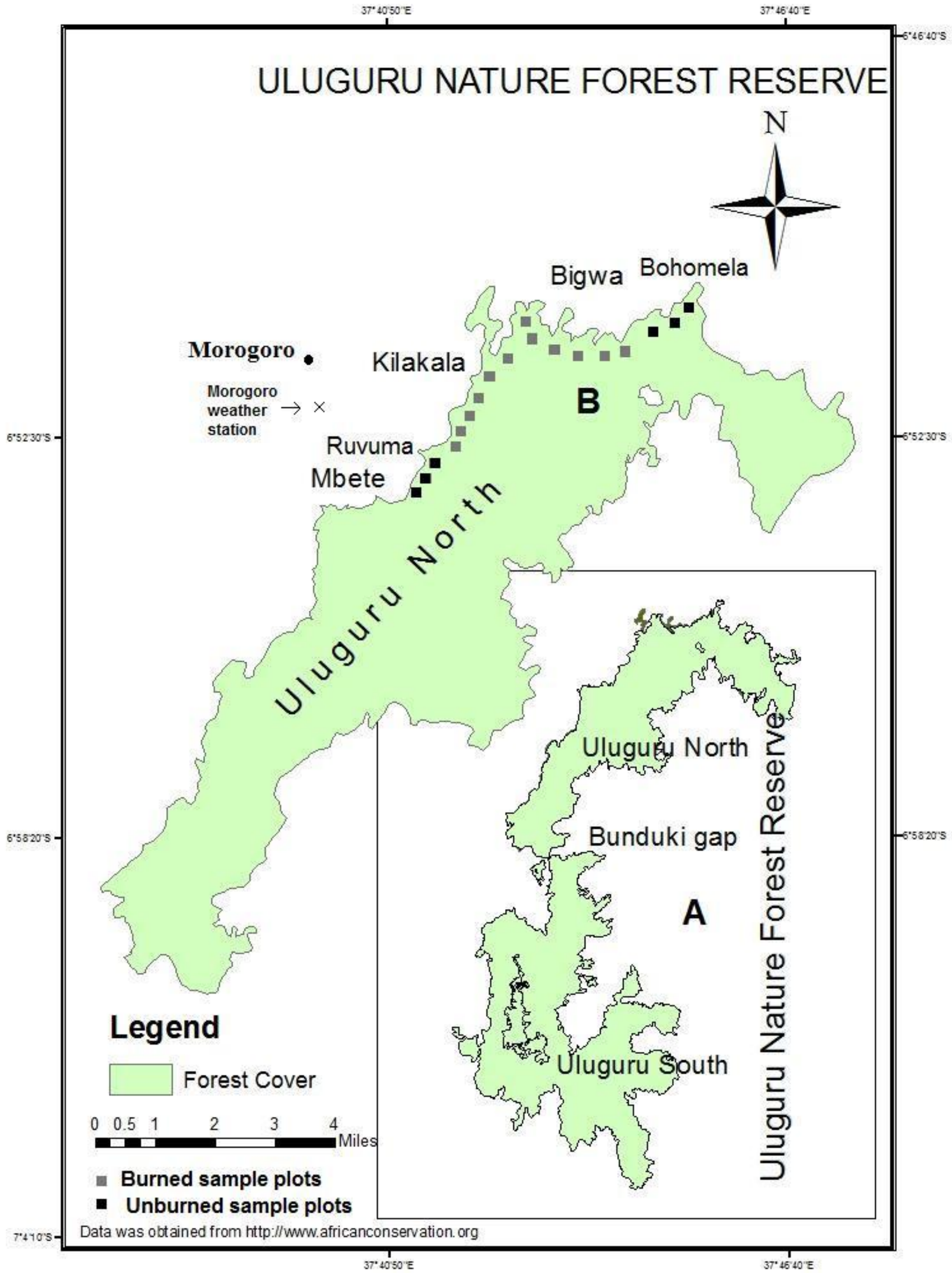

Figure 1 Uluguru Nature Forest Reserve (insert map A) and sample plots in northwest of Uluguru North (map B).

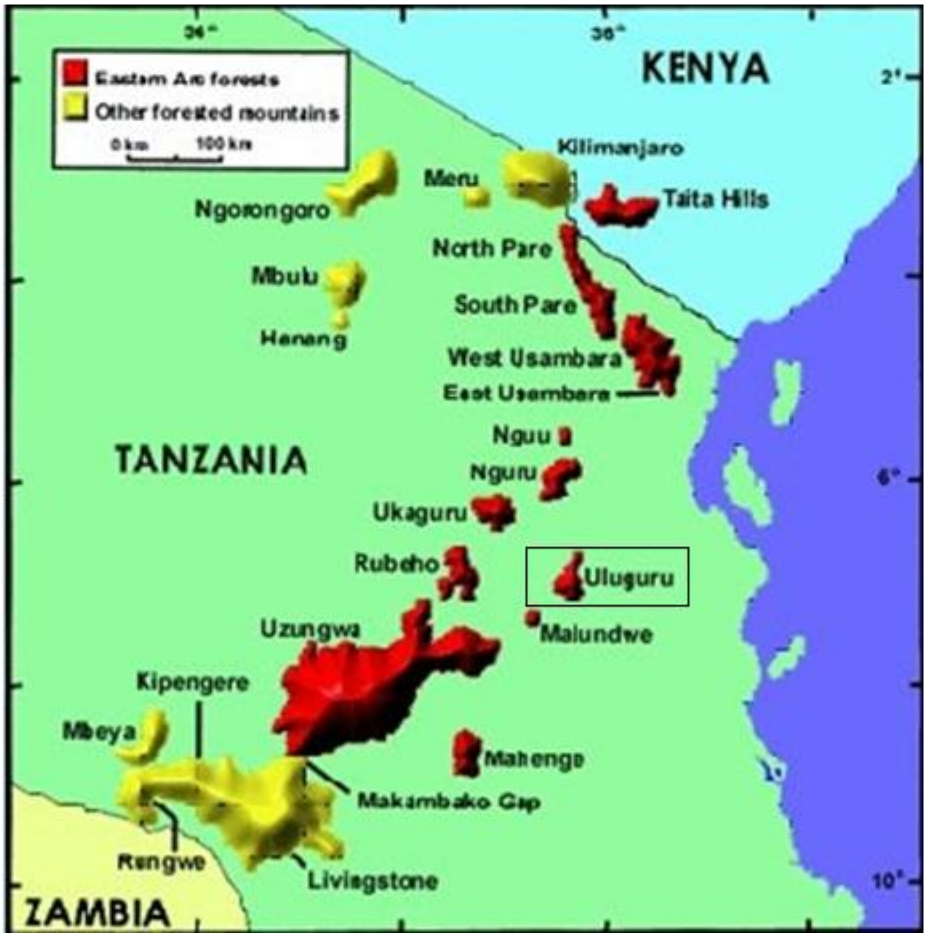

Figure 2 Map of Tanzania showing Uluguru (in box) and the Eastern Arc Mountains (red color). Source: www.easternarc.or.tz/eastarc

Data Collection

To capture spatial differences in species distribution between burned and unburned areas of the Uluguru I collected data from eighteen sample plots (stands). I located the 0.1 ha sample plots at a minimum of five meters from the boundary between the UNFR and land outside the UNFR to minimize edge effects (Ito et al., 2004). I located the plots at a similar elevation along a north-south oriented transect. Twelve plots – three each in Bigwa Lukuyu (BLKY), Bigwa Kisiwani (BKSN), Kilakala Ualimu (KIUM), and Kilakala Bong'ola (KIBG) – represented the area of the UNFR that burns most frequently (Figure 1, gray color code). In the area that burns frequently, fire burns almost annually. Six plots – three each in Ruvuma (RUVU) and Bohomela (BOH) – represented unburned areas (black color code) of the northwest UNFR. The fire return interval in unburned areas was about 3-5 decades[10]. For each site, the three plots are denoted as P1, P2, and P3 so that, for example, BLKY P1, BLKY P2, and BLKY P3 represent plots in Bigwa Lukuyu. I used a nested plot approach to obtain the number, basal area, and species of trees (>5cm dbh) in each plot. The nested plot consisted of the entire plot (0.1 ha) and a subplot (0.05 ha) inside the larger plot so it was easier to count, measure and identify tree species. I worked with a knowledgeable local elderly person to identify all species in the plots. I matched local names of all the species with scientific names in existing inventory reports on the Uluguru in Lovett and Pócs (1993), and Doggart *et al.* (2001).

Data Analysis

In order to answer the questions about species diversity and sere development in burned vs. unburned plots, I did ordination analysis using the Nonmetric Multidimensional Scaling (NMS or NMDS) module in PC-ORD version 5.10 (Mather, 1976, Kruskal, 1964) to describe relationships (similarity and dissimilarities) between

[10] Estimates of fire frequency based on opinions from foresters who have worked in the area for a long time and elderly local people who have lived in the area for more than five decades.

tree species, forest succession, and the effect of fire on tree species. Basal area data were standardized (column relativization using standard deviates) before using the data in NMS with a distance measure (Sørensen also known as Bray-Curtis). Before doing cluster analysis, tree-species basal-area data were transformed to presence/absence (binary form) (McCune and Grace, 2002). In this way I was able to establish associations among tree species in all stands along the transect. In addition, I was able to discern differences in species composition between burned and unburned stands. NMS is the most powerful analytical tool for ecological community data because it enables visualization of patterns in two dimensions (McCune and Grace, 2002) and it was the most effective ordination technique to analyze ecological community data from the study area as the data were non-normal (McCune and Grace, 2002). When running the NMS, I used a Sørensen[11] distance measure, and used a random starting configuration. The number of runs with real data was 250, and I assessed the dimensionality of the data by the Monte Carlo test with 250 runs to see if whether the NMS procedure extracted stronger axes than expected by chance ($p < 0.05$) (Table 1). I selected the best solution 2-D [using the criteria of least final stress] and re-ran the model with the least final stress ($p \leq 0.0040$) (Table 1). A large decrease in minimum stress from 22 in the first solution to 6 in the second solution (Table 1) suggested that the second axis was useful in explaining species composition. I produced joint plots based on Pearson correlation values ($p < 0.05$) to determine the strength of the relationship between species patterns and fire occurrence, and each of the first two axes of the NMS. To aid interpretation of the dynamics of

[11] A normalization method calculated by using absolute difference between variables divided by the summation of all variables. It is an effective way of assessing species and sample similarity.

species between burned and unburned plots in the UNFR, I included overlays and correlations of species with the axes, and other illustrative graphics.

Alpha diversity (Table 2) was measured as species richness[12] per 0.1 ha plot (the total number of species per plot) (Mueller-Dombois and Ellenberg, 2002). Shannon-Wiener Diversity (*H'*) and Simpson's Dominance (*D*) were computed for all plots and averaged for the entire transect (Magurran, 1988). I calculated diversity in two ways: with Simpson's diversity index (a measure of dominance) and with Shannon's diversity index (a measure of evenness). Simpson's diversity index measures the likelihood that

Table 1 STRESS IN RELATION TO DIMENSIONALITY (Number of Axes)

	Stress in real data 250 run(s)			Stress in randomized data Monte Carlo test, 250 runs			
Axes	Minimum	Mean	Maximum	Minimum	Mean	Maximum	p
1	22.045	45.120	55.242	30.181	47.517	54.433	0.0040
2	6.135	10.384	38.074	16.769	22.746	37.184	0.0040
3	4.540	4.758	15.005	9.753	13.970	17.891	0.0040
4	2.673	3.005	21.468	7.233	9.626	20.541	0.0040
5	1.604	2.012	13.659	5.160	6.924	14.523	0.0040
6	1.223	1.490	14.388	3.618	5.048	8.458	0.0040

p = proportion of randomized runs with stress < or = observed stress
i.e., p = (1 + no. permutations <= observed)/(1 + no. permutations)

two species chosen at random from two different plots will be different. The addition or loss of rare species does not affect this measure because Simpsons' index considers

[12] Calculated as the number of species in a plot (McCune and Grace, 2002) based on the number of all trees > 5cm dbh. It is interchangeably used with alpha diversity [species richness] because species richness is a measure of diversity (McCune and Grace, 2002). Species richness equates with species density when expressed per unit area (as cited in McCune and Grace, 2002, p.27).

common species, which makes it stable with sample size (McCune and Grace, 2002). I used cluster analysis (Ward's method and Euclidean distance measure) to define species groups based on their similarities using data on the presence/absence of species in all plots (Sneath and Sokal, 1973, McCune and Grace, 2002). Using the same approach I grouped similar plots (Figure 12). I calculated coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space using 18 entities, 153 entity pairs and Sørensen (Bray-Curtis) distance measure for original distance.

Results and Discussion

Forest structure and topography

In both unburned and burned plots the terrain was rugged and deeply dissected by rivers, narrow ridges, minor valleys, rocky outcrops and cliffs (Figures 3 and 4). The forest in Bohomela (unburned) is composed of evergreen montane forest with closed canopies and with some trees as tall as 30-50 meters (Figures 4 and 5). Some mature trees were big (200+ cm dbh) and buttressed (Figure 5, A and B). The forest consisted of a layer of young trees beneath the canopy. Tree species such as *Grewia similis* was the most dominant followed by *Myrianthus arboreus* and *Suregada zanzibariensis* (Table 3). *Grewia goetzeana* and *Erythrophleum suaveolens* were the third dominant species. A closed tree canopy structure also existed in Ruvuma (unburned) (Figure 6). However, in Ruvuma smaller trees were most dominant. *Parinary excelsa sabine* tree species were dominant, followed by *Newtonia buchanani* and “Mhalasindi” (second most dominant) and *Scolopia zeyheri*, *Vangueria infausta*, *Dodonea viscose,* and *Costus sarmentosus* (third most dominant).

Figure 3 Topography and vegetation at Bigwa Lukuyu showing burned area (foreground to middle ground)

Figure 4 Topography and vegetation structure at Bohomela (unburned area)

Figure 5 Tree size at Bohomela (unburned)

Figure 6 Forest structure at Ruvuma (unburned)

Figure 7 Forest structure at Bigwa Lukuyu (burned)

The Bigwa and Kilakala (burned) plots were characterized by open canopy woodland forests (Figure 7) with species such as *Brachystegia microphylla* and *Harrisonia abyssinica,* dominating most of the landscape (Table 3), and at different levels of growth. Other common tree species included *Diplorhynchus condylocarpon, Bothriocline tomentosa, Bobgunnia madagascariensis,Cassia abbreviate, Dalbergia melanoxylon, Combretum collinum Brachysteria bussei, Albizia petersiana,Combretum adenogonium,* "Mkalangananga" *(Albizia amara),* and *Syzygium cordatu.* In Bigwa Lukuyu and Bigwa Kisiwani there were more mature trees (Figure 8) while younger trees dominated in Kilakala (Figure 9). A list of all species identified in the 18 plots is given in Appendix IV.

Figure 8 Forest structure at Bigwa Kisiwani (burned)

Figure 9 Forest structure at Kilakala Ualimu (burned)

PC-ORD NMS Landscape level dynamics

My NMS ordination retained 89.7% of the variance in the original species data. Axis 1 explained 78.4% of variance and axis 2 explained 11.3% of variance (Figure 10). The primary gradients represented by Axis 1 were negatively correlated with *Parinari excels sabine, Grewia similis, Suregada zanzibariensis, Newtonia buchanani,* 'Mhalasindi', and *Myrianthus arboreus* species, and positively correlated with *Harrisonia abyssinica, Combretum mole, Brachystegia microphylla,* 'Mkalangananga' *(Albizia amara), Cassia abbreviate, Combretum collinum, Bobgunnia madagascariensis, Dalbergia melanoxylon, Bothriocline tomentosa,* and *Diplorhynchus condylocarpon.* Axis 2 was negatively correlated with *Parinari excels sabine*, 'Mkalangananga' *(Albizia amara), Newtonia buchanani,* and 'Mhalasindi' species, but it was positively correlated with *Harrisonia abyssinica, Grewia similis, Combretum mole, Brachystergia* *microphylla, Suregada zanzibariensis, Cassia abbreviate, Combretum collinum, Bobgunnia madagascariensis, Dalbergia melanoxylon, Bothriocline tomentosa, Diplorhynchus condylocarpon* and *Myrianthus arboreus* (Figure 10 and Appendix V).

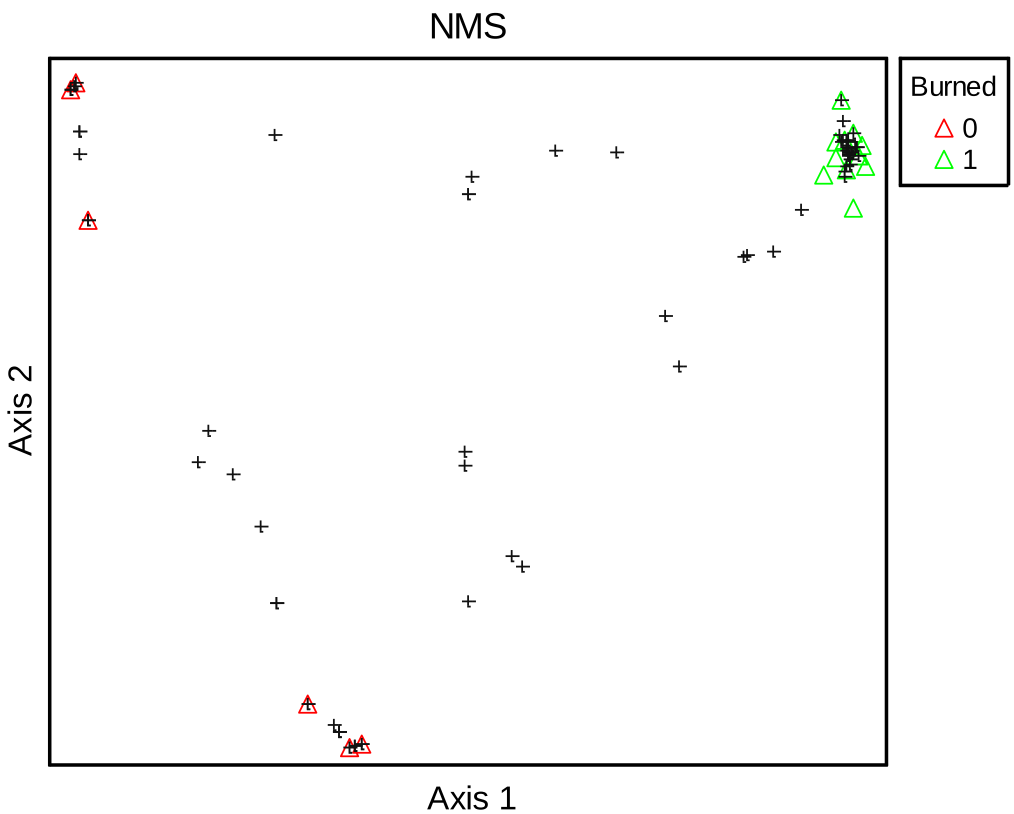

Figure 10. Scatterplot of abundance of species in relation to two ordination axes and stand type. 0=Unburned and 1=Burned plots. += Tree species. Closer points means those tree species are more associated with each other than with the species represented by the more dispersed points. Clustering of species in burned and unburned categories indicate ability of tree species to survive in those conditions.

Six dominant patterns emerge from my ordination. First, in both burned and unburned stands, overall species diversity is high (Simpson's Index between 0.93-0.96); however, species richness (alpha values) in the burned area had an inverse relationship with tree basal area, whereas there was a direct relationship between richness and basal area in the unburned plots.

Second, species richness between burned and unburned areas was not significantly different, although overall mean species richness was higher in unburned plots than in burned plots (Figure 11). In the unburned plots both basal area and species richness were higher in the northern (Bohomela) than in the southern (Ruvuma) part of the transect.

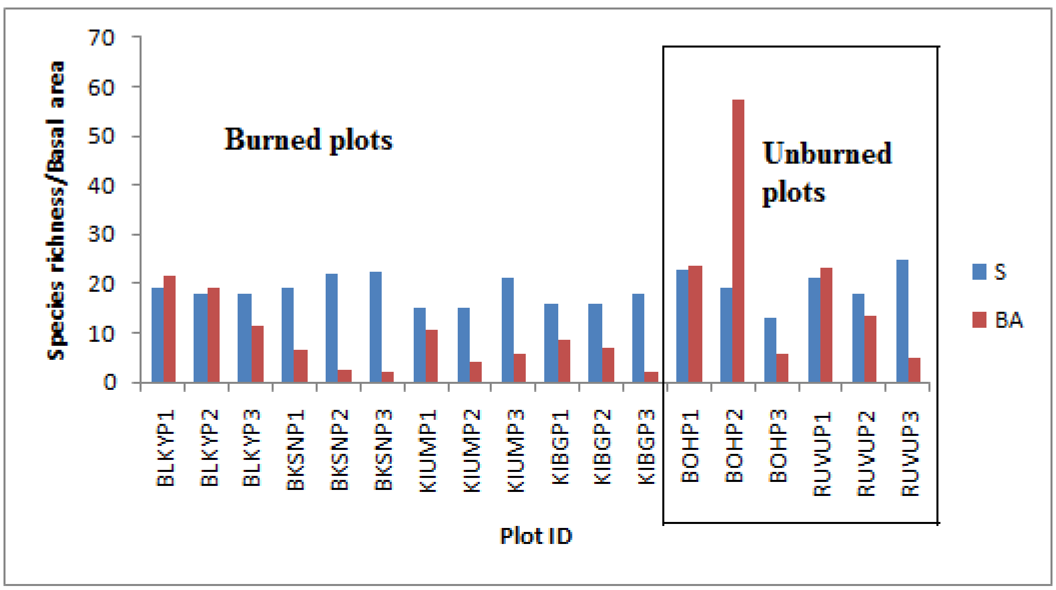

Figure 11. Species dominance based on species richness (S, number of species per ha) and on basal area (BA, m^2/ha) for plots in the burned and unburned areas.

Third, the mean basal area was significantly ($p \leq 0.05$) higher in unburned plots (21.33 m^2/ha) than in burned plots (8.5 m^2/ha). The difference in basal area between unburned and burned plots suggests that the higher number of species per unit area in burned plots corresponds with higher trees basal area, while the opposite is true for unburned areas. In the burned areas, the basal area of trees is larger in the north and smaller toward the south (Bigwa Lukuyu-Kilakala Bong'ola), although the variation in species richness is not significantly different.

Fourth, different sere development was observed between unburned and burned areas. Figures 4 and 6 show the successional stage in burned areas, and Figures 7-9 show the successional stage in unburned areas of the transect.

Fifth, a large proportion of tree species that dominated burned areas of the northwest UNFR (Table 3) were not found in unburned areas. However, a few tree species such as Mkalangananga (*Albizia amara*), *Suregada zanzibariensis,* and *Bothriocline tomentosa* grew in both burned and unburned stands (Table 4). *Albizia amara* was found in Kilakala Bong'ola and Bigwa Kisiwani (burned) and in Ruvuma (unburned). *Suregada zanzibariensis* thrived in Bohomela (unburned) and in one stand only in Kilakala Ualimu. *Bothriocline tomentosa* dominated 10 of 12 stands in burned areas in Bigwa and Kilakala whereas *B. tomentosa* existed in one stand in Ruvuma (unburned). A dendrogram of species presence/absence (Figure 12) shows these distinct tree species groups, and the tree species that cross over burned and unburned stands in the transect.

Sixth, two groups of stands of tree species emerge within the unburned stands indicating that there were differences in tree species types within unburned stands in Bohomela and Ruvuma. For example, tree species such as *Schefflera lukwangulensis, Strombosia scheffleri, Myrianthus arboreus, Grewia similis, Piliostigma thorningii,* and *Blighia unijugata* grow in Bohomela only. Stands in Ruvuma had tree species such as Chuwasesi, *Tabernaemontana pachysiphon, Scolopia zeyheri,* and *Dodonea viscose,* which grew in this area only. However, a few tree species such as *Newtonia buchanani, Macaranga capensis*, and Mbabala were found in both Bohomela and Ruvuma stands.

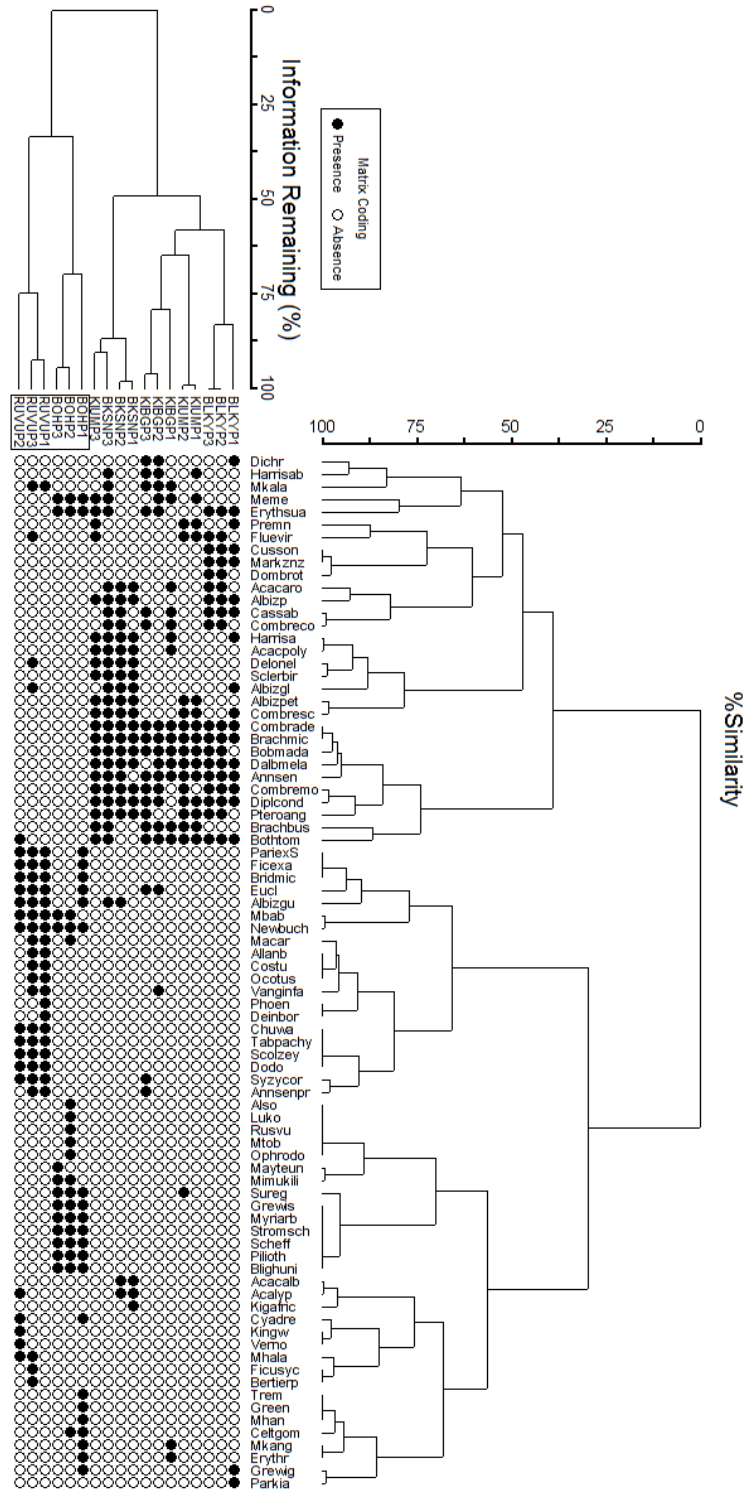

Figure 12 Dendrogram showing similarity (%) of species on the landscape and within plots, based on presence/absence of a species. Unburned plots are highlighted with a box. On the right and top is a list of all tree species and sampled plots, respectively.

Table 2 Diversity Indices

Plot ID	Burned	Alpha (α) diversity	Evenness (E)	Shannon-Wiener index (H)	Simpson's Diversity index (D)
BLKYP1	Yes	19	1	2.944	0.9474
BLKYP2	Yes	18	1	2.890	0.9444
BLKYP3	Yes	18	1	2.890	0.9444
BKSNP1	Yes	19	1	2.944	0.9474
BKSNP2	Yes	22	1	3.091	0.9545
BKSNP3	Yes	26	1	3.258	0.9615
KIUMP1	Yes	15	1	2.708	0.9333
KIUMP2	Yes	15	1	2.708	0.9333
KIUMP3	Yes	21	1	3.045	0.9524
KIBGP1	Yes	16	1	2.773	0.9375
KIBGP2	Yes	16	1	2.773	0.9375
KIBGP3	Yes	18	1	2.890	0.9444
BOHP1	No	23	1	3.135	0.9565
BOHP2	No	19	1	2.944	0.9474
BOHP3	No	13	1	2.565	0.9231
RUVUP1	No	21	1	3.045	0.9524
RUVUP2	No	18	1	2.890	0.9444
RUVUP3	No	25	1	3.219	0.9600

Note that Alpha diversity refers to diversity in sample plots (McCune and Grace, 2002)

Table 3 Species density[13], basal area and names of species dominant in each plot.

Location and plot code	Density (Stems/ha)	Basal area (m^2/ha)	Plot traits	Dominant Species (listed in order of dominance)
Bigwa Lukuyu				
BLKYP1	130	21.6	Burned	*Brachystegia microphylla, Cassia abbreviate, [Albizia petersiana,Combretum adenogonium]*
BLKYP2	141	19.3	Burned	*Brachystegia microphylla,Dalbergia melanoxylon, Cassia abbreviata*
BLKYP3	93	11.3	Burned	*Brachystegia microphylla, Cassia abbreviate, [Combretum adenogonium, Dalbergia melanoxylon & Diplorhynchus condylocarpon]*
Bigwa Kisiwani				
BKSNP1	176	6.5	Burned	*Brachystegia microphylla, Diplorhynchus condylocarpon, Combretum adenogonium*
BKSNP2	112	2.6	Burned	*Brachystegia microphylla, Diplorhynchus condylocarpon, Combretum collinum*
BKSNP3	107	2.2	Burned	*Brachystegia microphylla, Diplorhynchus condylocarpon , Combretum molle*
Kilakala Ualimu				
KIUM P1	252	10.7	Burned	*Brachystegia microphylla, Diplorhynchus condylocarpon, [Brachysteria bussei,Dalbergia melanoxylon]*
KIUM P2	118	4.0	Burned	*Brachystegia microphylla, Combretum collinum, Diplorhynchus condylocarpon*
KIUM P3	131	5.6	Burned	*Brachystegia microphylla, Diplorhynchus condylocarpon, Bobgunnia madagascariensis*
Kilakala Bong'ola				
KIBG P1	115	8.7	Burned	*Brachystegia microphylla,* [Mkalangananga,*Bobgunnia madagascariensis],* *[Cassia abbreviata,Harrisonia abyssinica]*

13 Calculated as the number of all trees [all species] per hectare (Mueller-Dombois and Ellenberg, 2002) based on all trees > 5cm dbh.

Table 3 continued

KIBG P2	98	7.0	Burned	*Harrisonia abyssinica, Bothriocline tomentosa, Bobgunnia madagascariensis*
KIBG P3	89	1.9	Burned	*Combretum molle, Brachystegia microphylla, [Syzygium cordatu,Diplorhynchus condylocarpon]*
Bohomela				
BOHP1	250	23.7	Unburned	*Grewia similis, Myrianthus arboreus, Grewia goetzeana*
BOHP2	176	57.4	Unburned	*Grewia similis, Myrianthus arboreus, Erythrophleum suaveolens*
BOHP3	72	5.7	Unburned	*Grewia similis, Suregada zanzibariensis, Myrianthus arboreus*
Ruvuma				
RUVUP1	246	23.1	Unburned	*Parinari excelsa Sabine, Newtonia buchanani, Scolopia zeyheri*
RUVUP2	102	13.3	Unburned	*Parinari excelsa Sabine*, Mhalasindi, *[Vangueria infausta,Dodonea viscose]*
RUVUP3	163	4.8	Unburned	*Parinari excelsa Sabine, Newtonia buchanani, [Scolopia zeyheri,Costus sarmentosus,Dodonea viscose]*

Table 4 Species found in both burned and unburned plots of northwestern UNFR and their distribution along the transect

Species name	Number of plots in unburned area	%	Number of plots in burned area	%
Mkalangananga	2	22.2	4	22.2
Memecylon semseii	3	16.7	5	27.8
Erythrophleum suaveolens	3	16.7	7	38.9
Flueggea virosa	1	5.6	5	27.8
Delonix elata	1	5.6	4	22.2
Albizia glaberrima	1	5.6	4	22.2
Bothriocline tomentosa	1	5.6	10	55.6
Euclea divinorum	4	22.2	2	11.1
Albizia gummifera	4	22.2	2	11.1
Vangueria infausta	2	11.1	1	5.6
Syzygium cordatum	3	16.7	1	5.6
Annona senegalensis	2	11.1	1	5.6
Suregada zanzibariensis	3	16.7	1	5.6
Acalypta fruticosa	1	5.6	2	11.1
Khaya anthotheca	1	5.6	1	5.6
Erythrina abyssinica	1	5.6	1	5.6
Grewia goetziana	1	5.6	1	5.6

Discussion

The results make sense in the context of fire, human disturbance, status as burned or unburned, topography, and the relationship between local climatic conditions and teleconnections. Six findings emerged from my ordination. (1) Both burned and unburned stands had high overall species diversity. However, species richness in the burned area had an inverse relationship with tree basal area (plots with more species had smaller tree basal area) that was not observed for the unburned plots. (2) Species richness did not vary significantly between burned and unburned plots, but (3) tree species types differed markedly between burned and unburned areas. (4) The basal areas of species in burned areas decreased from north to south (higher in Bigwa Lukuyu, lower in Kilakala Bong'ola), although variation in species richness was not significant. (5) Unburned areas had both higher basal area and higher species richness in the north (Bohomela) than south (Ruvuma). (6) Two distinct groups of tree species emerged within unburned stands, and some tree species cross over between burned and unburned stands. Next, I discuss and illustrate each finding.

The great diversity of tree species in both burned and unburned stands underscores the importance of the Uluguru Nature Forest Reserve for conservation of flora. My findings on high tree species diversity are in accord with results from other parts of Uluguru and at other locations of similar altitude in the Eastern Arc Mountains (Burgess et al., 2007, Lovett, 1996). Diverse plant communities in burned stands result from a number of factors. Burned stands' canopies are open (Figures 7 and 13). Trees such as *Brachystegia microphylla, Cassia abbreviate, Dalbergia menaloxylon,* *Diplorhynchus condylocarpon, Brachystergia bussei, Combretum collinum, Combretum molle, Combretum adenogonium, Bobgunnia madagascariensis, Harrisonia abyssinica*, and *Cassia abbreviate* dominate in burned stands. I did not find any of these species in unburned stands. The occurrence and dominance of these species only in burned areas suggests that these species have adapted to fires. Trees in burned plots adapt through regeneration after fire and survival during fire. I observed in the field, particularly in the Bigwa area, that mature larger trees such as *Brachystegia microphylla* have a relatively thick bark that would help them to withstand low intensity fires (Figure 13 B). Other species such as *Erythrophleum suaveolens* not only have thick bark that enable them to thrive in low intensity fires but also they are able to regenerate from stump after fires (Figure 14). However, a few tree species thrive in both burned and unburned stands; including Mkalangananga (*Albizia amara*), *Suregada zanzibariensis*, and *Bothriocline tomentosa*. *Albizia amara* prefers to grow in areas with plenty of light (open) because it was found in burned and unburned stands that had no shade (Kilakala and Bigwa). In the unburned Ruvuma stand *Albizia amara* tree species also grew in open areas. Because of the flat shape and lightness of *A. amara*'s seed pods, I cogitate that northwesterlies during the early and late dry season could have dispersed seeds from Bigwa to Ruvuma because the latter is located south of the former (Figure 1). Orwa et al. (2009) describes *Albizia amara* as a species that grows in strong light conditions, and the tree's shallow and spreading root system enables it to grow in areas with low rainfall (400-000 mm) and in soils poor in nutrients. *Suregada zanzibariensis* and *Bothriocline tomentosa* thrive in burned and unburned stands of the northwestern UNFR suggesting that they have the ability to grow in variable soil conditions. However *Bothriocline tomentosa* dominated burned areas and was rare in unburned plots, while the opposite was true for *Suregada zanzibariensis*. *S. zanzibariensis and Bothriocline tomentosa,* which have the ability to grow at different altitudes and shallow soils, are common species in the coastal forests of East Africa (Burgess and Clarke, 2000).

Figure 13 (A) Dominance of *Brachystegia microphylla* species (B) Mature *B. microphylla* with bark that can stand less intense fire that might kill other thin barked and younger trees

Although there is a lack of significant variation in tree species richness between burned and unburned plots of the northwest UNFR, I found that the types of tree species varied significantly between burned and unburned areas. Tree species that have adapted to fire dominated burned areas while tree species that are dominant in unburned areas are rare in the burned plots, suggesting that the dominant species in the unburned areas are not fire adapted.

Figure 14. A non dominant *Erythrophleum suaveolens* regenerates after fire. The lines connect to the same tree's picture of the branches and canopy.

The forest structure suggests that community succession in burned areas could be categorized as at a middle successional stage (Figure 8 and 15) while in other burned areas the forest community could be categorized as near-middle succession (Figure 9). A combination of factors such as fire, human encroachment for agriculture, and cutting of trees for construction material can explain the successional stage of, for example, the Kilakala Ualimu area, because of the settlement bordering the forest. Past variations in the intensity of human-induced forest disturbances may explain the current observable differences in forest structure and succession stage. The observed vegetation structure (Figures 9 and 15) may be a legacy of intense past land use of the area, unlike in other, less-utilized areas of transect. When frequent fires compound the effects of prior land uses it results in species such as *Brachystegia microphylla* competing favorably in these areas, hence, its dominance in the burned areas. I speculate that fire provides nutrients to early growing trees but when multiple species have grown in the area the occurrence of fire modifies succession through killing of some tree species while other tree species survive the fires.

Figure 15 Stand structure at Bigwa Kisiwani

The uniqueness of the size distribution of tree species and types that grow in Ruvuma and Bohomela (unburned) suggests that trees growing in these two areas do not require fire to sustain them. A few tree species that grow in the understory in Ruvuma and Bohomela tolerate shade. In the burned area (Bigwa through Kilakala), fire is a major controlling factor of trees growth. However, fire is not the only factor controlling tree growth because the current trees may be a relict of past successional stages that were interrupted by human induced land use changes, or at least human land use of the area may have been more significant than in the unburned areas. There were areas of the UNFR that were settled in the past but where people had been evicted, and where vegetation has regenerated to a level similar to areas that are known to have frequently burned. For example, although there are no settlements there now, it is known that the area around Kilakala was settled and farmed around the 1870s (personal communication, elderly resident of the Kilakala area, 2008), so that human-caused disturbance is a likely contributor to the present structure of the forest. The current vegetation structure in Kilakala shows a late early-to-middle seral stage of succession (Figure 9).

In unburned areas, the presence of large non-dominant trees, such as *Celtis gomphophylla* Bohomela (Figure 16), suggests that the stand in the area has reached or is near equilibrium. Lovett (1996) observed that equilibrium of large tree species diversity and endemics in the Eastern Arc Mountains, of which UNFR is part, is a result of long-term stochastic events on the landscape. These big trees create closed canopies that control the amount of light reaching the ground, inhibiting other species from establishing. Stands in Ruvuma are similar to Bohomela because trees are well established in this area too, indicating a successional stability. The geology and climate of the Eastern Arc Mountains have been relatively stable since the last glacial maximum (LGM) (38,000 years), which reflects a significant stability of a tropical montane forest (Mumbi et al. 2008, Lovett 1996), resulting in successional stability in the absence of fire or minimal fire interference. However, at local scale and in the northwestern UNFR in particular, short-term climate variations help to explain fire frequency in the burned areas (William, in preparation). William (in preparation) found that the Bohomela and Ruvuma areas are not much affected by fire[14] presumably because the amount of dry fuel in these areas is very low where closed canopies maintain a fuel moisture content at which fire is

[14] Based on personal observation and interviews with forest officers in charge of UNFR, local people, and available fire records Ruvuma and Bohomela did not burn regularly like other areas of northwest UNFR.

unable to spread (moisture of extinction). In contrast, at Kilakala and Bigwa, 1-hour and 10-hour fuel dominate the area, especially at forest margins.

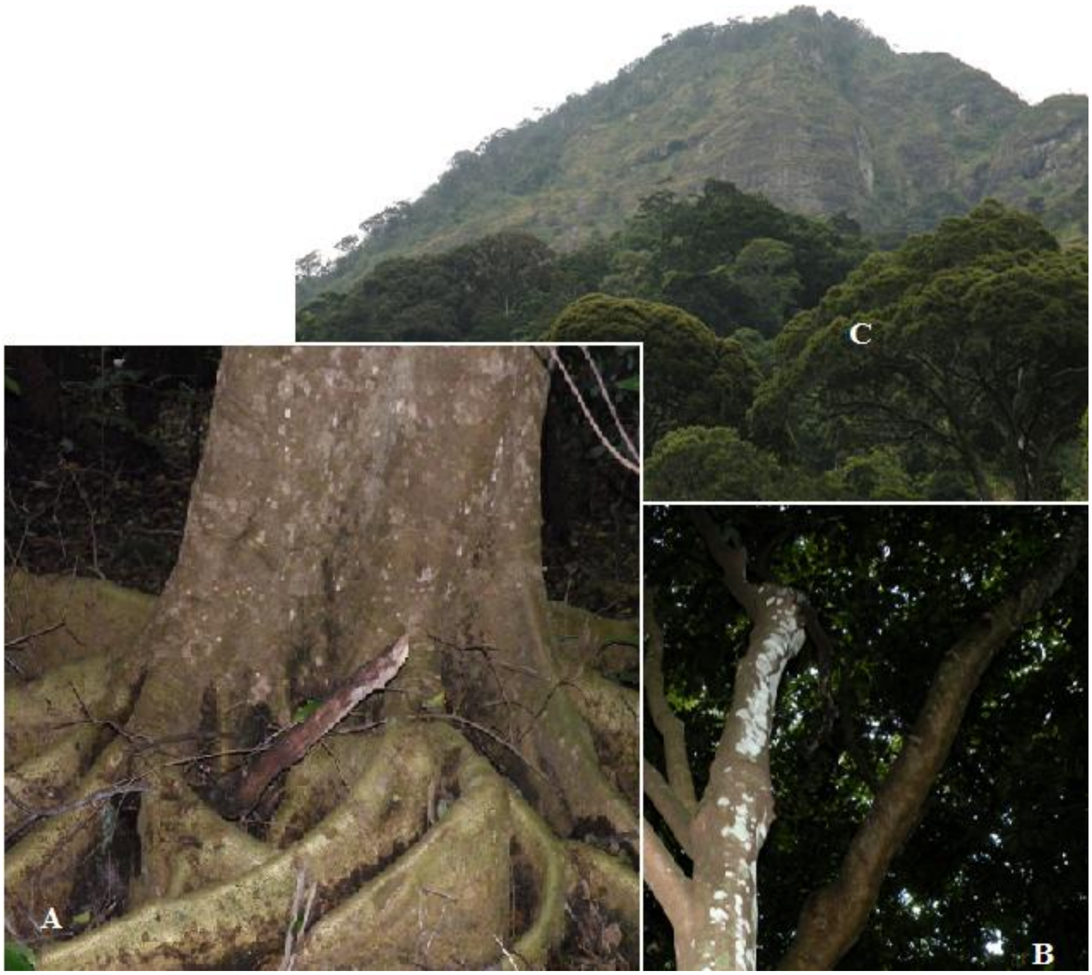

Figure 16 A: *Celtis gomphophylla* stem; B: Upper canopy of trees inside the forest; and C: Tree canopy at a distance

Stands in burned areas (Bigwa Lukuyu, Bigwa Kisiwani, Kilakala Ualimu, and Kilakala Bong'ola) have higher stem density than stands in unburned areas (Bohomela and Ruvuma), although the basal area in burned areas is lower than for unburned stands.

In Ruvuma in particular, trees were tall and had small dbh, suggesting a high competition for soil nutrients and light. The inverse relationship between stem density and basal area per unit area in burned areas is due to trees growing under the legacy of past human encroachment for agriculture, settlement and construction material, species competition for available resources (soil nutrients and light), and fire. The burned area's soil formation is poor, a problem that is compounded by fire occurrence. Burned forests reduce the soil's ability to hold water (Cochrane, 2009) because when vegetation cover has burned the rain falling on the steep slopes of the UNFR would easily wash away soil nutrients. Trees in the burned areas are slow growing trees with hard dense wood and the vegetation in this area represents a middle stage of forest succession. However, in Bohomela and Ruvuma there are lower stem densities but larger basal areas than in the burned areas, because trees have grown tall and have closed canopies that minimize species competition. Presumably, the trees in Bohomela and Ruvuma utilize nutrients for maximum growth rather than trying to outcompete other tree species for the same available resources (Figures 5 and 16). The competition for available resources in the study area is crucial because soils in the UNFR, as in most parts of the Eastern Arc Mountains, are nutrient poor and highly leached (Newmark, 2002) so any competition for soil nutrients is detrimental for a tree species survival.

Figure 17. Forest in Ruvuma. Local people's farms (cleared area) border the UNFR.

In the unburned plots both basal area and species richness show the highest values in the north (Bohomela) as compared to the south (Ruvuma). Because Bohomela and Ruvuma are located slightly north and south, respectively, of the highest peaks of the UNFR, they may benefit from moisture carried by the prevailing easterly flow from the Indian Ocean, which can sometimes reach these areas before being deprived of its moisture as it crosses the mountain ridge. The moisture, *ceteris paribus*, makes

Bohomela somewhat humid, which helps trees grow better in Bohomela than Ruvuma. The position of these sites relative to the UNFR may help to explain the differences in the tree growth of the UNFR. I also observed that soils in Bohomela and Ruvuma were relatively deep, as compared to the shallow soils in the burned areas.

At local scales fire, soils, and precipitation influence the distribution of tree species as well as species dominance and basal area. Because soils in the burned area are shallow, moisture stress not only affects tree growth but also increases the chances of trees being killed by fire. Trees that are already experiencing moisture stress are vulnerable to death when they are burned (Pohl and Camberlin, 2006). For the UNFR as a whole, however, fires and precipitation seem to reflect regional climate patterns and teleconnections (William, in preparation). Precipitation in the short rain season (October, November, December) is positively correlated with warm sea surface temperature (SST) anomalies in the western Indian Ocean (Ummenhofer *et al.*, 2009, Behera, *et al.*, 2005). Rainfall in the UNFR also varies in response to the El Niño-South Oscillation (ENSO), receiving normal to above normal rainfall in the short (October-December) and long rain (March-May) seasons during warm (El Niño) events (Indeje, *et al.*, 2000, Mutai, 2000). These dynamics play a major role in shaping tree growth variations in the UNFR. Although the climate of the Eastern Arc Mountains has been stable over time (Mumbi *et al.* 2008, Lovett, 1994, Burgess *et al.*, 2008) this long term stability obscures the effects of short term variations in climate. Year to year variation in precipitation affects the fire regime in the UNFR (William, in preparation), which in turn alters plant species survival, growth and distribution. There is likely to be an increase in fire events with increasing dry weather in the UNFR.

In conclusion, my findings suggest that tree species richness does not vary significantly between burned and unburned plots, but that species types do. A few tree species were found in both burned and unburned stands. However, basal area varies between burned and unburned areas indicating that fire constrains stand growth in burned areas. Unburned areas are dominated by species that are not fire tolerant while species in the burned areas were fire adapted. The large basal area of species in unburned areas indicates the absence of fire, less tree species competition for resources, and the stability of long-term climatic conditions. Trees in Bigwa and Kilakala are still at a young successional stage while in Bohomela and Ruvuma the successional process is stable with hardwood forest formation.

Short term climate variability determines how frequently fires occur in the UNFR. Both local and regional drivers of climate affect the dynamics of the forests in the UNFR (William, in preparation). It is logical to assume that as climatic conditions, and populations, in and around the UNFR and the Eastern Arc Mountains change, so will both the fire regime and the frequency of other human-caused forest disturbances. With fire suppression in the UNFR in progress, fuel build up is currently very high and should fire occur in the future, it will likely be severe and possibly reset the process of succession in the burned area. My findings also suggest that a combination of factors determine the distribution of tree species in the UNFR. Comparisons of burned and unburned stands show a distinction in tree species types that grow in the two areas indicating varying tree species tolerance to fire. Larger differences in basal area between burned and unburned areas indicate that unburned areas have approached a later succession stage (larger basal area) while the burned area is approaching or is in a middle stage of succession (small basal area).

As we consider conservation of the plant and animal species in the UNFR we need to factor in the role of fire as it affects forest tree species and ecosystem function. As such conservation should not be the sole responsibility of the Tanzania's conservation agency because the benefits of conserving the UNFR accrue to both local people and the international community. Rather it should be a collaborative role between local, regional, and international nature conservation agencies interested in biodiversity conservation because the benefits of biodiversity transcend national borders to benefit the global community.

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Chapter 5: Conclusion and Synthesis

The overarching objective of this study was to contribute to our understanding of the ecology of UNFR, the synergy between climate and fire, and challenges that emerge in the management of the UNFR. To address the aforementioned goal I focused on three interrelated themes: conflicts between local people and forest officials associated with fire incidents in the UNFR, the influence of short-term precipitation variability on the UNFR fire regime, and the effects of fire on tree species diversity in the region. Within the conflict theme, the question was why conflicts between forest officials and local people have persisted for more than a century despite measures in place to avoid such conflicts. The central question for the climate-fire theme was why fires continue to burn in the UNFR although efforts to stop them have been ongoing in the area since 1909. In the last theme I addressed to what extent fire was a threat to tree species diversity in the northwest UNFR.

Conflicts in the Management of UNFR

My findings in Chapter 2 show how changes in conceptions of the appropriate use of nature can trigger conflicts. I described how and why conflicts over the use of the UNFR emerge between forest managers and local people, and how these conflicts have different forms. The results showed that the relationship between local people and forest officials differed between the pre-independence and post-independence periods. I showed how the lack of information sharing among stakeholders (local people and forest officials), conflicting interests among stakeholders, structural power differences, and distrust between local people and forest officials culminate in different forms of conflict, typically focused around fire incidents. At the core of the conflicts is the creation of the Uluguru Forest Nature Reserve as an area that excludes human interaction, which belies both the history of the region (people have been living in the area for centuries) and the fact that humans are a part of "nature." The idea of nature as non-human is based on an ideology that humans always threaten the existence of nature and biodiversity, and that forest officers must intervene to prevent local people from using the resources within the Reserve. Such interventions have inevitably led to conflict. I documented in Chapter 2 that Tanzania's national forest policy for managing the UNFR must explicitly indicate how local people shall benefit from their (the local people') active involvement in the management of nature reserves around them. The government enforcement of rules and regulations is not enough, and it has not worked well in managing the UNFR. Root causes for the antagonistic relationship between local people and forest officers (the government) should be considered (or rather reconsidered) in planning for short, medium, and long-term management of the UNFR. The state should seek to identify how local peoples' activities and livelihoods can be brought into the management process so local people will feel a sense of ownership of the management plan and realize how important they are in the management of the UNFR. Without the local people feeling that they own the UNFR, their involvement in planning, implementation, and evaluation of the management plans will be lost. The process of managing the UNFR should be a constant learning platform, where along the way, changes (when necessary) must be made to correct or improve aspects in the plan. My findings contribute to nature management theories and the literature on the power asymmetry involved in the creation and management of nature reserves, and understanding of underlying causes of conflicts that stem from power imbalances between the state and the local people. In addition, I point to outcomes of the mismatch between policymaking at the state level and implementation of these policies at the local level, particularly when the voices of the local people are not incorporated in the policymaking process. This study has laid the groundwork for further studies that will provide a thorough understanding of both government and local community's characteristics (e.g. customary principles) that would provide empirical information useful in developing a sound management plan for the UNFR.

Fire-Climate Interrelationships

Research in the tropics on climate-fire relationships show there is a strong correlation between the two. However, the relationship between short-term climate variations and fire in the UNFR was unknown. My findings in Chapter 3 show that there is a climate (precipitation) signal in the UNFR's fire regime. Generally, precipitation variations determine the frequency of fire incidents in the UNFR. In addition, seasonality in climate corresponds with seasonality in fire incidents. I documented that at the local level, topography affects both the rainfall and the ecology of the forest on the northwest UNFR because it lies in the rain shadow of the Uluguru Mountains. On the other hand, teleconnections (Indian Ocean sea surface temperatures and the El Niño-Southern

Oscillation) also influenced rainfall during the short and long rainfall seasons, which in turn affected frequency of fire in the UNFR. Rainfall conditions in a year determine the frequency of fire in that year, and variations in monthly rainfall determine the number of monthly fire incidents. This study found that dry weather conditions might carry over from a rainfall deficient year to the following year, worsening drought conditions and fire incidents. Generally, almost every year the UNFR burns, with fires more frequent in August, September and October. The timing of fire use in managing farms around the UNFR is critical because at farm level the timing of use of fire will determine the ability of farmers to contain fires, or their inability to stop fire from escaping from their farms and burning into the UNFR. Although fires in the UNFR are human-caused, my research showed that precipitation variations played a significant role in modulating fire frequency. Other climatic and non-climatic factors, however, will also influence fires (e.g., land use, seasonal wind patterns, humidity, and temperature) and these other factors need research so the whole climate picture and its relationship with fires will be understood thoroughly.

Implications of Fire for Tree Species Diversity

Most researchers have been concerned with fires that burn in the UNFR noting that these fires are a threat to biodiversity. My research addressed this fire threat on tree species in northwest UNFR. My findings showed that tree species diversity was not significantly different between burned and unburned stands of the northwest UNFR. What differed was tree species type and tree basal areas. The difference in tree species type between burned and unburned stands suggest that trees that grow in the most fire prone stands were more adapted to fires. The basal area of trees were higher in unburned stands and lower in burned stands, indicating that, *ceteris paribus*, trees thrive better in the absence of fire. The burned areas were in the early to middle sere stage but was near or at equilibrium in unburned stands. However, trees are not the only biodiversity component of the UNFR. While fires may have not severely affected trees diversity, fires could have important effects on other plant types. There is a need for further study of plant types other than trees to establish their relationships with fire so that the UNFR can be managed to maintain overall biodiversity while benefiting local people too.

Implications for Management of UNFR and Future Studies

The fundamental implication of my research is that management of the UNFR must be people-centered and that a management plan must be based on UNFR-specific data that integrate climate variations and the concomitant variability in fire regime. Expert consensus is that fire is a human-caused but climate mediated disturbance in the northwest UNFR. Fires that occur in the UNFR have resulted in conflicts between forest officials and local people. Reliance on laws and regulations stipulated by bureaucrats for local people to follow does not work and the laws and regulations governing the UNFR need revision. Clauses that address the involvement of local people in the management of the UNFR must be clear in UNFR forest policy so the role of the local people and the benefits that accrue to them are overt. The latter will provide an incentive for local people to be involved in the management of the UNFR. Designation of responsibilities may differ among stakeholders depending on how much mutually agreed stake they have in the management of the UNFR.

Currently the Chief Conservator's Office in Morogoro is drafting a management plan for the UNFR. The new management plan is necessary because of the forest's change in status from the Uluguru Territorial Forest Reserve (UTFR) to the Uluguru Nature Forest Reserve (UNFR). However, the plan should not be considered final after the Ministry of Natural Resources and Tourism approves it. The document should allow for changes in the future, as empirical data pertinent to the management of UNFR accumulate. More empirical data are needed to establish a feasible (based on scientific data) management plan because the current model of depending on the enforcement of centrally developed rules and regulations and the policing of the boundaries of the UNFR is not effective. Policing the UNFR boundary is difficult due to a shortage of forest officials that would police every section of the UNFR boundary, especially given its rugged terrain and the conflicts that stem from enforcing stern rules and regulation. According to Temple (1972), "Excessive dependence on rules and regulations is no answer while the legacy of past policies and experience is a major barrier in the way of future ameliorative measures" (120). The challenge is not to preserve nature but people's interaction with nature, without this interaction people's capability to understand nature and connect with it fades (Adams, 2004). We need to sustain the connection between people and nature so we will be able to maintain both.

Documentation of fire records should include important aspects of fire behavior to enable analytical comparisons over time and space. The information on fire behavior will help in making sound management decisions. Recorders of a fire event should describe flame length, fire intensity, fuel type, wind speed and direction at the time of fire, slope of the area where fire burned, and an estimate of the area burned. These data and any other descriptive information should be stored in a database so it is easier to retrieve and analyze.

A fire management plan must itemize necessary equipment for fighting fires at different levels of fire intensity, fuel type and terrain condition. Professional fire fighters must be summoned whenever ground level fire fighters using crude tools such as tree branches, and creating fire breaks using hand hoes and machetes, are incapable of containing the fire, or when attempting to put out fire threatens ground crews' lives. Fire fighting should be a national priority particularly when the fire endangers human lives, human health, property, and ecological systems that sustain life such as the UNFR (e.g. water catchment). When putting out fire is a national priority, the army should fight fires using aerial tools. The UNFR is a watershed that supports the Morogoro, Pwani, and Dar Es Salaam administrative regions' population. The UNFR should deserve special attention when it comes to controlling fires because it benefits both humans and biodiversity.

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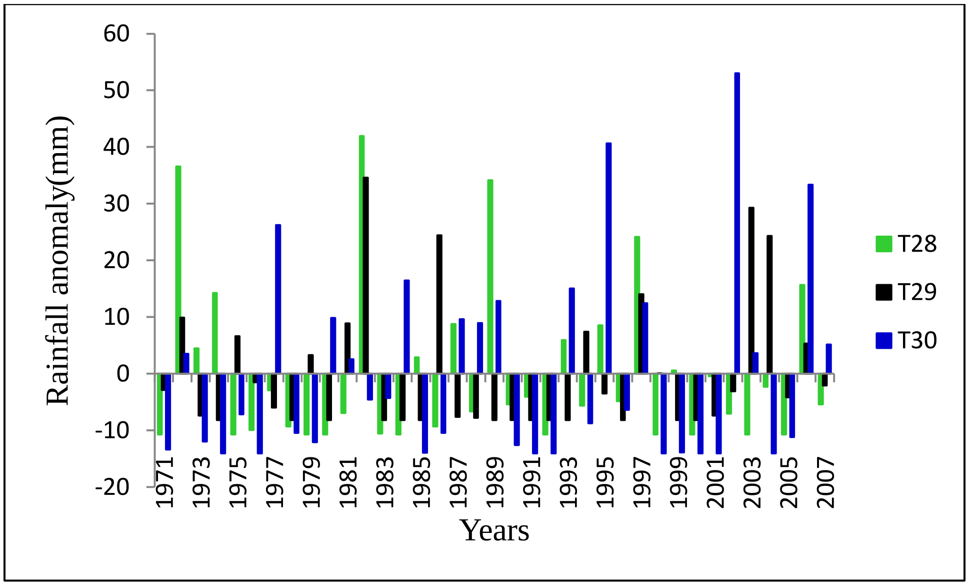
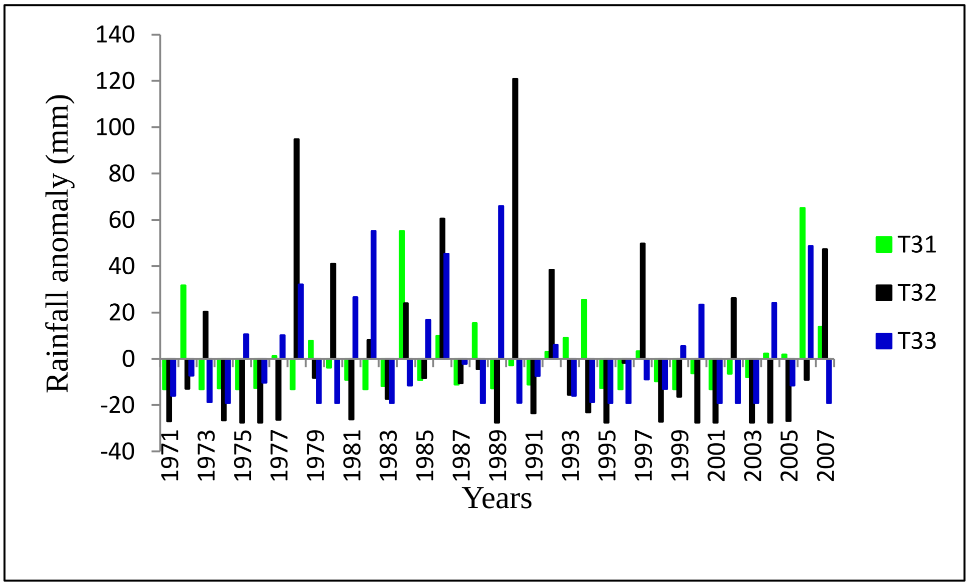
APPENDICES

APPENDIX I: DEKADs PRECIPITATION ANOMALY GRAPHS

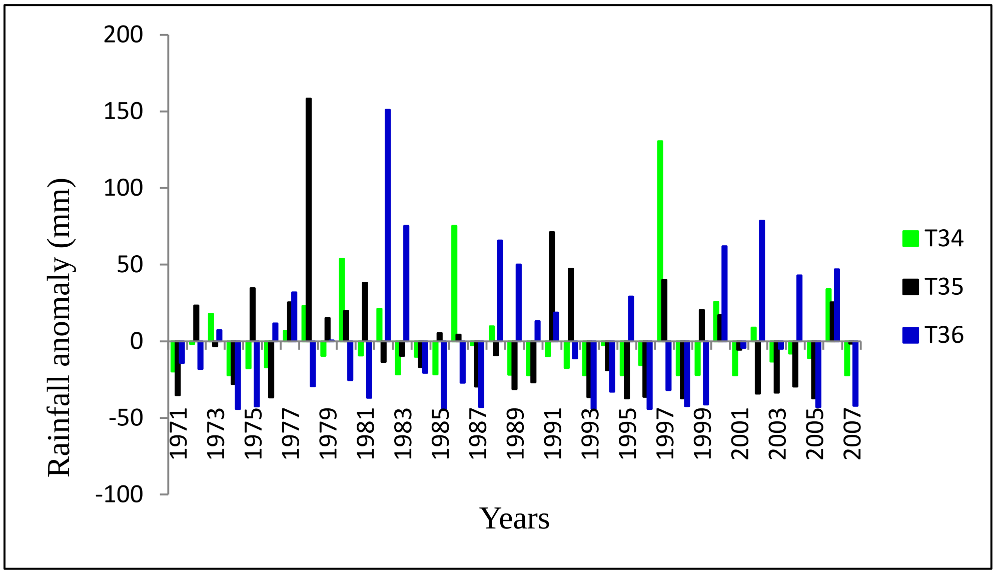
(a) UNFR October Precipitation anomalies (1971-2007). The letter T in the legend indicates one dekad, for example, T28 means the 28th dekad in a year.



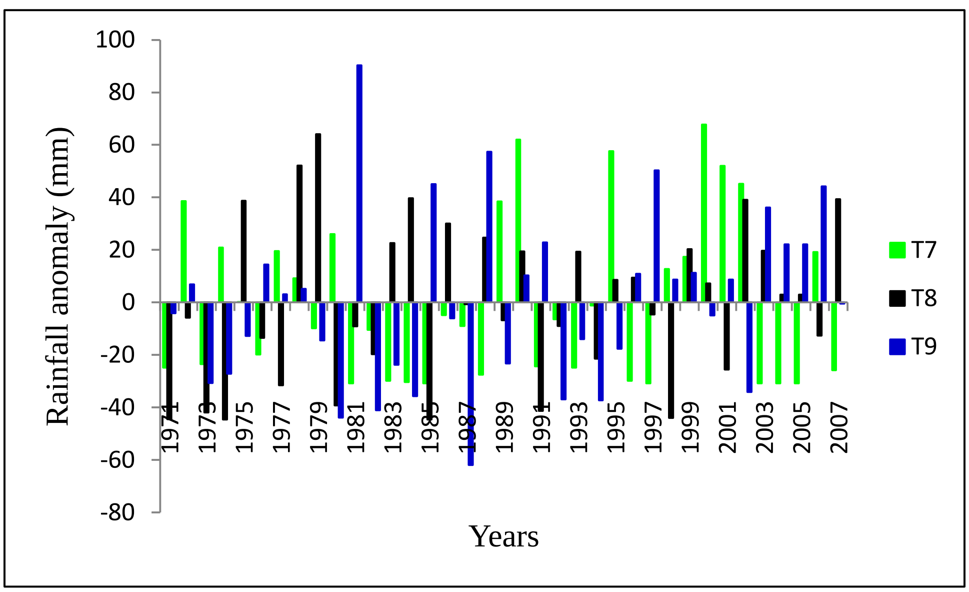
(b) UNFR November Precipitation anomalies (1971-2007)



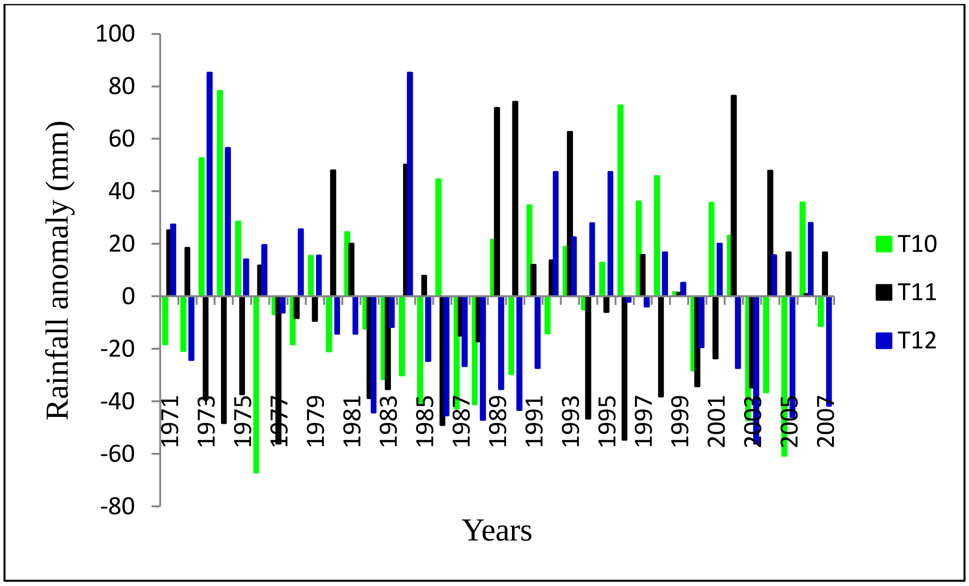
(c) UNFR station December Precipitation anomalies (1971-2007)



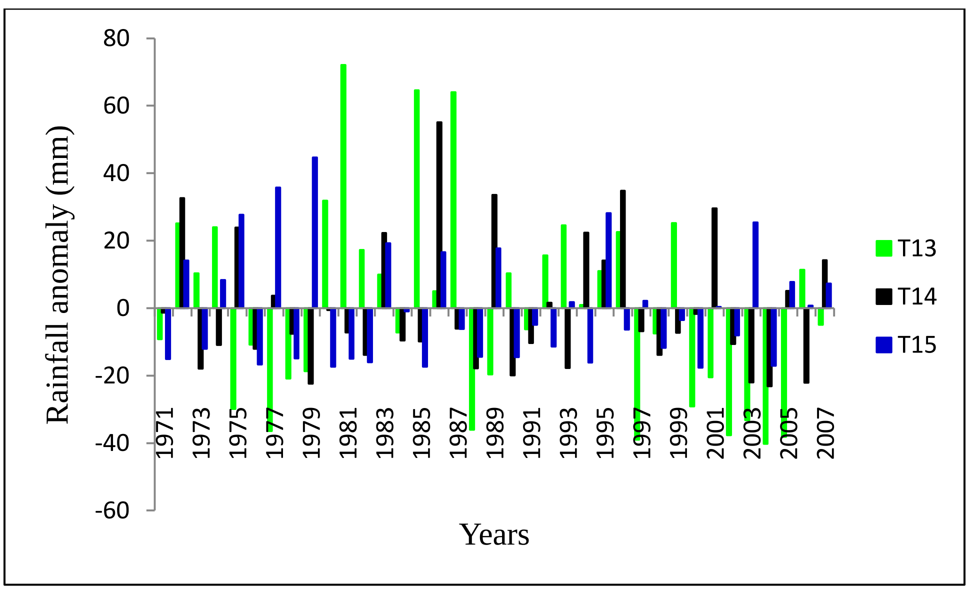
(d) UNFR March Precipitation anomalies (1971-2007)



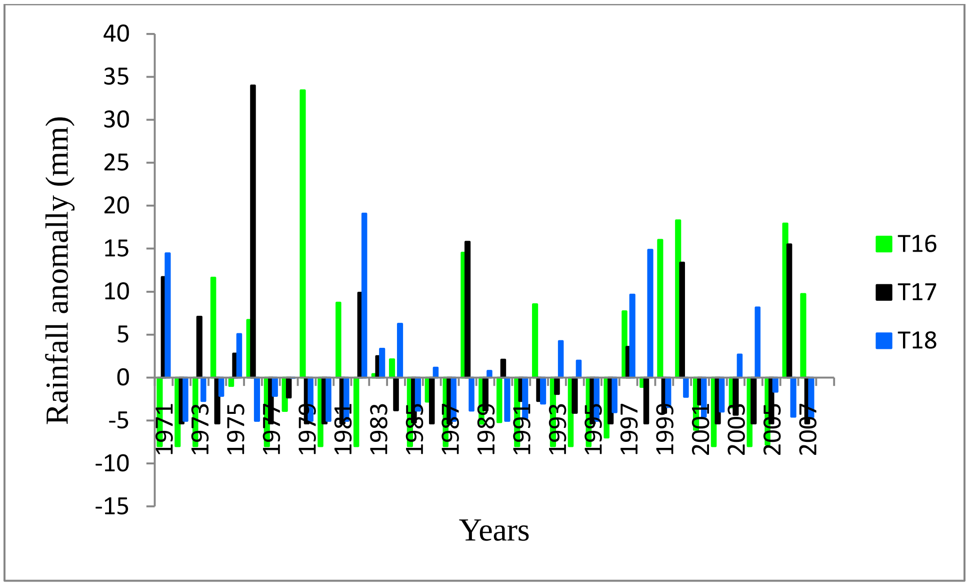
(e) UNFR April Precipitation anomalies (1971-2007)



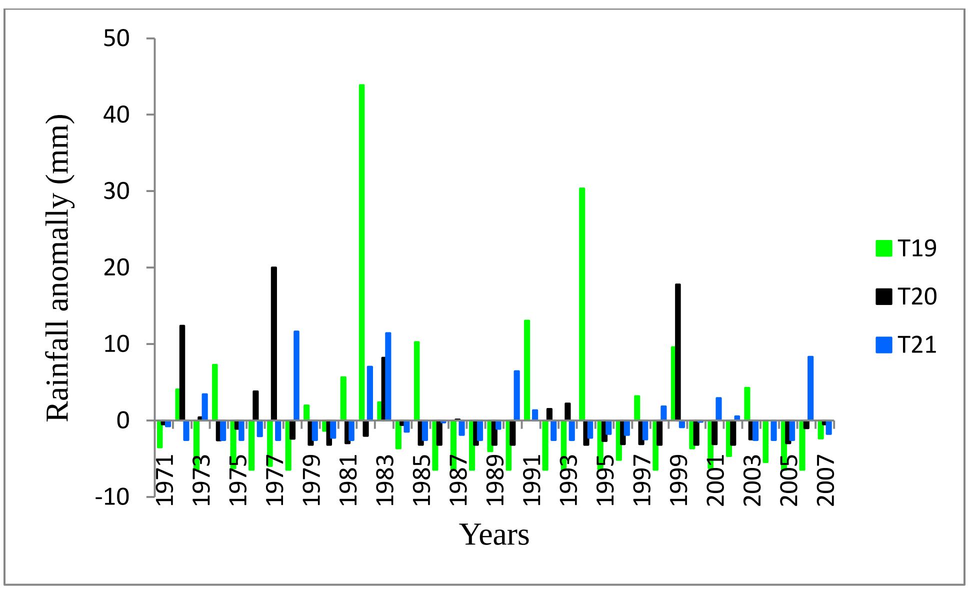
(f) UNFR May Precipitation anomalies (1971-2007)



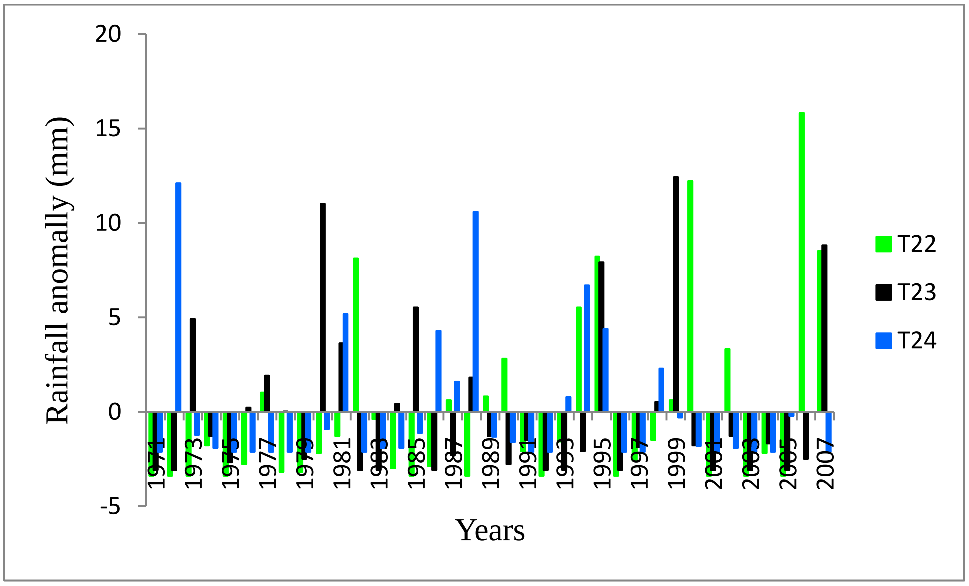
(g) UNFR June Precipitation anomalies (1971-2007)



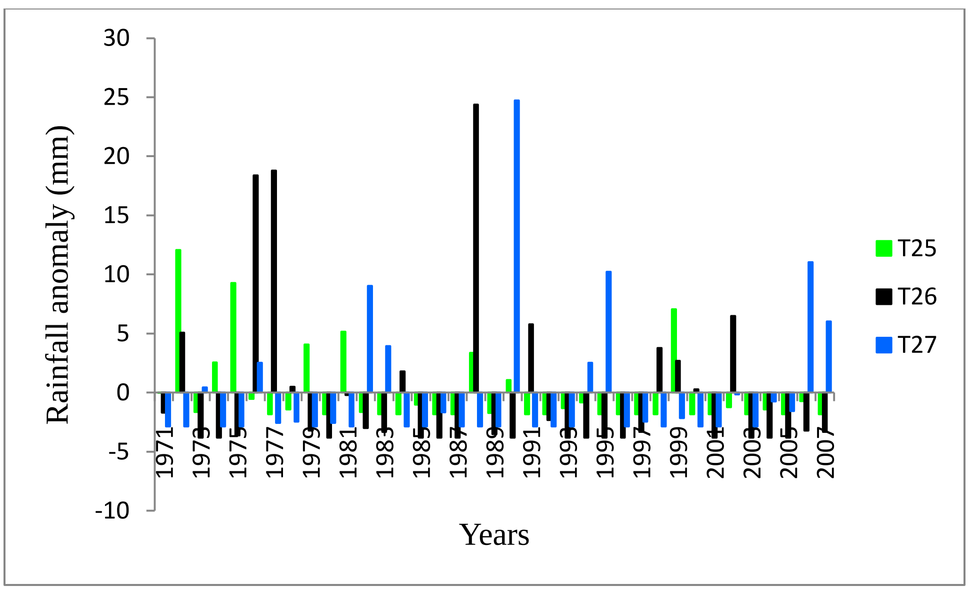
(h) UNFR July Precipitation anomalies (1971-2007)



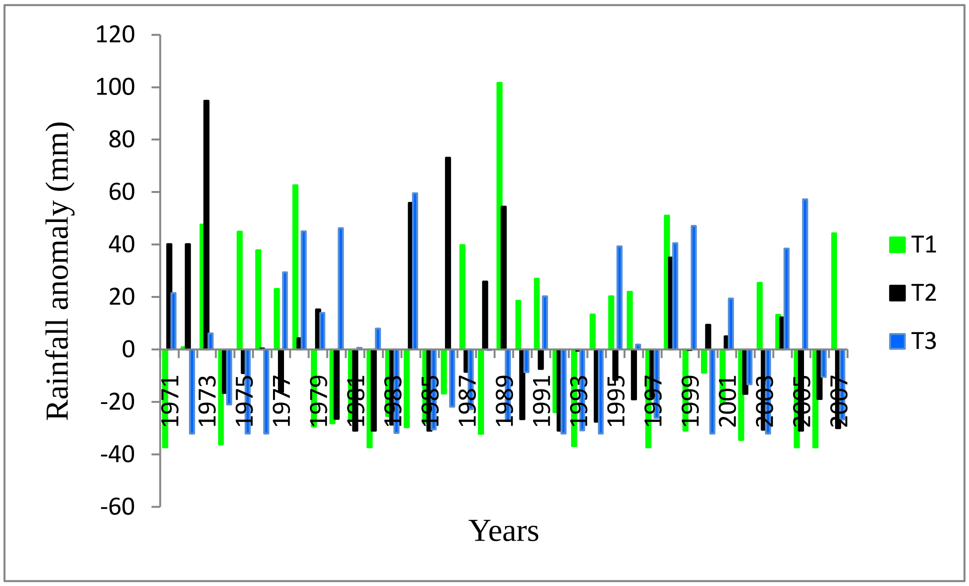
(i) UNFR August Precipitation anomalies (1971-2007)



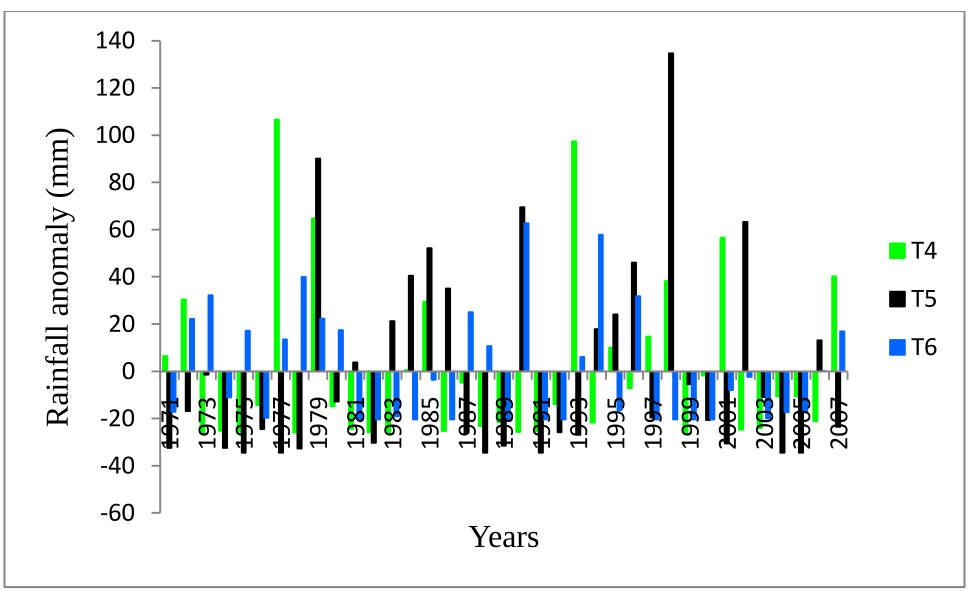
(j) UNFR September Precipitation anomalies (1971-2007)



(k) UNFR January Precipitation anomalies (1971-2007)

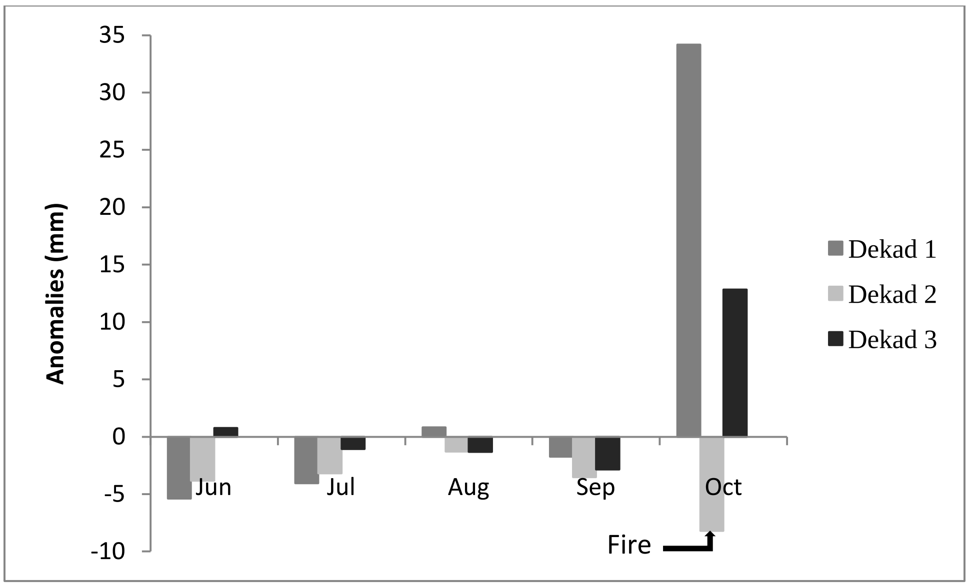


(l) UNFR February Precipitation anomalies (1971-2007)

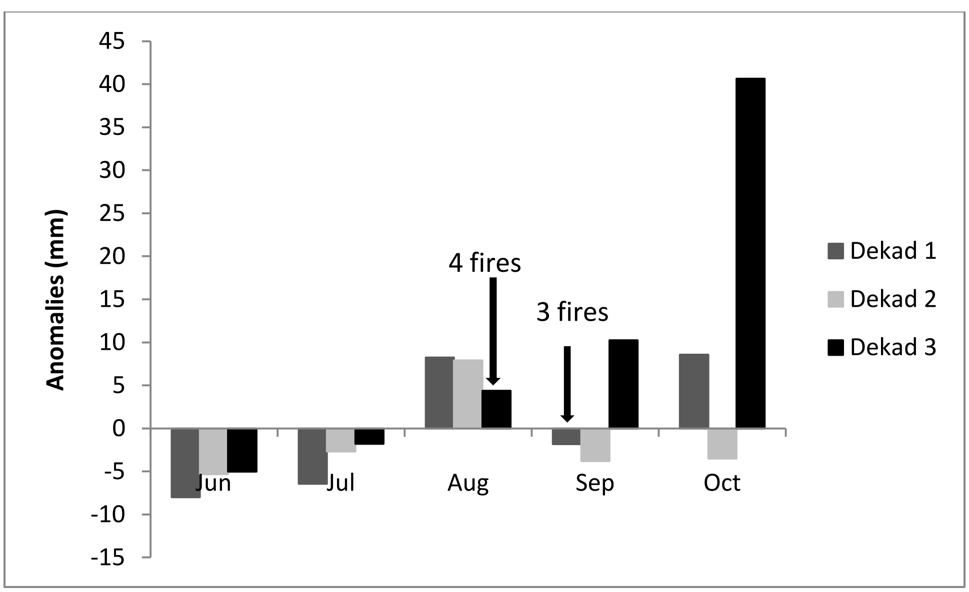


APPENDIX II: DEKADs PRECIPITATION ANOMALY GRAPHS AND FIRE INCIDENTS

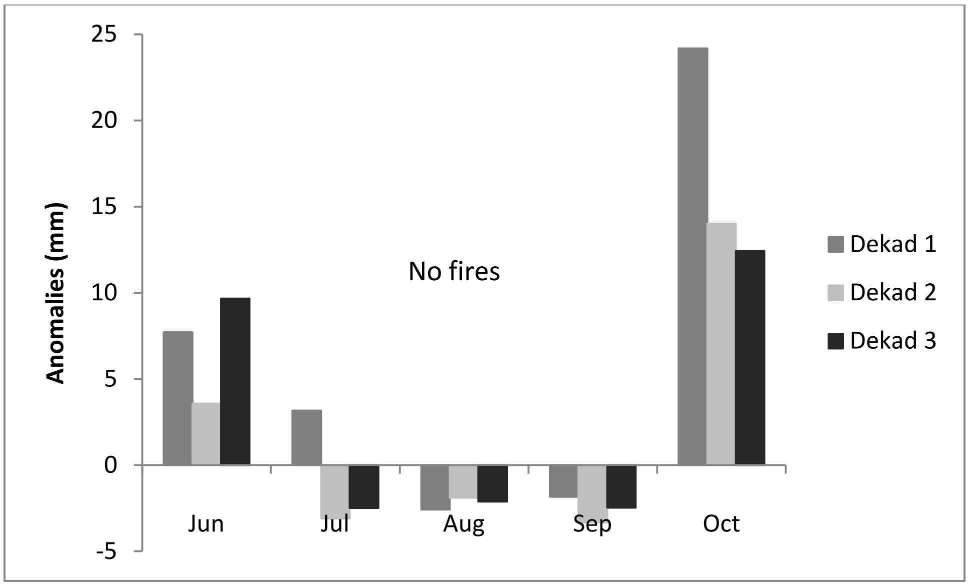
(a) Fire occurrence in an anomalous wet year (June-October 1989) due to dekadal less-than- normal-rainfall in the second dekad in October



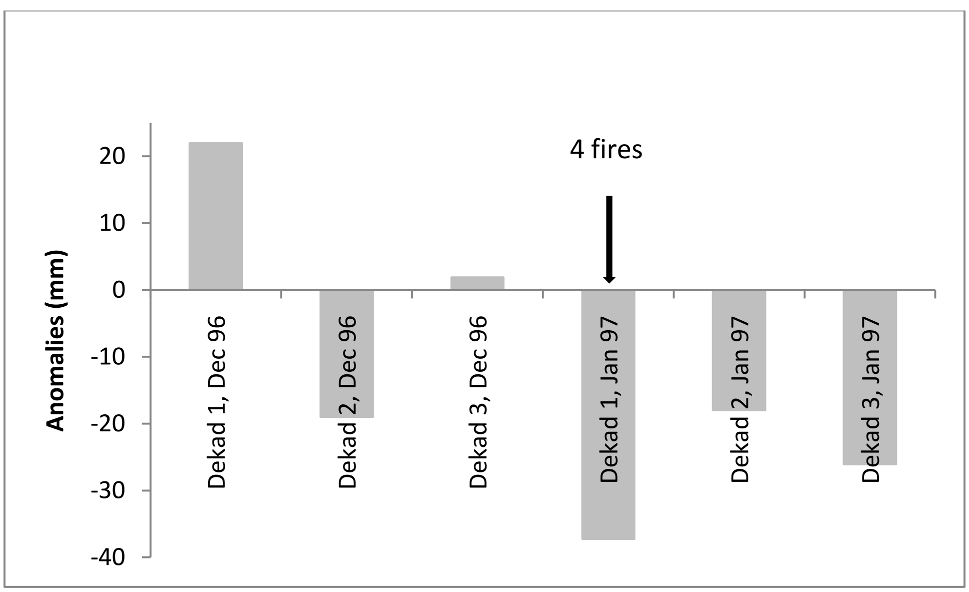
(b) Fire occurrence in an anomalous wet year (June-October 1995) due to dekadal less-than- normal-rainfall in the third and first dekads in August and September, respectively



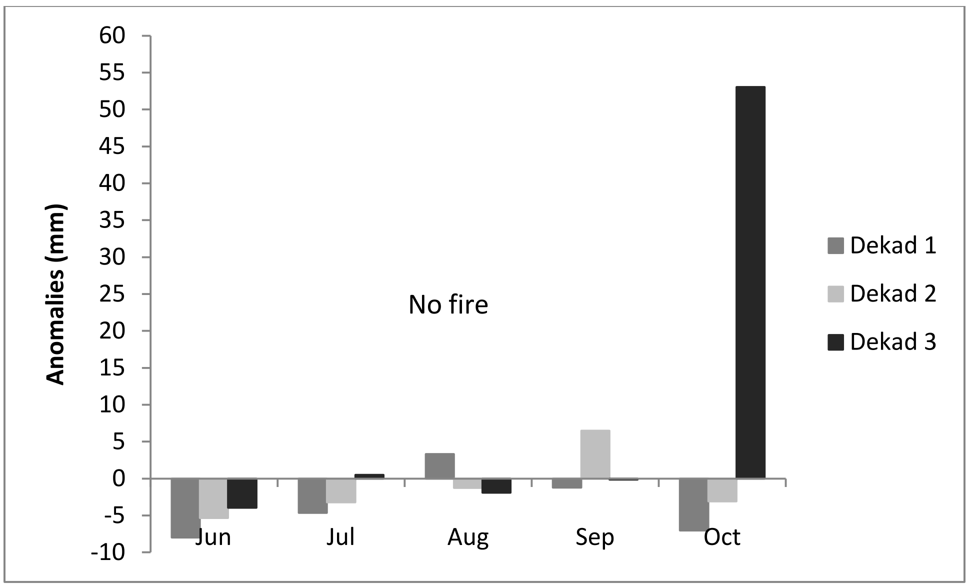
(c-i) An anomalous wet year (June-October 1997) showing no fire during the dry season



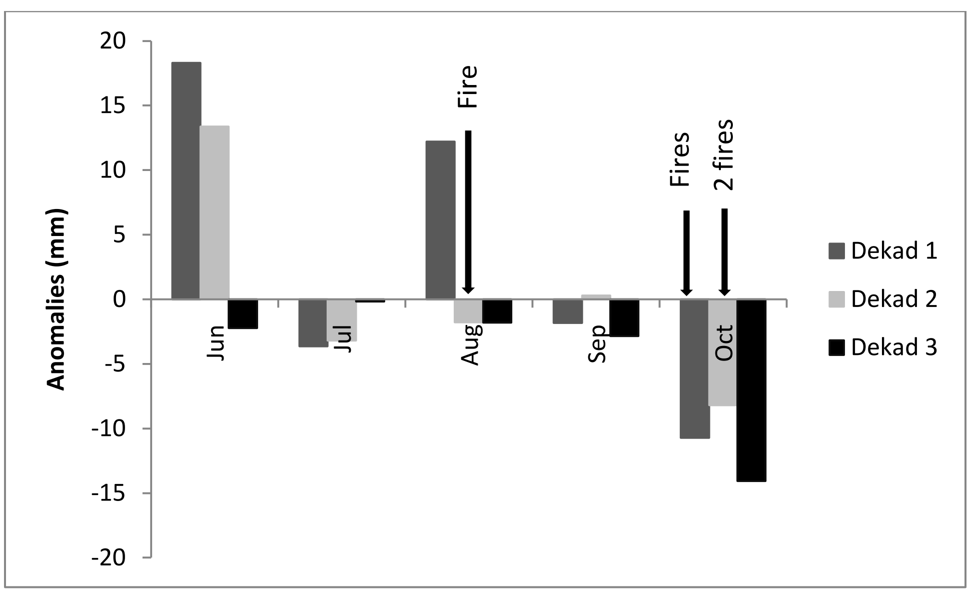
(c-ii) Fire occurrence during less-than-normal rainfall anomalies during December 1996-January 1997 period



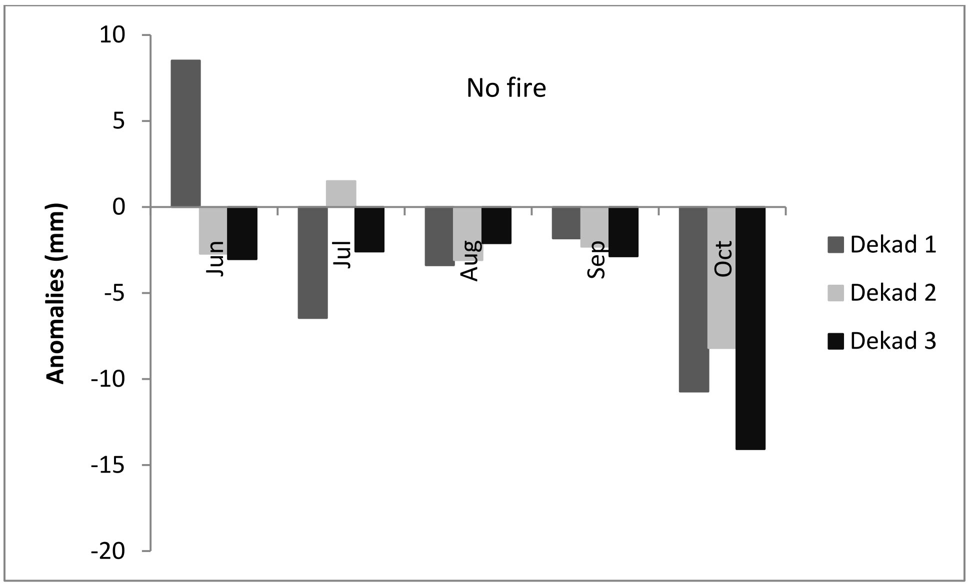
(d) An anomalous wet year (June-October 2002) showing no fire during the dry season



(e) Fire occurrence in an anomalous dry year (June-October 2000) due to dekadal less-than- normal-rainfall in the second dekad in August, and the first and second dekads in October



(f) No fire in anomalous dry year June-October (1992) suggesting the effect of forest patrol



APPENDIX III: INTERVIEW RECORDING FORM FOR VILLAGERS

I. General information

Interview number:

Date:

Start time: End time:

Sex: M F (circle one)

Age:

Education:

II. Local people's farm management

1. Do you own a farm near the Uluguru Biodiversity Hotspot?

   Yes No

2. Is there a firebreak between the Uluguru and your farm?

   Yes No

3. What types of vegetation is in your farm?

   Grasses Brush Wood and grasses Other (specify)

4. How do you clear your farm before planting?

   Use fire Use hand hoe and machete/axe Other (specify)

5. What month of the year do you clear your farm?

   5A. Give main reason why you clear you land at that time of the year.

6. Has fire ever run out of hand?

Yes No (circle)

6A. What did you do when fire escaped from your land?

Sought help from neighbors to put it out

Inform forest guards

Nothing

Other (specify)

III. Local people's knowledge of fire behavior

7. What is the right condition for burning your farm?

7A. What is the main reason for your answer in question 5?

8. What is the main thing you need to observe when setting fire to clear you farm?

8A. What is the main reason for your answer in question 7?

9. What determines the spread of fire when you burn your farm?

Slope of land vegetation cover wind other (specify)

10. Is there education provided to the local people for fire management in your farms?

Yes No

10A. If your answer is Yes to question 9 who provides that education?

11. Do you need to be educated on fire behavior?

Yes No

11A. If your answer is Yes or No what is the main reason for your answer.

IV. Perception of changes in fire regime and drought

12. Has drought increased or decreased in recent years compared to 1970s? (only if respondent's age is 45+)

Increased Decreased Don't Know

13. Has fire incidences increased or decreased in recent years compared to 1970s? (only if respondent's age is 45+)

Increased Decreased Don't Know

14. Do you remember any fire incidence that burned Uluguru Mountain?

Yes No Don't know

14A. What was the flame length of the fire you saw?

15. What is the name of the area you saw fire burning?

V. Interactions between forest guards/forest managers with local people

16. Do you interact well with forest guards/forest managers of the Uluguru?

Yes No Not sure

16A. If Yes or No in qtn 9, what is a main reason for your answer?

17. What do forest guards do when there is fire that started in this village?

18. What do you do when there is fire that started in this village?

19. Have you ever seen any arrest of people who are accused of starting fire that burned the Uluguru?

20. What do they do to the arrested person?

21. Are forest guards from this village of not?

Yes No Don't know

APPENDIX IV: SPECIES LIST OF NORTHWEST UNFR

UNFR species list; the table includes species abbreviations (Species code) and functional group (FG) in all 18 plots in the Northwestern UNFR

Local Name	Taxon	Code	FG
Chuwasesi		Chuw	Tree
Fern	*Pteridium equilinum*	Pteri	Fern
Fimbo ya mlungu	*Adiantum poiretii*	Adia	herb
Kihange/mhange	*Dodonea viscosa*	Dodo	Tree
Kikulagembe/Mkulagembe	*Dichrostachys cinerea*	Dichr	Tree
Kingwasu		Kingw	
Kinzekonzeko/Mnzekonzeko	*Premna senensis*	Premn	Shrub
Lukoko		Luko	
Lusigi		Lusi	
Luziwana (climbers)	*Landolphia buchananii*	Lando	Climber
Mbungo	*Saba comorensis*	Saba	Climber
Mbabala		Mbab	
Mbefu	*Trema orientalis*	Trem	Tree
Mbwetombweto	Alsodeiopsis schumanii	Also	Tree
Mdaha/Mdaa/Ludaha	*Euclea divinorum*	Eucl	Tree
Mdimupori	*Memecylon semseii*	Meme	Tree
Mdimu mwitu/mdimudimu (pori?)	*Suregada zanzibariensis*	Sureg	Tree
Mdosa	*Greenwayodendron suaveolens*	Green	Tree
Mdugutu mwitu	*Vernonia iodocalyx*	Verno	Tree
Menenambewa	*Harrisonia abyssinica*	Harrisab	Tree
Mfuleta/Mfulwe?	*Acalypa fruticosa*	Acalyp	Small Tree
Mgida	*Macaranga capensis*	Macar	Tree
Mgobedi	*Costus sarmentosus*	Costu	Tree
Mhalasindi		Mhala	Tree
Mhamvi	*Albizia petersiana*	Albizp	Tree
Mhanyi		Mhan	Tree
Muhulo	*Sericanthi odoratissima*	Muh	Tree
Mkalangananga		Mkala	Tree
Mkangazi	*Khaya anthotheca*	Mkang	Tree
Mkani	*Allanblacia ulugurensis*	Allanb	Tree
Mkenge	*Albizia gummifera*	Albizgu	Tree
Mkenge malala/Pori?	*Albizia glaberrima*	Albizgl	Tree
Mkindu (Raffia?)	*Phoenix reclinata*	Phoen	Tree
Mkole/mkole mwitu	*Grewia similis*	Grewis	Small Tree
Mkolebwambwa	*Grewia goetzeana*	Grewig	Tree

Species list continued

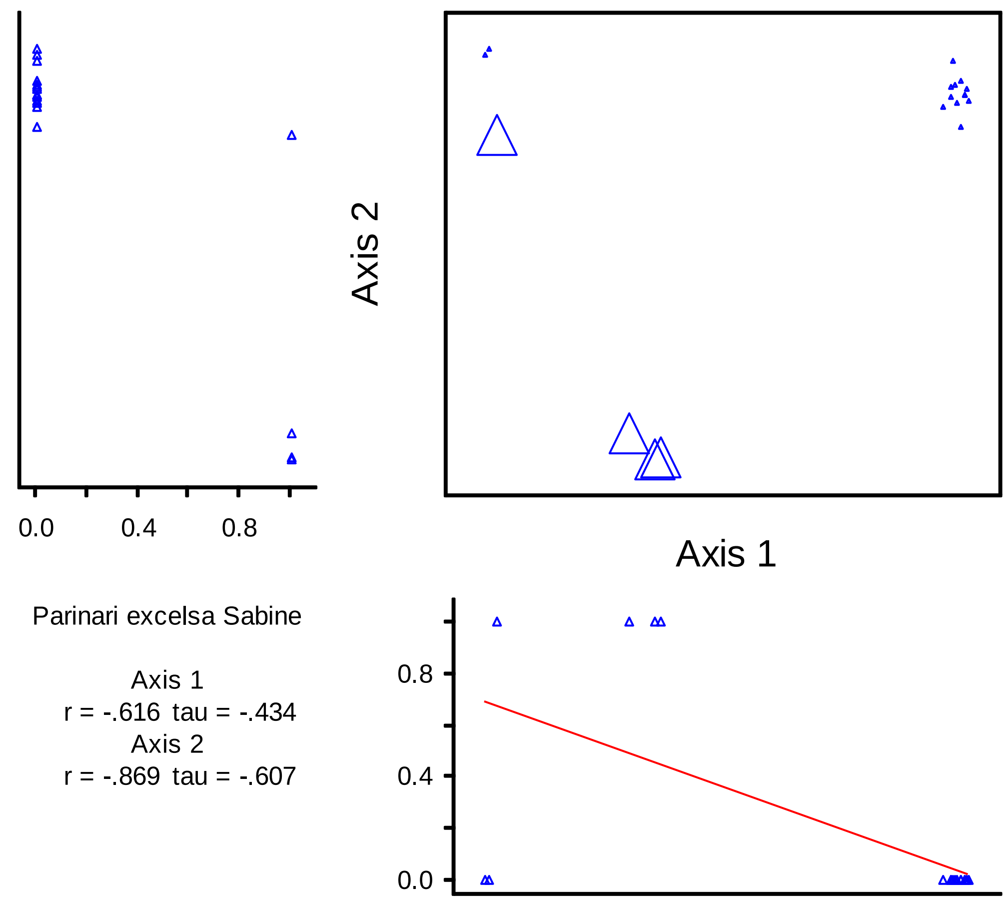
Mkololo	*Acacia albida (Faidherbia albida)*	Acacalb	Tree
Mkongowe	*Acacia robusta*	Acacaro	Tree
Mkula na chilo	*Rus vulgaris L.*	Rusvu	Tree
Mkundekunde	Cassia abbreviata	Cassab	Tree
Mkundi	*Parkia filcoidea*	Parkia	Tree
Mkunguga/Mkungunoro?	*Cussonia zimmermannii*	Cusson	Tree
Mkunguma (kipare)	Erythrina abyssinica	Erythr	Tree
Mkunungu/Msele	*Delonix elata*	Delonel	Tree
Mkunzu	*Harrisonia abyssinica*	Harrisab	Small Tree
Mkuvi	*Newtonia buchanani*	Newbuch	Tree
Mkuyu	*Ficus sycomorus*	Ficusyc	Tree
Mkwagaya	*Myrianthus arboreus*	Myriarb	Tree
Mkwambekwambe	*Flueggea virosa*	Fluevir	Shrub
Mkwangwa sale	*Smilax anceps*	Smilax	Climber
Mlalanzi/Ng'alala?	*Albizia Petersiana*	Albizpet	Tree
Mlama	*Combretum adenogonium*	Combrade	Tree
Mlama mweupe	*Combretum collinum*	Combreco	Tree
Mlama mweusi	*Combretum molle*	Combremo	Tree
Mlengela/mlengolengo?	*Tabernaemontana pachysiphon*	Tabpachy	Tree
Mmanga	*Brachysteria bussei*	Brachbus	Tree
Mmangemange	*Lygodium articulatum*	Lygoart	Climber
Mmula	*Maesopsis eminii*	Maesoemin	Tree
Mnembenembe	*Mimulopsis kilimandscharica*	Mimukili	Tree
Mngama	*Parinari excelsa Sabine*	PariexS	Tree
Mng'eng'ena	*Bobgunnia madagascariensis*	Bobmada	Tree
Mng'ongo (pori)	*Sclerocarya birrea*	Sclerbir	Tree
Mninga	*Pterocarpus angolensis*	Pteroang	Tree
Mnzekonzeko	*Premna senensis*	Premsen	Shrub
Mpera pori	*Combretum schumannii*	Combresch	Tree
Mpilipili	*Erythrophleum suaveolens*	Erythsuav	Tree
Mpingo	*Dalbergia melanoxylon*	Dalbmela	Tree
Mrangadu/Mlumangadu	*Schefflera lukwangulensis*	Scheffluk	Tree
Msada	*Vangueria infausta*	Vanginfa	Tree
Msada muhulo	*Syzygium cordatum*	Syzycor	Tree
Msambwa	*Deinbolia borbonica*	Deinbor	Tree
Msangana	*Strombosia scheffleri*	Stromsche	Tree
Msani	*Brachystegia microphylla*	Brachmicr	Tree
Msasa	*Ficus exasperata*	Ficexa	Tree
Mseli	*Ocotea usambarensis*	Ocotus	Tree
Msembe (tree fern)	*Cyathea dregei*	Cyadre	Tree
Msenze	*Celtis gomphophylla*	Celtgom	Tree
Msese/Msasa	*Ficus exasperata*	Ficexas	Tree
Msigisi/Msegese	*Piliostigma thorningii*	Pilioth	Tree
Msoto	*Bothriocline tomentosa*	Bothtom	Tree
Msumba/Mwiza	*Bridelia micrantha*	Bridmic	Tree

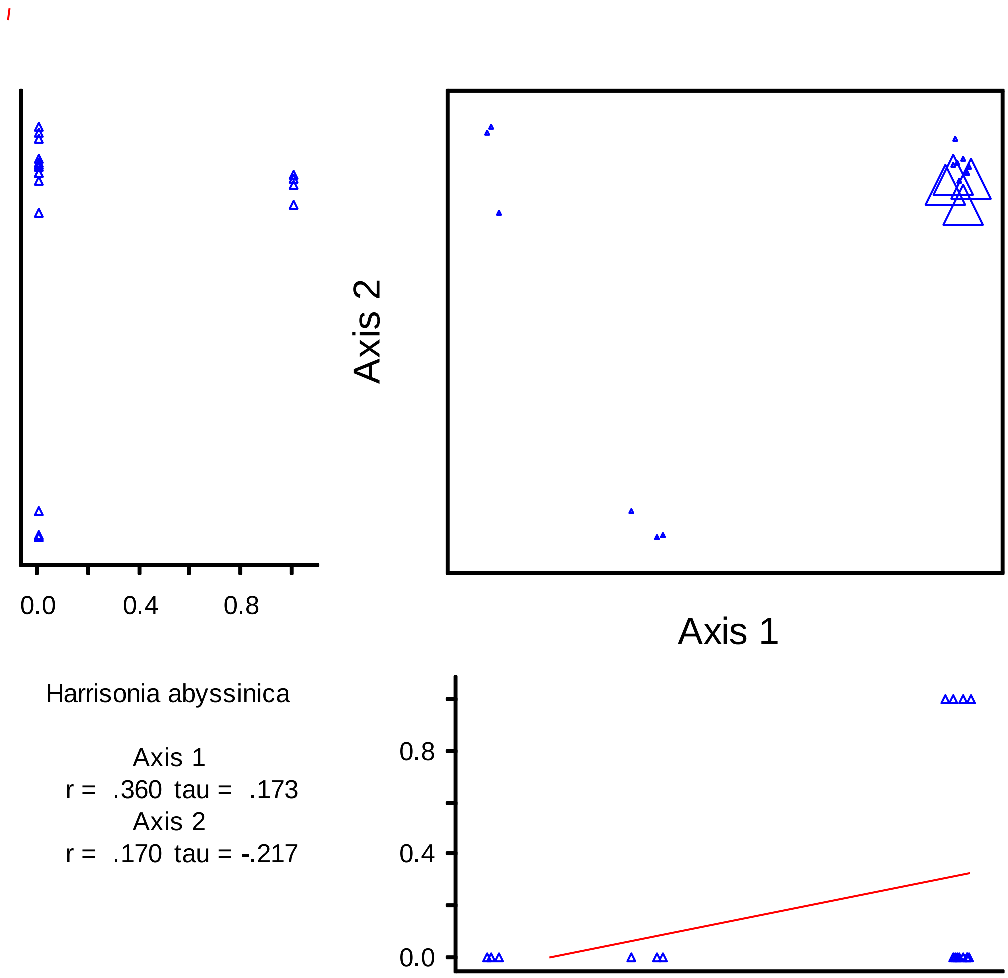
Species list continued

Mswayu	*Dombeya rotundifolia*	Dombrot	Tree
Mtelewanda	*Markhamia zanzibarica*	Markznz	Tree
Mtobola		Mtob	Shrub
Mtogo	*Diplorhynchus condylocarpon*	Diplcond	Tree
Mtomokwe	*Annona senegalensis*	Annsen	Tree
Mtopetope	*Annona senegalensis pers.*	Annsenpr	Tree
Mvule	*Milicia excelsa*	Miliexc	Tree
Mvule maji/Msungu	*Burttdavya nyasica*	Burttnya	Tree
Muwindi	*Acacia polyacantha*	Acacpoly	Tree
Mkongowe	*Acacia radiana Savi*	AcacradS	Tree
Mwegea	*Kigelia africana*	Kigafric	Tree
Mmwana	*Ophrypetalum odoratum*	Ophrodo	Small Tree
Mzinda muulo	*Blighia unijugata*	Blighunij	Tree
Mzinda nguruwe	*Maytenus undata*	Mayteun	Tree
Mzona	*Scolopia zeyheri*	Scolzey	Tree
Ndago grass	*Cyperus ajax*	Cypajx	Grass
Upupu (Buffalo beans)	*Mucuna gigantea*	Mucgig	Climber
Velvet bean	*Mucuna pruriens*	Mucprur	Climber

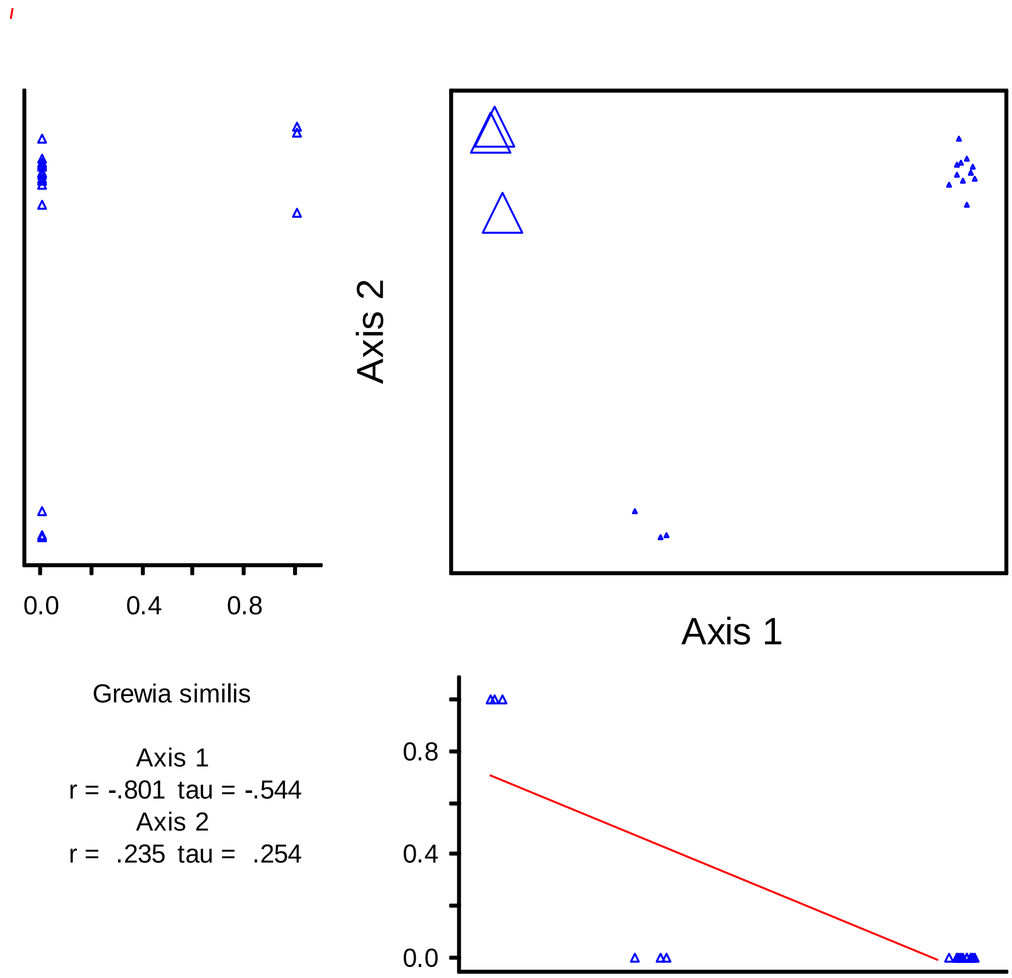
APPENDIX V: NMS ORDINATION RESULTS

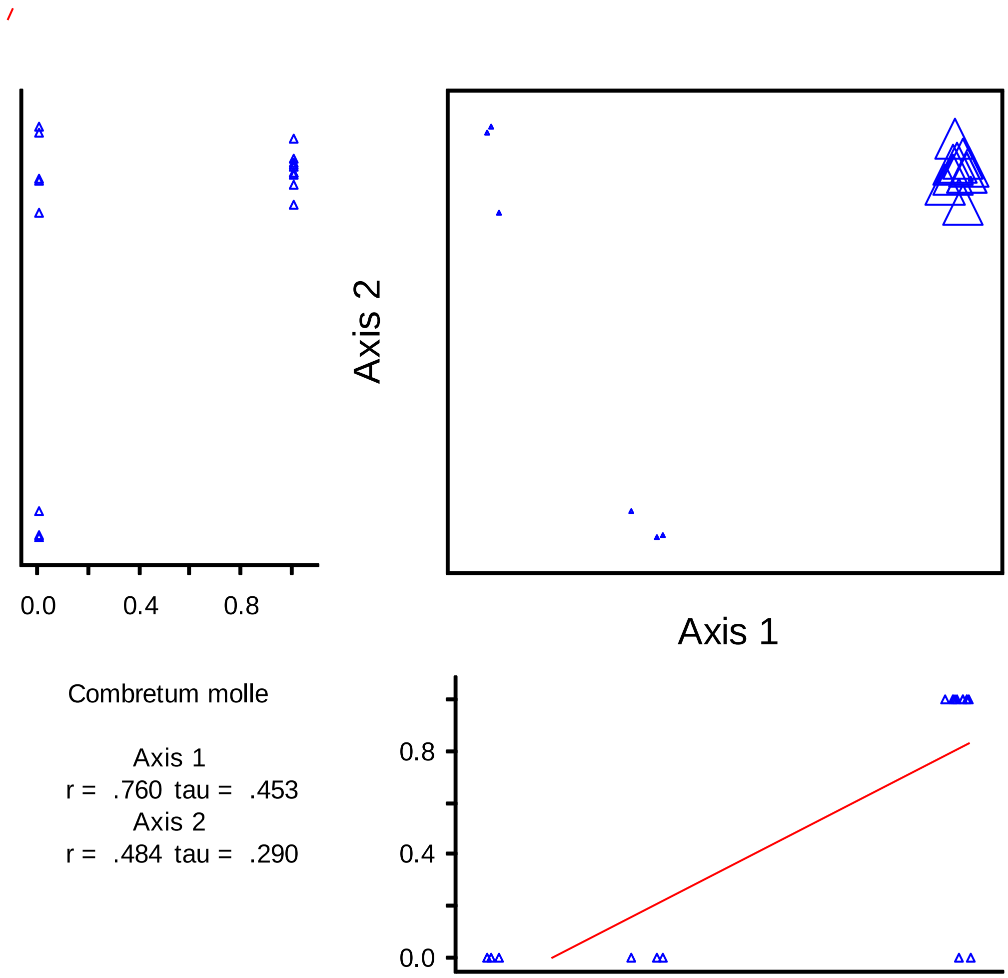
Scatterplots of abundance of species in relation to two ordination axes. Each point in the graphs represents a stand. The size of the symbol is proportional to species abundance, the larger the size of the symbol the higher the abundance of a species in that stand. In each graph upper right is a 2-D ordination of species composition. Lower right is scatterplot of abundance of a species against a score on Axis 1. Upper left is a scatterplot of abundance of a species against Axis 2. The list of species below include tree species that dominated either in unburned area or burned area. Kendall's tau measures correlation strength between the variable and the axes.

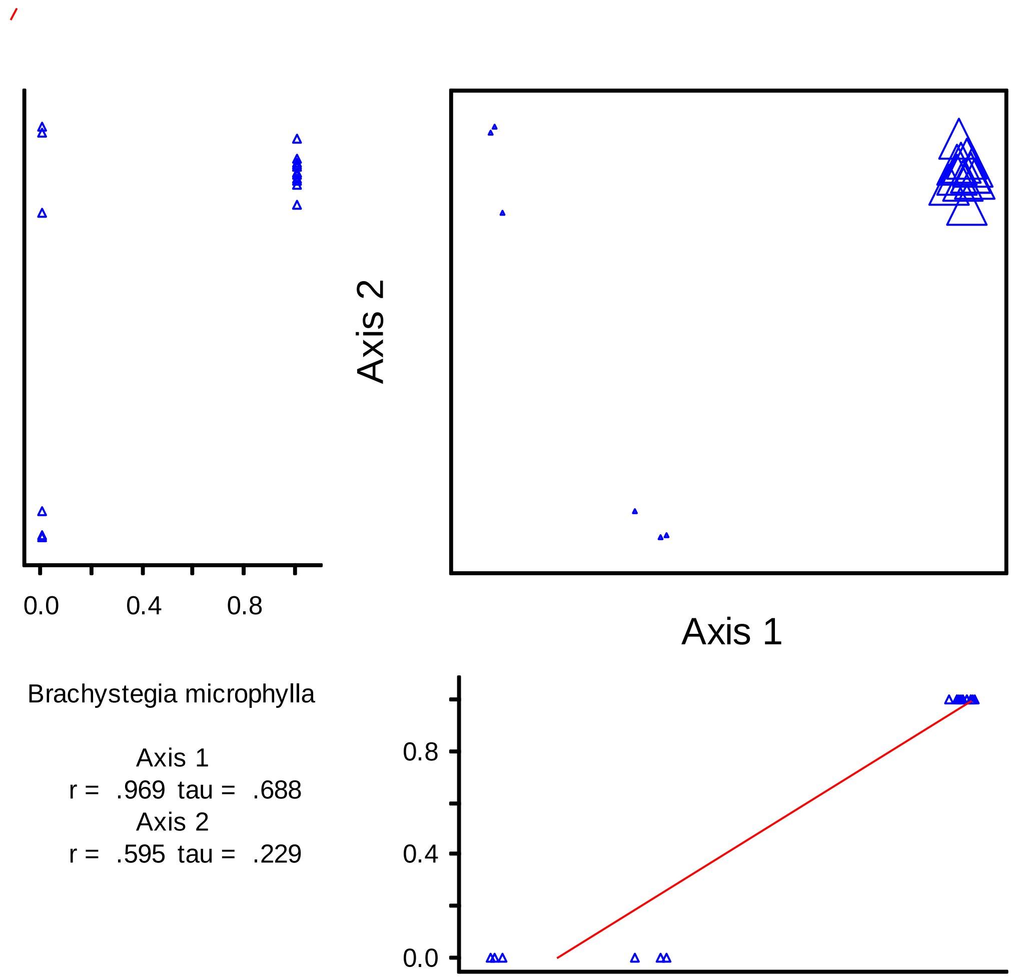




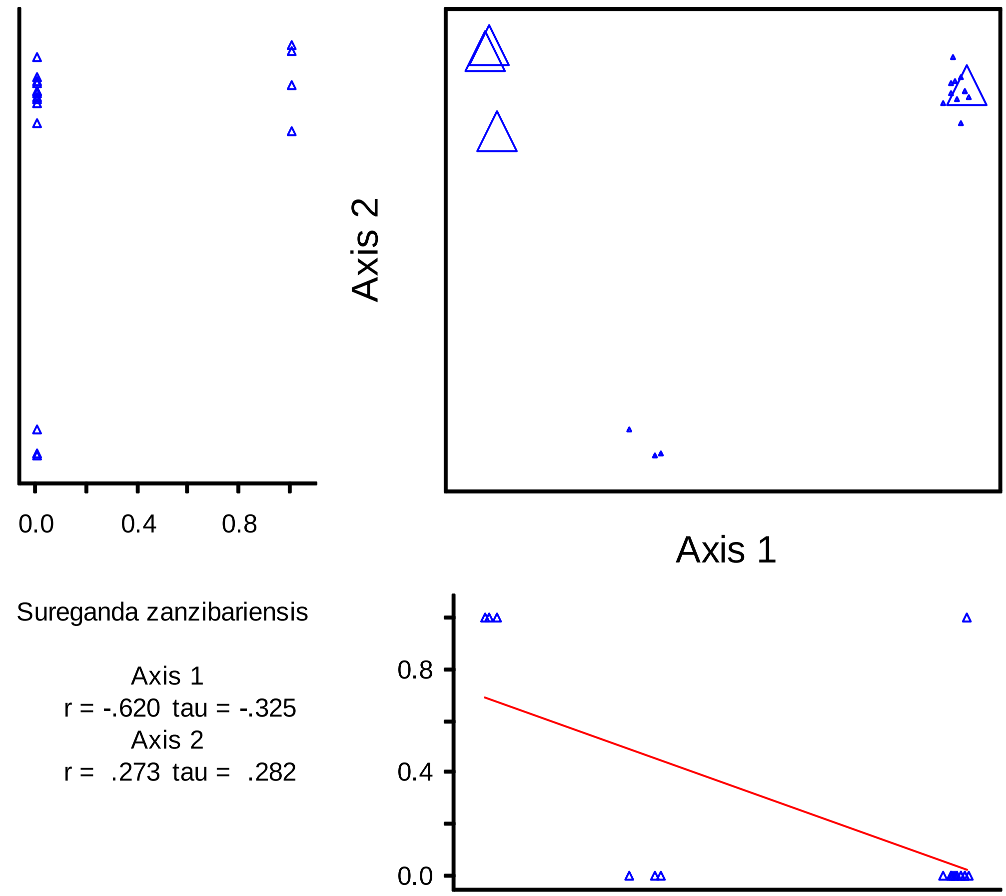
0.0
0.4
0.8
Axis 2
Axis 1
Harrisonia abyssinica
Axis 1
r = .360 tau = .173
Axis 2
r = .170 tau = -.217
0.8
0.4
0.0

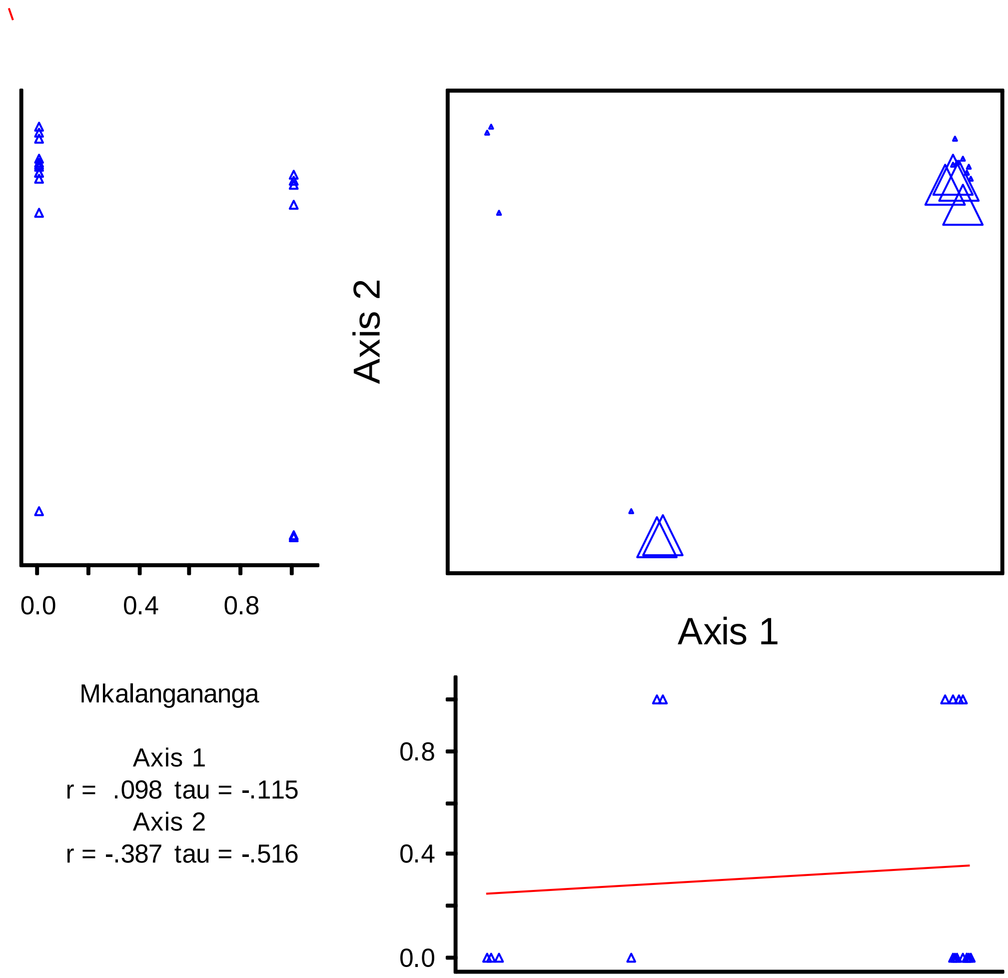

Axis 2
Axis 1
0.0
0.4
0.8
Grewia similis
Axis 1
r = -.801 tau = -.544
Axis 2
r = .235 tau = .254
0.8
0.4
0.0

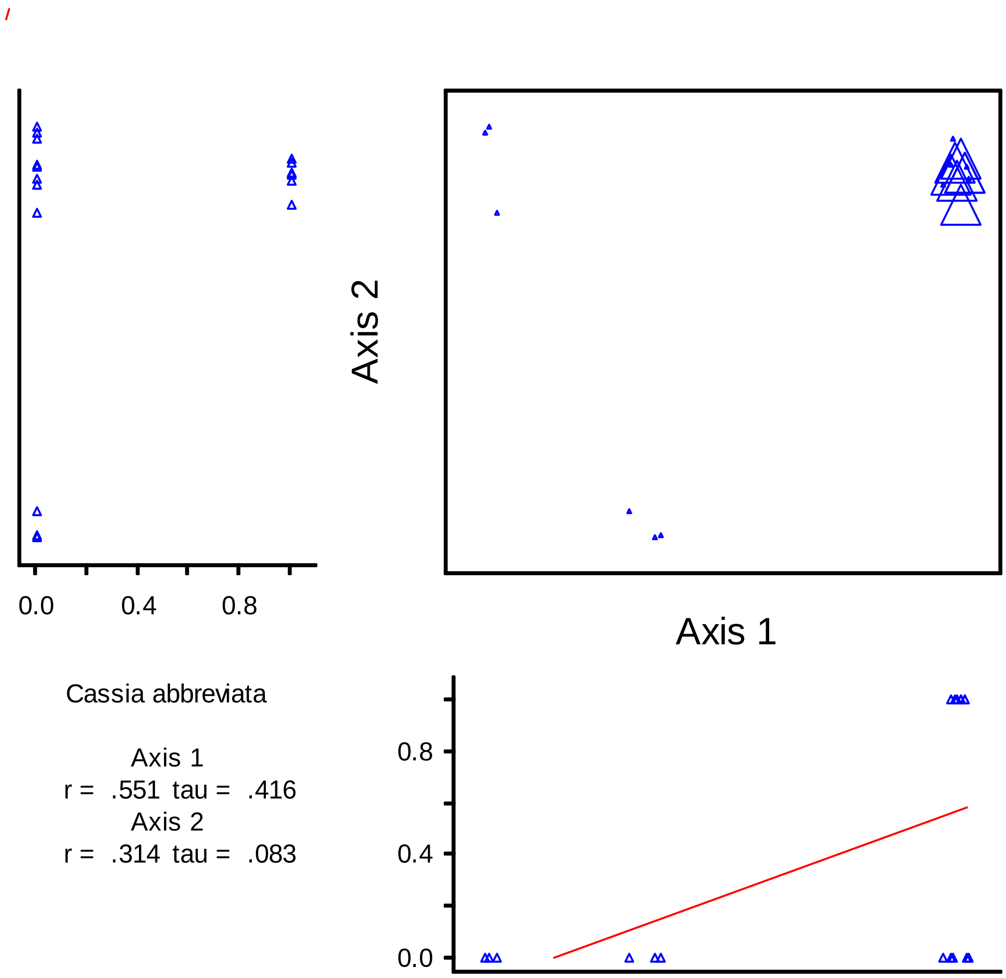

Axis 2
Axis 1
0.0
0.4
0.8
Combretum molle
Axis 1
r = .760 tau = .453
Axis 2
r = .484 tau = .290
0.8
0.4
0.0



0.0
0.4
0.8
Axis 2
Axis 1
Brachystegia microphylla
Axis 1
r = .969 tau = .688
Axis 2
r = .595 tau = .229
0.8
0.4
0.0

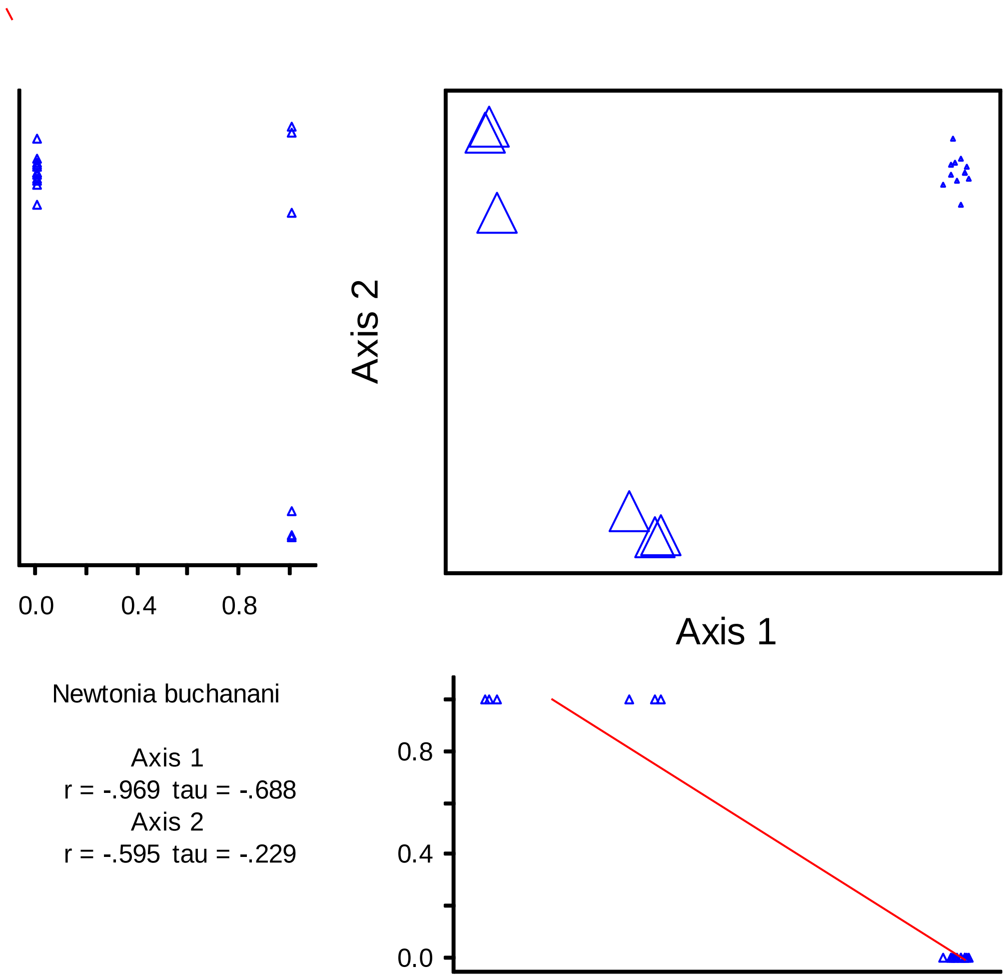

Axis 2
Axis 1
0.0
0.4
0.8
Sureganda zanzibariensis
Axis 1
r = -.620 tau = -.325
Axis 2
r = .273 tau = .282
0.8
0.4
0.0

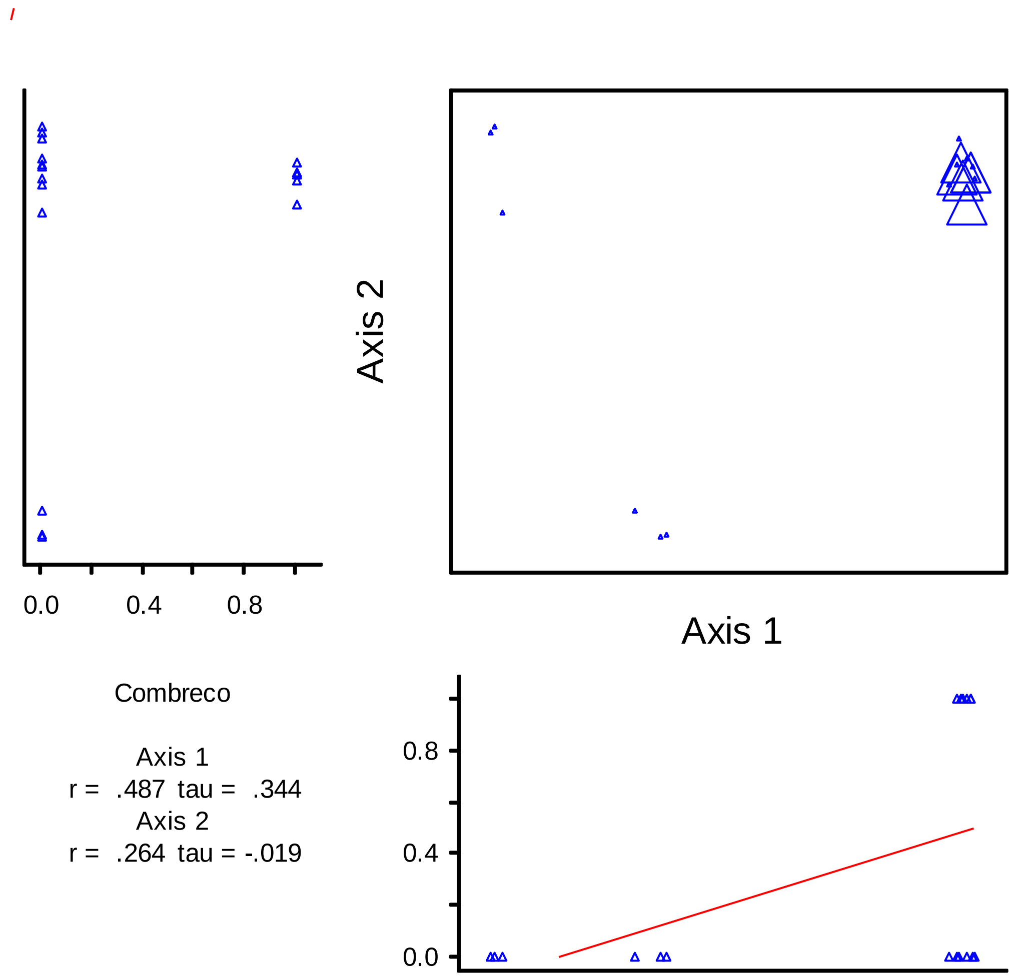

Axis 2
Axis 1
0.0
0.4
0.8
Mkalangananga
Axis 1
r = .098 tau = -.115
Axis 2
r = -.387 tau = -.516
0.8
0.4
0.0



Cassia abbreviata

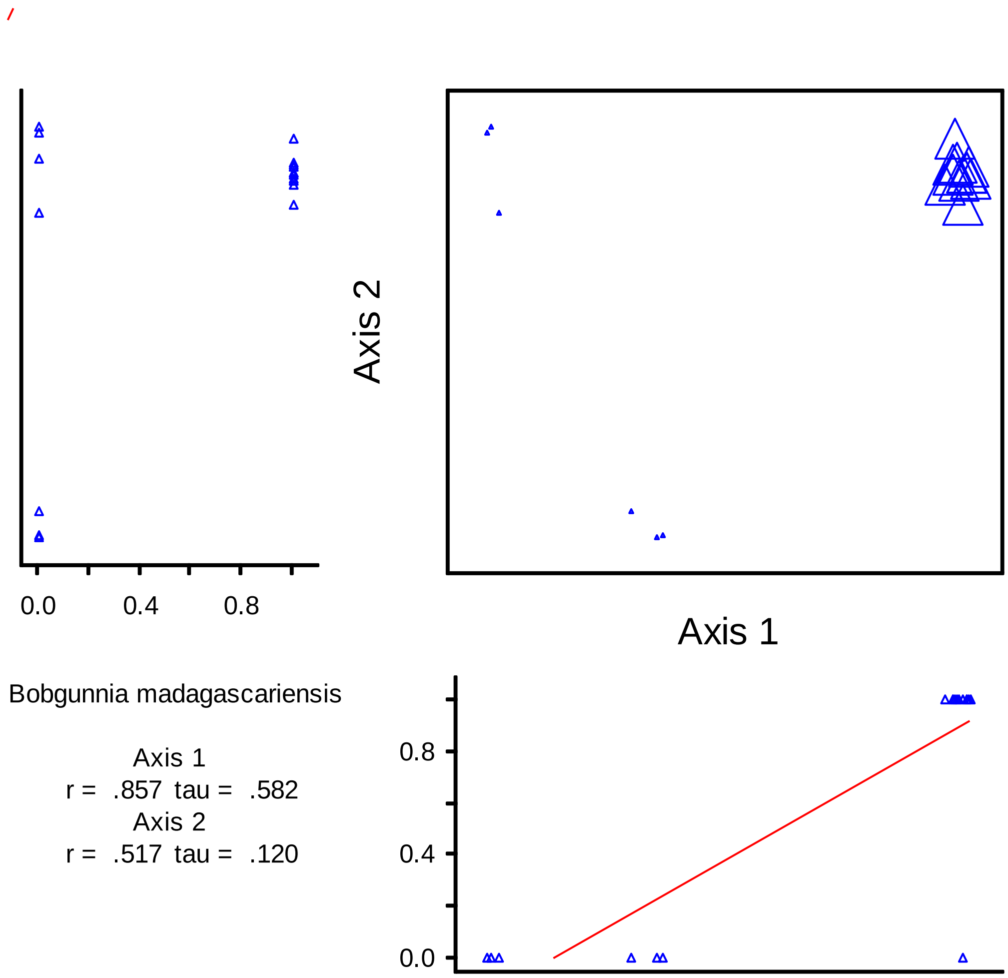
Axis 1
r = .551 tau = .416
Axis 2
r = .314 tau = .083

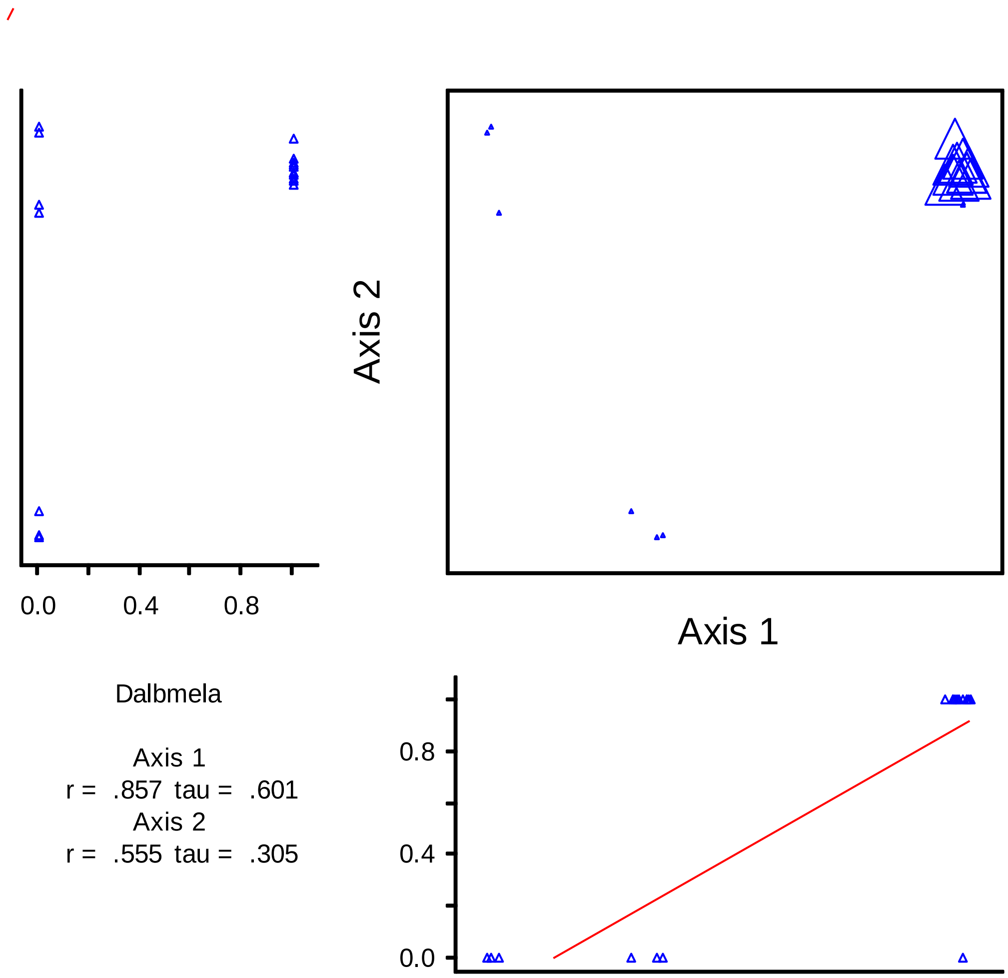

0.0
0.4
0.8
Axis 2
Axis 1
Newtonia buchanani
Axis 1
r = -.969 tau = -.688
Axis 2
r = -.595 tau = -.229
0.8
0.4
0.0

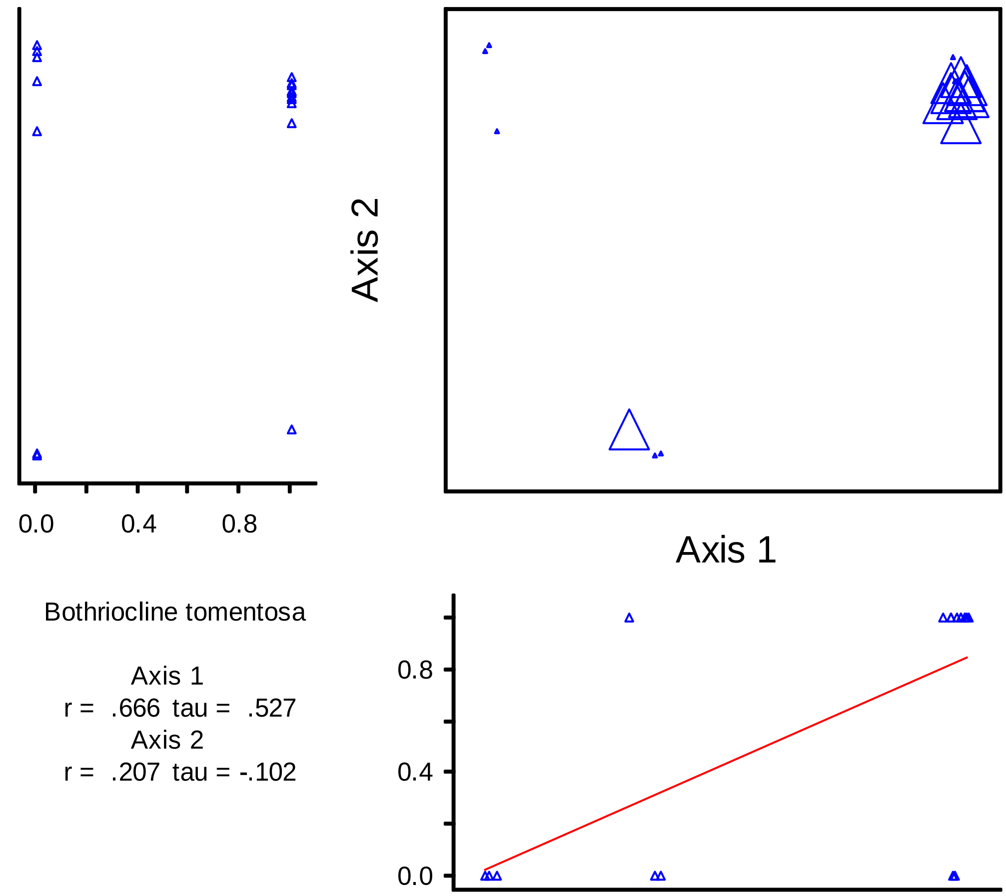


Combreco

Axis 1
r = .487 tau = .344
Axis 2
r = .264 tau = -.019

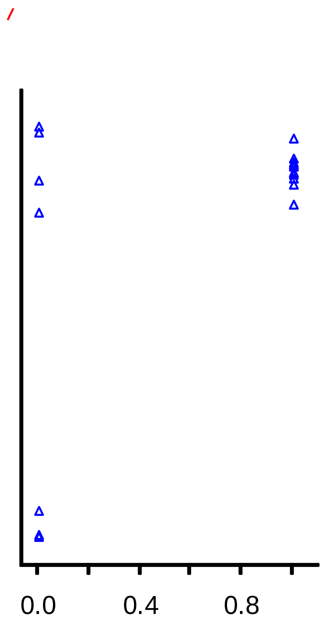

0.0
0.4
0.8
Axis 2
Axis 1
Bobgunnia madagascariensis
Axis 1
r = .857 tau = .582
Axis 2
r = .517 tau = .120
0.8
0.4
0.0

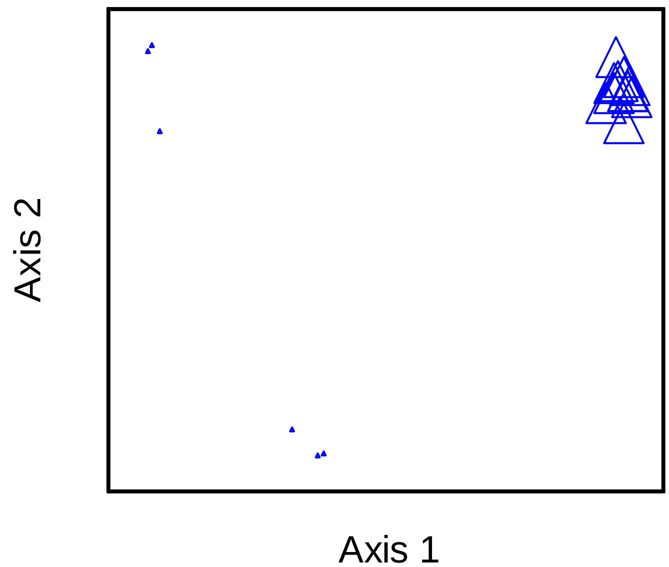

Axis 2
Axis 1
0.0
0.4
0.8
Dalbmela
Axis 1
r = .857 tau = .601
Axis 2
r = .555 tau = .305
0.8
0.4
0.0



Bothriocline tomentosa

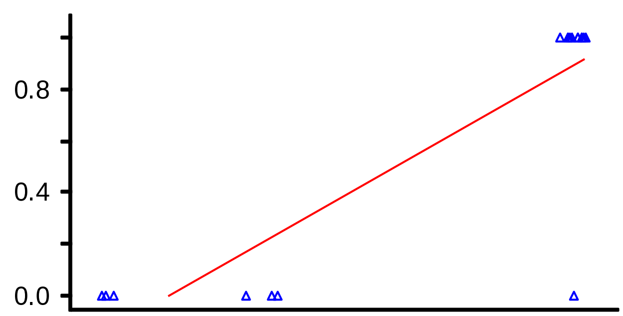
Axis 1
r = .666 tau = .527
Axis 2
r = .207 tau = -.102

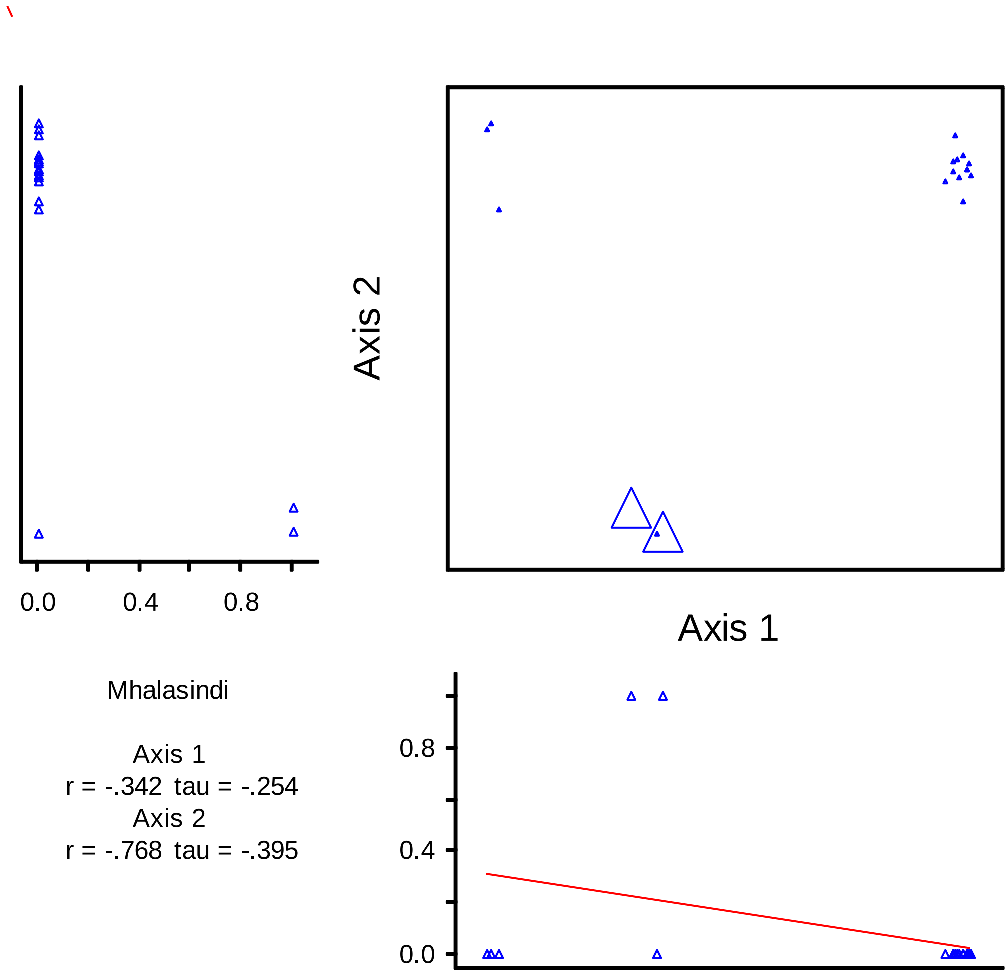


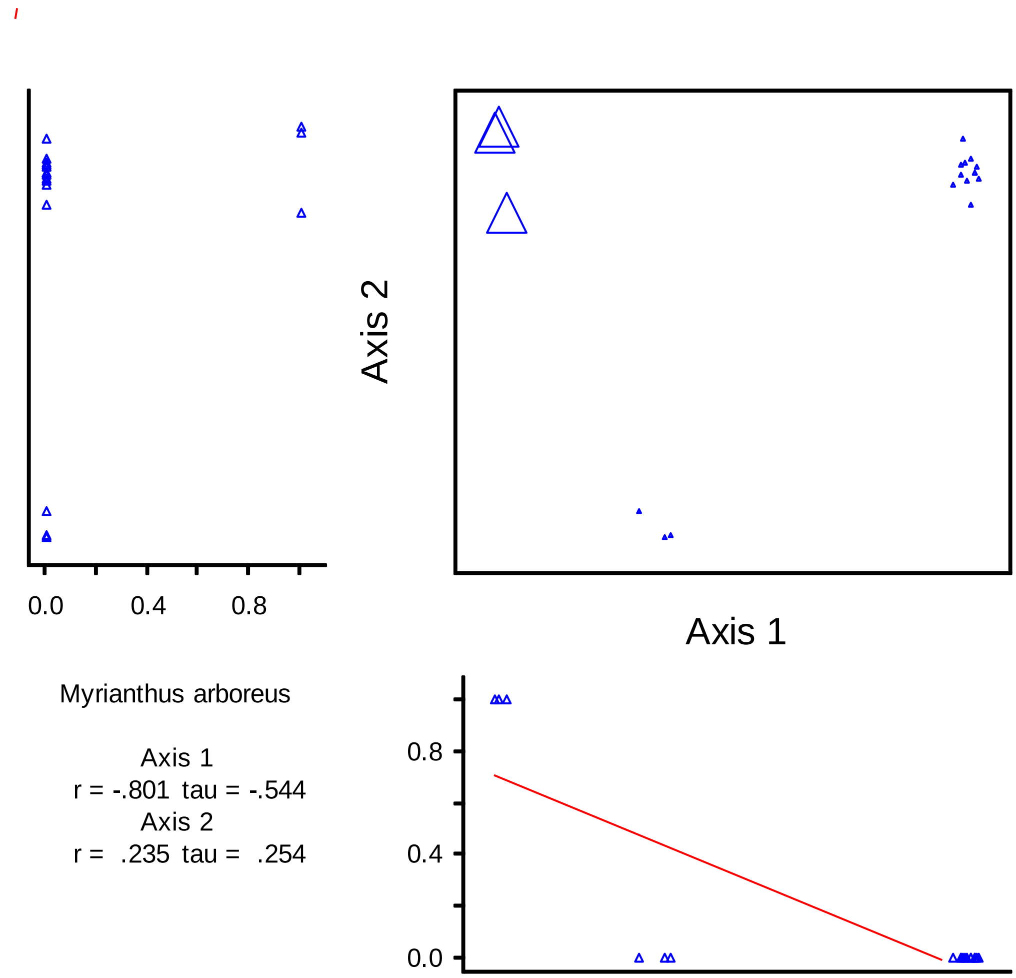


Diplorhynchus condylocarpon

Axis 1
r = .860 tau = .619
Axis 2
r = .535 tau = .268




Axis 2
Axis 1
0.0
0.4
0.8
Mhalasindi
Axis 1
r = -.342 tau = -.254
Axis 2
r = -.768 tau = -.395


Axis 2
Axis 1
0.0
0.4
0.8
Myrianthus arboreus
Axis 1
r = -.801 tau = -.544
Axis 2
r = .235 tau = .254
0.8
0.4
0.0