British Journal of Environment and Climate Change
1(4): 172-189, 2011

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Potential Impact of Climate Change on Termite Distribution in Africa

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Review Article

Received 11th July 2011
Accepted 26th August 2011
Online Ready 18th September 2011

ABSTRACT

Termites (Order: Isoptera) constitute an integral component of various ecosystems in Africa. Termites are also amongst the most difficult insects to study because of their cryptic behaviour and natural nesting habitat. There are around 2600 species of termites in 280 genera which have been described worldwide and about 39% of the total termite species are found in Africa. Termite identification is crucial to understanding termite distribution and their relationship to climate change. Some termite species are well known pests of agricultural crops, forest trees, wood products and timber-in-service causing considerable damage in Africa.
This review paper attempts to collate information on African termite distribution and climate change and highlights some knowledge gaps. Africa is the origin of the termite family of Macrotermitinae. The paper focuses more on economically important termite species in Africa. The use of traditional identification methods coupled with molecular techniques in resolving some of the challenges in termite distribution with particular reference to climate change in Africa are discussed.
There is scant information on published literature on the impact of climate change on

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termites with particular reference to termite distribution in Africa. However there is anectodal evidence to suggest that African termite species will be affected by changes in the local and global climate.

Keywords: Isoptera; termites; distribution; climate change; Africa;

1. INTRODUCTION

Termites (Isoptera) are a large and diverse group of insects consisting of over 2600 species in 280 genera worldwide. Africa is by far the richest continent in termite diversity (Eggleton, 2000). Termites are important pests of building timbers, forestry and crops in Africa. In general, damage by termites is greater during dry periods or droughts than periods of regular rainfall, in lowland rather than highland areas, and in plants under stress (Wightman, 1988, 1991). Despite their economic importance, limited published economic loss studies due to termites and related costs of protecting crops and houses/structures currently exist (Sekamatte and Okwakol, 2007). In addition, limited detailed studies have been conducted to document the pestiferous termite species in the region (Nyeko and Olubayo, 2005; Sekamatte and Okwakol, 2007). These studies are usually complicated by the large number of termite species involved, their cryptic and unpredictable foraging patterns, the interaction with plant stress and the broad range of crops damaged as well as non-crop damage (Logan et al., 1990). This information is critical in developing termite management strategies (Nyeko and Olubayo, 2005).

Global climate change is likely to affect plant and animal biodiversity on earth. In order to deal with the uncertainties associated with climate change; the Intergovernmental Panel on Climate Change (IPCC, 1992, 1995, and 1997) regularly evaluates available evidence to formulate a consensus opinion on likely outcomes. The present view is that a global mean temperature increase of approximately 2^{o}C is a realistic expectation over the next 50 years (Shackleton, 1996; Hansen, 2009). Moreover, as large-scale extinctions, and movements of species were precipitated in the past (Gates, 1993), the need to predict the biodiversity consequences of climate change is becoming increasingly important (McNeely et al., 1995). It is likely that African termite species will be affected by changes in the local and global climate.

The aim of this paper is to discuss termite distribution with reference to climate change in Africa and the limitations of traditional methods of termite identification and the potential use of new techniques such as near-infra red spectroscopy, phylogenetics, and molecular methods for termite species identification.

1.1 The Scope of Literature Review Conducted

A literature review of termite diversity, distribution and impacts in relation to climate change in Africa was conducted. Several papers on termites were found by searching the web of science databases, personal communications, and published studies across Africa. Emphasis was placed on eastern and southern Africa because this is the geographic area where the Macrotermitinae, which are the most serious pests in agriculture and forestry, reach their highest densities (Jones, 1990).

2. TERMITE DIVERSITY AND DISTRIBUTION IN AFRICA

Due to its climatic conditions, Africa has a rich termite fauna. To-date over 664 known species of termites have been recorded in Africa (Wanyonyi et al., 1984) but species diversity varies within and between regions. Due to the xeric conditions in northern Africa, species diversity is low (less than 15 species) compared to the eastern, southern and western regions of the continent (Sileshi et al., 2010). Records of termites from Ethiopia indicate 61 species belonging to 25 genera and four families. The distributions within Ethiopia of at least some of the species correlate with overall African distributions (Cowie et al., 1990). Out of this, 143 species belong to the East African fauna proper, which is also continuous with that of Somalia, Eritrea, Djibouti, Ethiopia and Sudan to the North, and Malawi, Zimbabwe and Mozambique to the South (Sileshi et al., 2010). Some 165 species have been recorded from the southern Africa region, including South Africa, Zimbabwe, Mozambique, Botswana, Swaziland, Lesotho and Namibia. The termites of southern Africa have been surveyed thoroughly, probably more so than any other region during the 'National survey of the Isoptera of southern Africa' by Coaton and Sheasby (1972). Table 1 gives the genera with approximate numbers of termite species found in Africa. However, the numbers are likely to be underestimated because the taxonomy of African termites is notoriously difficult, and many new species are yet to be described.

African termites can be divided into lower termites which include the families Kalotermitidae, Termopsidae, Rhinotermitidae and Hodotermitidae, and higher termites all belonging to the family Termitidae. Among the lower termites, the Kalotermitidae and Rhinotermitidae feed on dry wood, while the Termopsidae feed mainly on decaying wood. The Hodotermitidae feed mainly on grass although they also damage structural timber. The Termitidae are probably the most notorious for wood damage. In Africa the Termitidae are represented by over 601 species (>90% of all known species) (Eggleton, 2000) in four subfamilies (Apicotermitinae, Termitinae, Macrotermitinae and Nasutitermitinae). The subfamily Apicotermitinae is currently reported to have some 70 species in Africa (Eggleton, 2000; Cowie et al., 1990). However, the number is likely to increase when the description of the large number of unidentified species is completed. The subfamily Termitinae consists of about 272 African species (Eggleton et al., 2002). The subfamily Nasutitermitinae consists of 56 species, which mainly feed on grass, leaf litter and wood (e.g. logs, stumps and standing dead trees). The Macrotermitinae (fungus growing termites) consisting of over 165 African species (Eggleton et al., 1999), and arguably the most destructive wood-feeding insects. Economically important genera in the subfamily *Macrotermitinae* include *Macrotermes, Odontotermes* and *Microtermes*.

Economic damage by pestiferous termites has to be considered from the fact that they are present throughout the year, every year and are an integral component of the environment (Wood, 1995). Southern Zambia has been experiencing periods of drought over the years, resulting in severe termite attack on crops, plantation trees and building timber in thatched houses. Based on a survey conducted in 1998 after a drought, a list of pestiferous termite species found in Southern Zambia is shown in Table 2. The normal mean annual rainfall in Agro-ecological I is between 600-800 mm, Agro-ecological II has a normal mean rainfall which lies between 800-100mm.

The distribution pattern of termites is influenced by several factors. In Uganda Pomeroy (1976), observed that the distribution of *Macrotermes bellicosus* mounds was correlated very strongly with temperature, and that large termite mounds were absent in areas of lower temperatures such as forests and swamps. Pomeroy (1977) reported *M. bellicosus* and *M.*

subhyalinus in central, western, eastern and northern regions of Uganda while *Pseudacanthotermes* species occurred only in the central region of the country. He further observed that the distribution of these large mound builders was not correlated with soils, climate and vegetation. In contrast, Okwakol (1976) observed that the distribution of Cubitermes mounds in Uganda was determined by grass species, soil depth and clay content. Kemp (1955) suggested that climate was the principal factor determining the distribution of termites in North –Eastern Tanganyika (Tanzania). These contrasting findings suggest that different termite taxa may respond differently to variations in environmental conditions, and thus exemplify the need for a case-by-case study.

3. CURRENT TERMITE STATUS IN AFRICA

Recent studies show that some regions of sub-Saharan Africa (SSA) have experienced a shift toward more extreme rainfall events (Khogali, 1999; Lovett et al., 2005). The El Niňo-Southern Oscillations climate event has been predicted to become more frequent and of greater magnitude in Africa (Lovett et al., 2005). Global climate change may lead to higher potential evapo-transpiration, decreasing precipitation and increasing frequency of high intensity rains (Beaudrot et al., 2011). However, the expected changes vary from one region of Africa to another. For instance, for the period 2000-09 a wet signal is expected for the Sahel as opposed to a dry signal for southern Africa (Harrington et al., 2001). Southern Africa has so far displayed a remarkable occurrence of extremely wet and dry years and average years with about equal likelihood (Gommes and Petrassi, 1996). Farmers in Uganda and Zambia mentioned that termite problems are more serious now than in the past (Sekamatte and Okwakol 2007; Sileshi et al., 2009). Damage by termites is greater during dry periods or droughts than periods of regular rainfall (Logan et al., 1990). The increases in termite damage could also be associated with climate change induced drought. In recent decades, drought linked to El Niño episodes has become more intense and widespread in southern Africa.

Despite the much talked about Climate change in Africa, there is paucity of data on extent of change in climate that has occurred in Zambia, particularly with regard to rainfall and temperatures.

Globally, the net effect of climate change has been predicted to increase pest damage to crops and trees. The introduction and distribution of alien insect pests are also likely to be driven by climate change as well as global trade. A large number of unidentified termite pests have established themselves in Africa (Nkunika Per. Comm.). The direct and indirect effects from climate change will possibly alter key demographic attributes, thus resulting in unanticipated population level consequences. There have been some rather spectacular documented cases of how climate can influence insect populations (Parmesan et al., 1999; Crozier, 2002).

4. TERMITE BIOLOGY AND IDENTIFICATION

Although considerable termite identification work has been carried out in Africa, a large number of termite species still remain unidentified (Nkunika, 1994; Eggleton et al., 1999, 2002), due to lack of adequate termite experts and identification facilities in Africa.

Table 1. Approximate number of termite species in Africa

Family	Subfamily	Genus	Number of species
Kalotermitidae	Kalotermitinae	*Bicornitermes*	4
		Bifiditermes	7
		Cryptotermes	4
		Epicalotermes	4
		Kalotermes	3
		Neotermes	17
Hodotermitidae	Hodotermitinae	*Hodotermes*	2
		Microhodotermes	1
Rhinotermitidae	Coptotermitinae	*Coptotermes*	6
		Psammotermes	4
	Rhinotermitinae	*Schedorhinotermes*	2
Termitidae	Apicotermitinae	*Acholotermes*	4
		Adaiphrotermes	3
		Aderitotermes	UC
		Adynatotermes	1
		Aganotermes	1
		Alyscotermes	2
		Anenteotermes	UC
		Apicotermes	15
		Astalotermes	16
		Astratotermes	6
		Ateuchotermes	8
		Skatitermes	2
	Termitinae	*Amitermes*	17
		Angulitermes	6
		Basidentitermes	9
		Batillitermes	1
		Ceratotermes	UC
		Crenetermes	5
		Cubitermes	70
		Euchilotermes	3
		Lepidotermes	3
		Megagnathotermes	2
		Microcerotermes	46
		Noditermes	9
		Okovangotermes	2
		Ophiotermes	6
		Ovambotermes	1
		Pericapritermes	11
		Procubitermes	20
		Promirotermes	10
		Pseudomicrotermes	1
		Termes	7
		Unguitermes	7
		Unicornitermes	1
	Macrotermitinae	*Acanthotermes*	1
		Allodontootermes	3

Table 1 continues..

		Ancistrotermes	10
		Macrotermes	13
		Microtermes	42
		Odontotermes	78
		Pseudacanthotermes	8
	Nasutitermitinae	*Baucaliotermes*	2
		Euternellus	2
		Fulleritermes	5
		Grallotermes	1
		Mimeutermes	6
		Nasutitermes	10
		Rhadinotermes	1
		Spatulitermes	1
		Trinervitermes	17

Compiled from Kambhampati and Eggleton (2000); UC = Uncertain

Moreover, the identification of Macrotermitinae, which includes several agricultural, structural timber and forestry pests, is notoriously difficult, and many species are not easy to identify with certainty (Darlington et al., 2008). Unfortunately, current recommendations for termite management in Africa do not take into account the difficulty of termite identification (Sileshi et al., 2009).

Termites' colony can often seem just as integrated as an individual organism "super-organisms" (Wilson, 1968; La Fage et al., 1983). Termites are a highly successful group of insects coevolving for over 300 million years and constituting an integral component of the ecosystem (Dobzhansky, 1941; Emerson, 1943; French, 1988). It seems logical to imagine that the success of these social insects highly depends on the behavioural diversity of its individual working groups and the characters they share in common (Bates, 1854). These may include morphological, ecological, behavioural and biochemical characteristics. The external morphology of termites has received much attention mostly due to its importance in systematics and classification. Comparative termite studies focus in particular on the dentition of the imago-worker mandible, wing venation and the mandible and labrum of the soldier (Bagine, 1992). Many workers have carried out statistical study on the variability in the body parts i.e. morphormetric analysis. Internal morphology has also been considered especially when studying phylogenetics relationships (Noirot and Kavoor, 1958; Johnson, 1979). The most current classification of termites is summarized by Engel and Krishna (2004).

Recently the nest structures, ecological characteristics and biochemical investigations including cuticular hydrocarbon compounds and isoenzymes have contributed significantly in the field of termite systematics (Bagine, 1992). Also, near-infra red spectroscopy has reliably opened up the fields of insect age determination (Robson et al., 2006) and identification of termite and mosquito species (Aldrich et al., 2007: Mayagaya et al., 2009). As new biochemical techniques such as cuticular hydrocarbon studies (Haverty et al., 1991), genetic comparisons of DNA hybridization studies (Broughton and Kister, 1991); fluorescence spectrophotometer (Robson et al 2006); near-infrared spectroscopy (Aldrich et al., 2007; Mayagaya et al., 2009); and molecular techniques (Badawi et al., 2008) become more widely used, further changes in African generic taxonomy could occur. Concerted affirmative efforts are however necessary to build African human and infrastructural capacity in the use of such technologies for termite identification. As pointed out by Sekamatte and

Okwakol (2007), "the lack of impetus for young scientists to specialize in biosystematics and prohibitive costs of taxonomic services overseas make research in this area less attractive".

4.1 Molecular Genetics in Termite Classification

Current termite classification and identification is still relying on past knowledge, experiences and skills of morphological and physiological features. Molecular phylogenetics of termites will be fundamental in the development of future termite classification and identification with reference to climate change adaptation techniques and in the quarantine and pest control systems (Ahmed and French, 2008; Su and Scheffrahn, 2000). Research into molecular phylogenetics with better termite morphology, ecology and physiology understanding is needed (Lo et al., 2006). But this new research must be linked with existing knowledge and data to developing and implementing a sound classification, identification, adaptation and distribution of African termites.

Most termite identification systems, in the past, relied almost solely on the taxonomist with the use of morphological and physiological features as the major classification and identification system (Su and Scheffrahn, 2000). In Australia, Europe and USA molecular phylogenetics is considered as an alternative approach to termite identification, classification and distribution as the existing taxonomical classification is limited in its' scope and use of identification. The lack of qualified taxonomists needs a fresh look and a wholly biorational approach to termite taxonomy and distribution studies (Ahmed and French 2005; French, 1994).

In order to develop termite identification, classification, adaptation and distribution strategies, it is important to have a clear understanding of termite ecology, biology, foraging behaviour, intra-specific and inter-specific (Eggleton 2000; French, 1994). Termite classification systems based on morphological and physiological systems will not be able to provide key termite adaptation indicators in reference to climate change, attention must be given to termite molecular phylogeny, near infra red spectrometry and other new systems (Ahmed and French 2005).

The focus of research on termites in reference to climate change will adopt new molecular phylogenetics and infra red spectrometry to identify termite adaptability to climate change based on genetic markers (Badawi et al., 2008). In addition research has been lacking, in the past, on termite nesting, reproductive, distribution and termite adaptability as successful pests in different climatic conditions (Ahmed and French 2005). Once this understanding is better achieved, more efficient and more effective alternative identification DNA finger print can be developed and implemented to assist as an indicator of adaptation to climate change (Ahmed et al., 2006). Many recent studies demonstrated the need for a sound knowledge of termite molecular phylogenetics when applying termite adaptability to different climatic conditions and possible termite control (Lo et al., 2006).

Existing geographical distribution of termites demonstrates the ability of these termites to adapt to a range of climatic conditions with success. In order to achieve the comparative data of termite adaptability and behavioural change due to climate change phylogenetics studies have a great potential in developing representation of phylogenetics models to implement the different analytical methods, which will use sequences of several genes to configure out the Maximum parsimony, Maximum likelihood and Bayesian Analysis into harlequin computer based tool for better understanding of haplotypes dispersals in Africa (Ohkuma et al., 2004; Badawi et al., 2008). It is expected that the framework will effectively reflect the clear identification of species and spatial distribution and provide the desired compromise between different termite species and within same species. Moreover, termite phylogenetics and geographical distribution study based on DNA mapping will be fundamental contribution to the study of climate change and finding key indicators of climate change in termite species (Lovett et al., 2005). The proposed research outcome will improve understanding of termites' identification, classification, and enhanced phylogenetics to broader ecological, economic, and pest control outcomes.

Termite molecular phylogeny will assist to enhance our understanding of termites' phylogenetics, geographical distributions and uses of mitochondrial and nuclear genes which can explore the existence of new species (Badawi et al., 2008) (Fig 1).

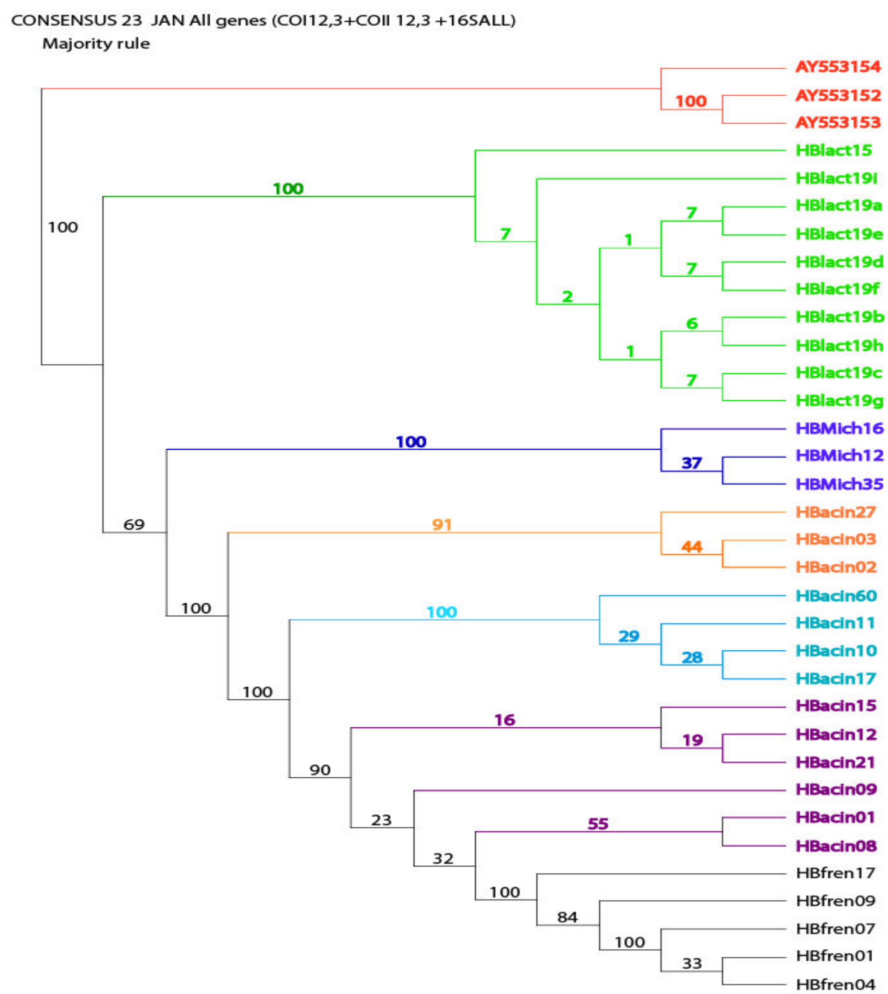

Fig. 1. Molecular phylogeny of Coptotermes spp. based on COI+COII+16S.
The topology yielded by using a maximum parsimony (MP) 50% Majority rule bootstrap analysis (1000 replicates). Values above the tree branches are posterior probability values from BI (Bayesian inference; Badawi, 2010 Ph. D thesis in progress).

Table 2. List of termite species found in Southern province districts in Agro-ecological Regions I and II (After Nkunika, 1998)

District	Agro-ecological Region	Family Sub-family	Genera	Species	Feeding Habits
Kalomo		Termitidae	*Alodontotermes*	*A.rhodeosiensis**	R,B,S,W
		Macrotermitinae	*Macrotermes*	*M. falciger**	R,B,S
			Pseudacanthotermes	*P. militaris*	R,W
	I			*P. spiniger*	R,W
			Allodontotermes	*A. schultzei*	S,R
			Odontontermes	*O. lacustris*	S,F,L
	II			*O. latericius*	S,F,L
				O. badius	S,W
			Microtermes	*M. subhyalinus.*	R,S,W
				*T. rhodesiensis**	G
Choma		Termitidae	*Macrotermes*	*M. falciger**	R,B,S
		Macrotermitinae	*Microtermes*	*Microtermes sp**	R,S
	II		*Odontotermes*	*O. badius**	S,W,W
			Psuedacanthotermes	*P. militaris*	R,W
				P. spiniger	R,W
				Odontotermes sp	R,W
Gwembe	I		*Macrotermes*	*M. falciger**	R,S,B
			Microtermes	*M. luterus**	R,S,B
Monze			*Pseudacanthotermes*	*P. militaris**	B,S,R,W
				P. spiniger	R,W
			Macrotermes	*M. falciger**	R,S,B
				M. michaelseni	R,S,F
	II		*Allodontotermes*	*A. schultzei**	R,S
			Odontotermes	*O. lacustris**	S,F,L
				O. latericius	S,F,L
			Microtermes	*Microtermes sp*	R,S,W
			Ancistrotermes	*A. latinotus*	R,S

Table 2 continues..

		Termitidae	*Macrotermes*	*M. falciger**	R,S,B
Mazabuka	II	Macrotermitinae		*M. michaelseni**	R,S,F
				A. schultizei	R,S
			Allodontotermes	*O. lacustris*	S,F,L
			Odontotermes	*O. latericius*	S,F,L
				O. badius	S,W
				Odontotermes sp	R,W
			Microtermes	*Microtermes sp**	R,S,W
			Ancistrotermes	*A. latinotus*	R,S
			Pseudacanthotermes	*P. militaris**	B,S,R,W
Livingstone	1		*Macrotermes*	*M. falciger**	R,S
			Amitermes	*A. truncatidens**	R
				Odontotermes sp	R,W

Key: Feeding Habits: root(R); Bark (B), Stem(S), Leaves (L), Fruit (F), Drying or Dry wood (W), Grass (G),
** Results obtained during this survey. Some species are yet to be described.*

5. CLIMATE CHANGE AND POSSIBLE IMPACT ON TERMITE DISTRIBUTION

The nature of climate change and its impacts on flora and fauna in Africa is not known with any great confidence. What is known is that temperatures are likely to continue to rise over most of Africa and rainfall will increase or decrease depending on the region (Fig. 2). However, significant variations occur between seasons and on a relatively small-scale especially in southern Africa (Shongwe et al., 2009). There is paucity of detailed climate change impact case studies of Africa (Van Jaarsveld et al., 2009; Cannon, 1998). This seems due to a combination of factors including: a lack of locally calibrated models, a shortage of observational data on computer-readable form and an exclusion of African scientists from accessing the results of global climate and climate impact models (Hulme et al., 2001).

Although there are still many unknowns in the climate equation in Africa, recent projections indicate increased risks of drought during the twenty-first century (Lobel et al., 2011). For example, a trend towards increased aridity since 1950 has emerged over southern Africa. According to the African Centre for Disaster Studies (ACDC 2006), the potential changes to the southern African climate over the next 50 years included: (1) a warming of 1-3 ^{0}C, (2) reduction of 5-10% of current rainfall, (3) increased daily maximum temperatures, (4) increased incidents of drought and floods. According to a recent study (Lobell et al., 2011) roughly 65% of present maize-growing areas in Africa would experience yield losses for 1°C of warming under optimal rain-fed management, with 100% of areas harmed by warming under drought conditions.

There is a growing consensus that sub-Saharan Africa (SSA) is one of the most vulnerable regions to climate change. Recent studies show that some regions have experienced a shift toward more extreme rainfall events (Lovett et al., 2005). The El Niňo-Southern Oscillations climate event has been predicted to become more frequent and of greater magnitude in Africa (Lovett *et al.,* 2005).

Global climate change may lead to higher potential evapo-transpiration, decreasing precipitation and increasing frequency of high intensity rains. However, the expected changes vary from one region of Africa to another. For instance, for the period 2000-49 a wet signal is expected for the Sahel as opposed to a dry signal for southern Africa (Gaston and Williams, 1996; Harrington et al., 2001). Southern Africa has so far displayed a remarkable occurrence of extremely wet and dry years and average years with about equally likelihood (Gommes and Petrassi, 1996; Lovett et al., 2005).

Temperature for Zambia is 0.032^{o}C per year or 0.32^{o}C per decade. Predicted average increase in mean annual temperature for Zambia for the period 2000 to 2100 based on the above warming rate is about 3.2^{o}C ± 1.0˚C. In the Southern Province of Zambia, the average increase in the mean annual temperature is between 0.35 and 0.40^{o}C (Shitumbanuma personal communication, 2010). From the results of analysis by Shitumbanuma (2008) in Fig. 3, it is clear that there is a trend of climatic warming over southern and Eastern Zambia.

Potential impacts of climate change on pests such as termites are yet to be established. However, in recent times, there are few studies that have attempted to identify and establish the link between termites' distribution, invasions and climate; and how this distribution might change with global warming and changes in drought frequency (Ahmed et al., 2006).

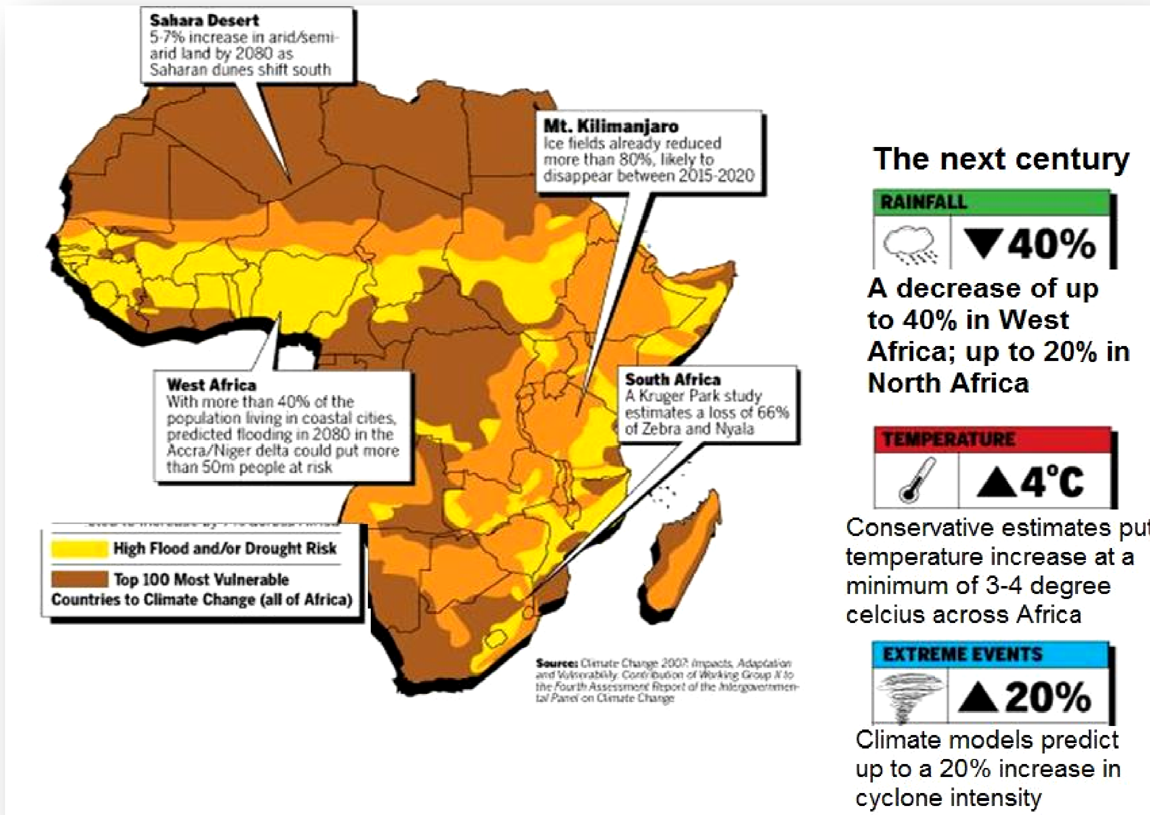

Fig. 2. Predicted impact of climate change in Africa (IPCC, 2005)

Farmers in Uganda and Zambia mentioned that termite problems are more serious now than in the past (Sekamatte and Okwakol 2007; Sileshi et al., 2009). Damage by termites is greater during dry periods or droughts than periods of regular rainfall (Logan et al., 1990). The increases in termite damage could also be associated with climate change induced drought. In recent decades, drought linked to El Niño episodes has become more intense and widespread in southern Africa (Harrington and Stork, 1995).

Globally, the net effect of climate change has been predicted to increase pest damage to crops and trees(Lovett et., 2005). The introduction and distribution of alien insect pests are also likely to be driven by climate change as well as global trade. A large number of alien invasive termites have established themselves in Africa. The direct and indirect effects from climate change will alter key demographic attributes, thus resulting in unanticipated population level consequences. There have been some rather spectacular documented cases of how climate can influence insect populations (Parmesan et al., 1999; Crozier, 2002). These include latitudinal and high-elevation expansion of butterfly and fruit fly distributions in Europe, shifts in life-histories, changes in plant defense chemistry affecting insects. In Africa, responses by pest insect populations to anticipated environmental shifts in the course of global climate change are largely unknown. An increase in temperature could result in an extension of ranges of some termites, with some being able to establish themselves in areas where they were previously unable to survive.

According to Shitumbanuma (Personal communication, 2010), Zambia and other Southern African countries have experienced seemingly increasing incidences of dry spells and droughts Fig. 3: Shows the warming patterns in the country.

Move to conclusion.

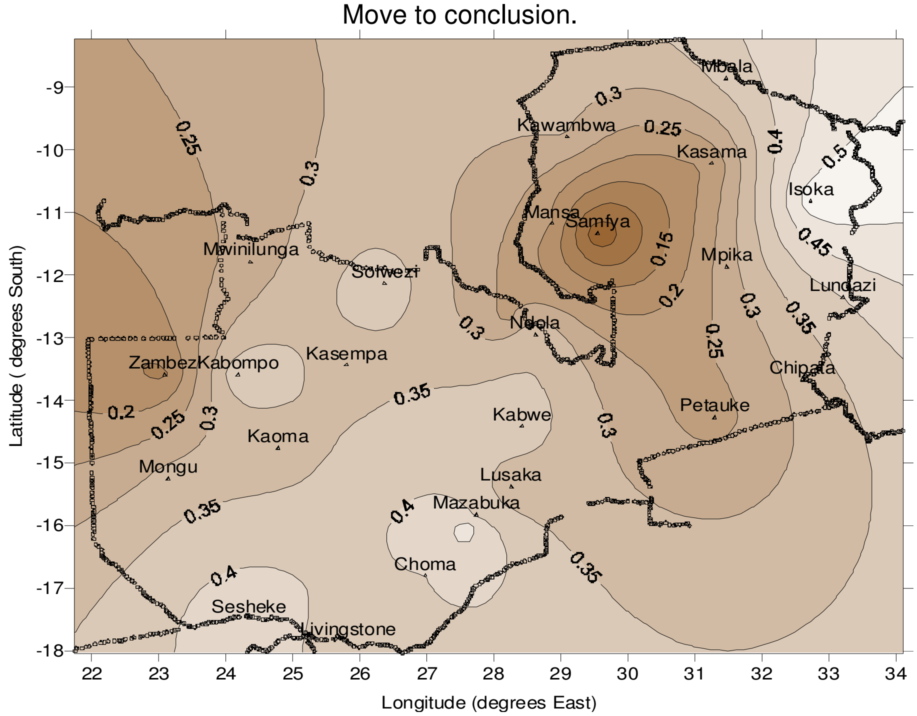

Fig. 3. Temperature contour map for Zambia

Attempts to assess the impact of climate change on termites must consider complex interactions. Process-based modeling can be useful in demonstrating the combined effects of some interactions, but it may not be possible to parameterize all interactions in a system. Long-term datasets can be useful in validating predictions. However, historical and current termite distribution data in Africa are scanty and available at very low resolutions. This makes development of empirical models of species' range, and predicting future termite distributions and impacts under climate change scenarios difficult. Development of elaborate databases on the diversity, distribution and impacts of African termites within and between countries, and careful long-term monitoring of a wide range of termite species are apparently the first steps in the strategies to understand and deal with the effects of climate change on termites in Africa.

6. CONCLUSIONS

With "global climate change expected" not only termite distribution will be affected and pest problems response change, but the effectiveness of termite management strategies will also change. As the majority of f termites are soil dwellers; soil degradation and drought are the major factors affecting distribution and foraging behaviour of termite in tropical and subtropical ecology.

The potential for increases in economically devastating termite outbreaks in response to climate change in Africa is high and warrants intensive investigation into the effects of climate on crop pests. New pests would require the development of monitoring programs and the availability of new pest control strategies such as integrated pest management (IPM) packages. Pest management strategies in agriculture and forestry will require adjustment.

REFERENCES

ACDC. African Centre for Disaster Studies [On line] (2006). http://acds.co.za/uploads/newsletters, November 2006.pdf.

Aldrich, B.T., Maghirang, E.B., Dowell, F.E., and Kambhampati, S. (2007). Identification of termite species and subspecies of the genus Zootermopsis using near-infrared reflectance spectroscopy. J. Insect Sci., 18, 1-7.

Ahmed, B. M., French, J.R.J. (2008). An overview of termite control methods in Australia and their link to aspects of termite biology and ecology. Pak. Entomol., Vol. 30, No.2, pp 1-18.

Ahmed, B.M., Elmahdi, A., French, J.R.J., Edis, R. (2006). Biomimicry of termite engineering for water and soil conservation. SOCIAL SCIENCES CONFERENCE 2007. The International Conference on Interdisciplinary Social Sciences. University of Granada, Granada, Spain, 10-13 July, 2007.

Ahmed, B. M., French, J.R.J. (2005). Report and recommendations of the National termite workshop, Melbourne 17 April 2002. International Biodeterioration and Biodegradation, 56: 69 – 74.

Badawi, H.M., Ahmed, B. M. (Shiday), French, J. R. J., Schwarz, M. P. (2008). The uses of Molecular techniques in studying Australian subterranean termites Genus Coptotermes. International Research Group on Wood Preservation Do No IRG/WP/08-10669.

Bagine, R. K. (1992). Problems in identification and control of termites In: Proceedings of the 1st Regional Workshop on Termite Research and Control, Wetlands, Nairobi, Kenya.

Bates, G. (1854). On some particulars in the natural history and habits of termites. In. Proc. Linn. Soc. London., Vol. 2. Pp. 333.

Beaudrot, L., Du, Y., Rahman Kassim, A., Rejma´nek, M., Harrison, R.D. (2011). Do epigeal termite mounds increase the diversity of plant habitats in a tropical rain forest in peninsular Malaysia? PLoS ONE 6(5), e19777. doi:10.1371/journal.pone.0019777.

Broughton, R.E. Jr., Kistner, D.H. (1991). A DNA hybridization study of the termite genus Zootermopsis (Isoptera: Termopsidae). Sociobiology, 19, 15-40.

Cannon, R.J.C. (1998). The implications of predicted climate change for insect pests in the UK, with emphasis on non-indigenous species. Global Change Biology, 4, 785-796.

Coaton Sheasby. (1972). Preliminary report on a survey of the termites (Isoptera) of South West Africa. Cimbebasia Mem. No .2.

Cowie, R.H., Wood, T.G., Barnett, E.A., Sands, W.A., Black, H.I.J. (1990). African Journal of Ecology, 28, 21-33.

Crozier, L. (2002). Climate change and its effect on species range boundaries: a case study of the Sachem Skipper butterfly, *Atalopedes campestris*. In: Wlidlife Responses to Climate Change, pp. 57-91. Root T.L. and Schneider S.H. (Eds.). Island Press, Washington, DC.

Crozier, L. (2002). Climate change and its effect on species range boundaries: a case study of the Sachem Skipper butterfly, *Atalopedes campestris*. In: Wlidlife Responses to Climate Change, pp. 57-91. Root T. L. and Schneider S.H. (Eds.). Island Press, Washington, DC.

Darlington, J.P. E. Benson, R. B., Cook, C. E., Walker, G. (2008). Resolving relationships in some African fungus-growing termites (Termitidae, Macrotermitinae) using molecular phylogeny, morphology, and field parameters. Insectes Sociaux., 55, 256–265.

Dobzhansky, T. (1941). The dynamics of termites. In. Columbia University press. Pp. 446.

Engel, M.S. and K. Krishna. (2004): Family-group names of termites (Isoptera). American Museum, Novitiates, 3432, 1-9

Eggleton, P., Homathevi, R., Jones, D.T., Macdonald, J., Jeeva, D., Bignell, D.E., Davies, R.G., Maryati, M. (1999). Termite assemblages, forest disturbance, and greenhouse gas fluxes in Sabah, East Malaysia. Philosophical transactions of the Royal Society, series B., 354, 1791-1802.

Eggleton, P. (2000). Global patterns of termite diversity. In: Termites, evolution, sociality, symbioses, ecology, ed. T. Abe, Bignell, D. E., and Higashi, Dordrecht, M., pp. 25–51 Kluwer Academic Publishers.

Eggleton, P., Bignell, D. E., Hauser, S., Dibog, L., Norgrove, L., Madong, B. (2002). Termite diversity across an anthropological gradient in the humid forest zone of West Africa. Agriculture, Ecosystems and Environment., 90, 189-202.

Emerson, A. E. (1943). Ecology, evolution and society. Amer. Nat., 77(1), 97 –118.

Engel, M.S., Krishna, K. (2004), Family-group names of termites (Isoptera). American Museum, Novitates, 3432, 1-9.

French, J.R.J., Ahmed, B. (2009). Building with termites: The challenge of biomimetic design for carbon neutral buildings. 40th Annual Meeting of the International Research Group on Wood Protection. IRG/WP 09-20405I.

French, J.R.J. (1994). Combining physical barriers bait and dust toxicants in future strategies for subterranean termite control (Isoptera). Sociobiology, 24, 77-91.

French, J. R. J. (1988). Ecosystem-level experimentation in termite research. Sociobiology, 14, 269 - 280.

Gaston, K. J., Williams, P.H. (1996). Spatial patterns in taxonomic diversity. In: Biodiversity (ed. Gaston KJ), pp. 202 - 229. Blackwell Science, Oxford.

Gates, D.M. (1993). Climate Change and its Biological Consequences. Sinauer Associates, Sunderland. Mass.

Hansen, J. (2009). Storms of my grandchildren: The truth about the coming climate catastrophe and our last chance to save humanity. pp. 304. Bloomsbury, New York, Berlin, London.

Harrington, R., Fleming, R. A., Woiwod, I. P. (2001). Climate change impacts on insect management and conservation in temperate regions: can they be predicted? Agricultural and Forest Entomology, 3, 233 – 240.

Harrington, R., Stork, N.E., eds. (1995). Insects in a Changing Environment. Academic Press, London.

Harrington, R., Woiwod, I., Sparks, T. (1999). Climate change and trophic interactions. Trends in Ecology and Evolution, 14, 146 - 150.

Haverty, M.I., Nelson, L. J., Page, M. (1991). Preliminary investigations of the cuticular hydrocarbons from North American Reticulitermes and tropical and subtropical Coptotermes (Isoptera: Rhinotermitidae) for chemotaxonomic studies. Sociobiology, 19, 51 - 76.

Hulme, M. D., Conway, D., Kelly, M., Subak, S., Downing, T.E. (2001). Ambiete.sp.gov.br. Climate Research, School of Environmental Sciences, University of East Anglia.

IPCC. (1992). IPCC supplement: Scientific Assessment of Climate change. Report prepared by Working Group 1. WHO-UNEP. Houghton, J.T., Callender, B.A. and Varney, S. (eds.) Cambridge University Press, Cambridge.

IPCC. (1995). IPCC Second Assessment Synthesis of Scientific-Technical Information relevant to Interpreting Article 2 of the UN Framework Convention on Climate change. http://www.opcc.ch/pub/sarsyn.html.

IPCC. (1997). Summary of Policy makers: The Regional Impacts of Climate Change- an Assessment of Vulnerability. http://www. Ipcc.ch/pub/sr97.html.

IPCC. (2005). IPCC Technical Support Unit Working Group III. Report on emission scenario. IPCC Expert meeting on emission scenarios, 12-14 January 2005, Washington DC, USA.

Johnson, R.A. (1979). Configuration of the digestive tube as an aid to identification of worker Termitidae (Isoptera). Systematic Entomology, 4, 31 - 38.

Jones, J.A. (1990). Termites, Soil fertility and carbon cycling in dry tropical Africa: a hypothesis. Journal of Tropical Ecology, 6, 291 - 305.

Kambhampati, S., Eggleton, P., (2000). Taxonomy and phylogeny of termites. Termites: evolution, sociality, symbioses, ecology (eds T. Abe, D.E. Bignell and M. Higashi) Kluwer Academic Publishers, Dordrecht, The Netherlands, 1-23.

Kemp, P.B. (1955). The termites of North-Eastern Tanaganyika (Tanzania): their distribution and biology. Bulletin of Entomological Research, 46, 113 - 135.

Khogali, M.M. (1991). Famine, desertification and vulnerable populations: the case of Umm Ruwaba District, Kordofan Region, Sudan. Ambio 20, 204 – 206.

Korman, A.K., Pashley, D.P. (1991). Genetic comparisons among US populations of Formosan subterranean termites. Sociobiology, 19, 41 - 50.

Lo, N., Eldridge, R. H., Lenz, M. (2006). Phylogeny of Australian Coptotermes (Isoptera: Rhinotermitidae) species inferred from mitochondrial COII sequences. Bulletin of Entomological Research, 96, 433 - 437.

Lobell, D.B., Bänziger, M., Magorokosho, C., Vivek, B. (2011). Nonlinear heat effects on African maize as evidenced by historical yield trials. Nature Climate Change DOI: 10.1038/NCLIMATE1043.

Logan, J.W.M, Cowie, R.W., Wood, T.G. (1990). Termite (Isoptera) control in agriculture and forestry by nonchemical methods: a review. Bulletin of Entomological Research, 80, 309 - 330.

Lovett, J.C., Midgley, G.F., Barnard, P. (2005). Climate change in Africa. African Journal of Ecology, 43, 167 - 169.

Mayagaya, V.S., Michel, K., Benedict, M.Q., Killeen, G.F., Wirtz, R.A., Ferguson, H.M., Dowell, F.E. (2009). Non-destructive determination of age and species of Anopheles gambiae s.1. Using near-infrared spectroscopy. American Journal of Tropical Hygiene, 81(4), 622 - 630.

McNeely, J, A., Gadgil, M., Leveque, C., Redford. (1995). Human influences on Biodiversity. In: Global Biodiversity Assessment. Heywoord, V.H and Watson, R.T. (eds.) Cambridge University Press, Cambridge.

Nkunika, P.O.Y. (1994). Control of termites in Zambia: Practical realities. Insect Science and its Application, 15, 241 - 245.

Nkunika, P.O.Y. (1998). Termite survey, identification, damage and control in southern province. Land Management and Conservation Farming, Soil Conservation and Agro forestry Extension Report, Lusaka, Zambia.

Noirot, C., Koovor, J. (1958). Comparative anatomy of the digestive tract of termites. I. Sub-family Termitinae (In French). Bull. Union Int. Etude Insect. Soc., 5(4), 439 - 471.

Nyeko, P., Olubayo, F.M. (2005). Participatory assessment of farmers' experiences of termite problems in agroforestry in Tororo District, Uganda. Agricultural Research and Extension Network paper No. 143. London; Overseas Development Institute.

Ohkuma, M., Yuzawa, H., Amornsak, W., Sornnuwat, Y., Takematsu, Y., Yamada, A., Vongkaluang, C., Sarnthoy, O., Kirtibutr, N., Noparatnaraporn, N., Kudo, T., Inoue, T. (2004). Molecular phylogeny of Asian termites (Isoptera) of the families Termitidae and Rhinotermitidae based on mitochondrial COII sequences. Molecular Phylogenetics and Evolution, 31, 701 – 710.

Okwakol, M.J.N. (1976). Some aspects of the ecology of termites of the Genus Cubitermes (Isoptera: Termitidae). Unpublished M.Sc. thesis submitted to Makerere University, Kampala, Uganda.

Parmesan, C., Ryrholm, N. Stefanescu, C., Hill, J.K., Thomas, Descimon, C.D.H., et al. (1999). Poleward shifts in geographic ranges of butterflies associated with regional warming. Nature, 399, 579 - 583.

Pomeroy, D.E. (1976). Studies of population of large termite mounds in Uganda. Ecological Entomology, 1, 49 - 61.

Pomeroy, D.E. (1977). Distributions and abundance of large termite mounds in Uganda. Journal of Applied Ecology, 14, 456 - 475.

Robson, S.K.A., Vickers, M., Blows, M.W., Crozier, R.H. (2006). Age determination in individual wild-caught *Drosophila serrata* using pteridine concentration. J. Experimental Biol., 209, 3155 - 3163.

Shackleton, L.Y. (1996). Global climate change. Shackleton, L.Y., Lennon, S.J., Tosen, G.R. (eds.). Environmental Scientific Association, Cleveland, South Africa.

Shitumbanuma, V. (2008).What has happened to Climate in Zambia in Recent Decades? Paper presented at the 3rd SADC EU International Scientific Symposium-Towards Meeting the Challenges of Climate Change: Institutional Structure and Best Practices in Land and Water Management in Southern Africa. 27-30th May 2008, Cresta Golfview Hotel, Lusaka, Zambia.

Sekamatte, M.B., Okwakol, M.J.N. (2007). The present knowledge on soil pests and pathogens in Uganda. African Journal of Ecology, 45(2), 9 - 19.

Shongwe, M.E., Oldenborgh, van, G.J., van, den, Hurk, B.J.J.M., de Boer, B., Coelho, C.A.S., van Aalst, M.K. (2009). Projected changes in mean and extreme precipitation in Africa under global warming. Part I: Southern Africa. Journal of Climate, 22, 3819–3837.

Sileshi, G.W., Nyeko, P., Nkunika, P.O.Y., Sekamatte, B.M., Akinnifesi, F.K., Ajayi, O.C. (2009). Integrating ethno-ecological and scientific knowledge of termites for sustainable termite management and human welfare in Africa. Ecology and Society, 14(1), 48.

Sileshi, G.W., Arshad, M.A., Konaté, S., Nkunika, P.O.Y. (2010) Termite-induced heterogeneity in African savanna vegetation: mechanisms and patterns. Journal of Vegetation Science, 21, 923-937.

Su, N-Y., Scheffrahn, R. H. (2000). Termites as pests of buildings. In: Takuya A, David, B. and Masahiko, H. (Eds). Termites: Evolution, Sociality, Symbioses, Ecology. Kluwer Academic Publishers, Dordrecht, pp. 437-453.

Van, Jaarsveld, A.S., Chown, S.L., Erasmus, B.F.N., Kshatriya, Wessels, K.J. (2009). Vulnerability and adaptation of South African taxa to climate change. Biodiversity Monitoring and Assessment Programme. University of Pretoria.

Wanyonyi, K., Darlington, J.P.E.C., Bagine, R.K.N (1984). Checklist of the species of termites (Isoptera) recorded from east Africa. Journal of East African Natural History Society, 181, 1-10.

Wightman, S.A. (1988). Contribution of insects to low groundnut yields in Southern Africa. Proceedings of the Third Regional Groundnut Workshop, 13-18th March 1988, Lilongwe, Malawi.

Wightman, J.A. (1991). Soil insect problem in African groundnut crops, In: Advances in Management and Conservation of Soil Fauna, ed. G.K. Veeresh, D. Rajagopal and C.A. Viraktamath. pp. 171-176. Oxford/IBH Publ., New Delhi.

Wood, T.G. (1995). The agricultural importance of termites in the tropics. Agricultural Zoology Reviews, 7, 117-155.

Wilson, E. O. (1968). The superorganism concept and beyond. In. L'effet de groupe chez les animaux. The effect of group in animals. Paris, Centre National de la Recherche Scientifique. (Colloques Internationaux du centre National de la Recherche Scientifique, no. 173). pp 27 – 39.
