Journal of Ecology and The Natural Environment

Volume 6 Number 5, May 2014

ISSN 2006-9847

Academic Journals

ABOUT JENE

The **Journal of Ecology and the Natural Environment (JENE)** (ISSN 2006-9847) is published Monthly (one volume per year) by Academic Journals.

Journal of Ecology and the Natural Environment (JENE) provides rapid publication (monthly) of articles in all areas of the subject such as biogeochemical cycles, conservation, paleoecology, plant ecology etc.

The Journal welcomes the submission of manuscripts that meet the general criteria of significance and scientific excellence. Papers will be published shortly after acceptance. All articles published in JENE are peer-reviewed.

Submission of Manuscript

Please read the **Instructions for Authors** before submitting your manuscript. The manuscript files should be given the last name of the first author

Click here to Submit manuscripts online

If you have any difficulty using the online submission system, kindly submit via this email jene@academicjournals.org.

With questions or concerns, please contact the Editorial Office at jene@academicjournals.org.

Editorial Board

Instructions for Author

Electronic submission of manuscripts is strongly encouraged, provided that the text, tables, and figures are included in a single Microsoft Word file (preferably in Arial font).

The **cover letter** should include the corresponding author's full address and telephone/fax numbers and should be in an e-mail message sent to the Editor, with the file, whose name should begin with the first author's surname, as an attachment.

Article Types

Three types of manuscripts may be submitted:

Regular articles: These should describe new and carefully confirmed findings, and experimental procedures should be given in sufficient detail for others to verify the work. The length of a full paper should be the minimum required to describe and interpret the work clearly.

Short Communications: A Short Communication is suitable for recording the results of complete small investigations or giving details of new models or hypotheses, innovative methods, techniques or apparatus. The style of main sections need not conform to that of full-length papers. Short communications are 2 to 4 printed pages (about 6 to 12 manuscript pages) in length.

Reviews: Submissions of reviews and perspectives covering topics of current interest are welcome and encouraged. Reviews should be concise and no longer than 4-6 printed pages (about 12 to 18 manuscript pages). Reviews are also peer-reviewed.

Review Process

All manuscripts are reviewed by an editor and members of the Editorial Board or qualified outside reviewers. Authors cannot nominate reviewers. Only reviewers randomly selected from our database with specialization in the subject area will be contacted to evaluate the manuscripts. The process will be blind review.

Decisions will be made as rapidly as possible, and the journal strives to return reviewers' comments to authors as fast as possible. The editorial board will re-review manuscripts that are accepted pending revision. It is the goal of the AJFS to publish manuscripts within weeks after submission.

Regular articles

All portions of the manuscript must be typed double-spaced and all pages numbered starting from the title page.

The Title should be a brief phrase describing the contents of the paper. The Title Page should include the authors' full names and affiliations, the name of the corresponding author along with phone, fax and E-mail information. Present addresses of authors should appear as a footnote.

The Abstract should be informative and completely self-explanatory, briefly present the topic, state the scope of the experiments, indicate significant data, and point out major findings and conclusions. The Abstract should be 100 to 200 words in length.. Complete sentences, active verbs, and the third person should be used, and the abstract should be written in the past tense. Standard nomenclature should be used and abbreviations should be avoided. No literature should be cited.

Following the abstract, about 3 to 10 key words that will provide indexing references should be listed.

A list of non-standard **Abbreviations** should be added. In general, non-standard abbreviations should be used only when the full term is very long and used often. Each abbreviation should be spelled out and introduced in parentheses the first time it is used in the text. Only recommended SI units should be used. Authors should use the solidus presentation (mg/ml). Standard abbreviations (such as ATP and DNA) need not be defined.

The Introduction should provide a clear statement of the problem, the relevant literature on the subject, and the proposed approach or solution. It should be understandable to colleagues from a broad range of scientific disciplines.

Materials and methods should be complete enough to allow experiments to be reproduced. However, only truly new procedures should be described in detail; previously published procedures should be cited, and important modifications of published procedures should be mentioned briefly. Capitalize trade names and include the manufacturer's name and address. Subheadings should be used. Methods in general use need not be described in detail.

Results should be presented with clarity and precision. The results should be written in the past tense when describing findings in the authors' experiments. Previously published findings should be written in the present tense. Results should be explained, but largely without referring to the literature. Discussion, speculation and detailed interpretation of data should not be included in the Results but should be put into the Discussion section.

The Discussion should interpret the findings in view of the results obtained in this and in past studies on this topic. State the conclusions in a few sentences at the end of the paper. The Results and Discussion sections can include subheadings, and when appropriate, both sections can be combined.

The Acknowledgments of people, grants, funds, etc should be brief.

Tables should be kept to a minimum and be designed to be as simple as possible. Tables are to be typed double-spaced throughout, including headings and footnotes. Each table should be on a separate page, numbered consecutively in Arabic numerals and supplied with a heading and a legend. Tables should be self-explanatory without reference to the text. The details of the methods used in the experiments should preferably be described in the legend instead of in the text. The same data should not be presented in both table and graph form or repeated in the text.

Figure legends should be typed in numerical order on a separate sheet. Graphics should be prepared using applications capable of generating high resolution GIF, TIFF, JPEG or Powerpoint before pasting in the Microsoft Word manuscript file. Tables should be prepared in Microsoft Word. Use Arabic numerals to designate figures and upper case letters for their parts (Figure 1). Begin each legend with a title and include sufficient description so that the figure is understandable without reading the text of the manuscript. Information given in legends should not be repeated in the text.

References: In the text, a reference identified by means of an author‘s name should be followed by the date of the reference in parentheses. When there are more than two authors, only the first author‘s name should be mentioned, followed by ’et al‘. In the event that an author cited has had two or more works published during the same year, the reference, both in the text and in the reference list, should be identified by a lower case letter like ’a‘ and ’b‘ after the date to distinguish the works.

Examples:

Abayomi (2000), Agindotan et al. (2003), (Kelebeni, 1983), (Usman and Smith, 1992), (Chege, 1998; 1987a,b; Tijani, 1993,1995), (Kumasi et al., 2001)
References should be listed at the end of the paper in alphabetical order. Articles in preparation or articles submitted for publication, unpublished observations, personal communications, etc. should not be included in the reference list but should only be mentioned in the article text (e.g., A. Kingori, University of Nairobi, Kenya, personal communication). Journal names are abbreviated according to Chemical Abstracts. Authors are fully responsible for the accuracy of the references.

Examples:

Chikere CB, Omoni VT and Chikere BO (2008). Distribution of potential nosocomial pathogens in a hospital environment. Afr. J. Biotechnol. 7: 3535-3539.

Moran GJ, Amii RN, Abrahamian FM, Talan DA (2005). Methicillinresistant Staphylococcus aureus in community-acquired skin infections. Emerg. Infect. Dis. 11: 928-930.

Pitout JDD, Church DL, Gregson DB, Chow BL, McCracken M, Mulvey M, Laupland KB (2007). Molecular epidemiology of CTXM-producing Escherichia coli in the Calgary Health Region: emergence of CTX-M-15-producing isolates. Antimicrob. Agents Chemother. 51: 1281-1286.

Pelczar JR, Harley JP, Klein DA (1993). Microbiology: Concepts and Applications. McGraw-Hill Inc., New York, pp. 591-603.

Short Communications

Short Communications are limited to a maximum of two figures and one table. They should present a complete study that is more limited in scope than is found in full-length papers. The items of manuscript preparation listed above apply to Short Communications with the following differences: (1) Abstracts are limited to 100 words; (2) instead of a separate Materials and Methods section, experimental procedures may be incorporated into Figure Legends and Table footnotes; (3) Results and Discussion should be combined into a single section.
Proofs and Reprints: Electronic proofs will be sent (e-mail attachment) to the corresponding author as a PDF file. Page proofs are considered to be the final version of the manuscript. With the exception of typographical or minor clerical errors, no changes will be made in the manuscript at the proof stage.

Fees and Charges: Authors are required to pay a $550 handling fee. Publication of an article in the Journal of Ecology and the Natural Environment is not contingent upon the author's ability to pay the charges. Neither is acceptance to pay the handling fee a guarantee that the paper will be accepted for publication. Authors may still request (in advance) that the editorial office waive some of the handling fee under special circumstances

Submission of a manuscript implies: that the work described has not been published before (except in the form of an abstract or as part of a published lecture, or thesis) that it is not under consideration for publication elsewhere; that if and when the manuscript is accepted for publication, the authors agree to automatic transfer of the copyright to the publisher.

Disclaimer of Warranties

In no event shall Academic Journals be liable for any special, incidental, indirect, or consequential damages of any kind arising out of or in connection with the use of the articles or other material derived from the JENE, whether or not advised of the possibility of damage, and on any theory of liability.

This publication is provided "as is" without warranty of any kind, either expressed or implied, including, but not limited to, the implied warranties of merchantability, fitness for a particular purpose, or non-infringement. Descriptions of, or references to, products or publications does not imply endorsement of that product or publication. While every effort is made by Academic Journals to see that no inaccurate or misleading data, opinion or statements appear in this publication, they wish to make it clear that the data and opinions appearing in the articles and advertisements herein are the responsibility of the contributor or advertiser concerned. Academic Journals makes no warranty of any kind, either express or implied, regarding the quality, accuracy, availability, or validity of the data or information in this publication or of any other publication to which it may be linked.

Journal of Ecology and the Natural Environment

Table of Contents: Volume 6 Number 5, May 2014

ARTICLES

academicJournals

Vol. 6(5), pp. 140-153, May 2014
DOI: 10.5897/JENE2013.0431
Article Number: E2875CB43791
ISSN 2006-9847

http://www.academicjournals.org/JENE

Journal of Ecology and the Natural Environment

Full Length Research Paper

Prospects and potentials of Kakum Conservation Area, Ghana

Kweku A. Monney and Kwaku B. Dakwa*

[1]Department of Entomology and Wildlife, School of Biological Sciences, University of Cape Coast, Cape Coast, Ghana.

Received 12 May, 2013; Accepted 27 February, 2014

The Kakum Conservation Area (KCA) is a protected remnant semi-deciduous forest of Ghana's fast dwindling portion of the Upper Guinea Forest. The prospects and potentials for sustainable conservation and their challenges were the main concern of this study; that is whether there is the opportunity for KCA to increase tourism drive as a means of ensuring self-funding for sustainable conservation in the long term. In this paper, we highlight the main features of KCA that present enviable opportunity to promote tourism and increase internal-generating funds as well as appealing to donor sources, and set it apart as one of the most successful attempts at management, protection and conservation of biodiversity in a developing country. We adopted a thorough search and used an analytical - descriptive approach to provide information. We found that although only a small portion of the KCA is primary and a greater portion remains secondary because of logging records, KCA contains great faunal diversity including charismatic ones that attract tourists, hundreds of herbaceous plants and woody plant species and various sceneries including the "big tree", which altogether hold great potential for being an enviable tourist attraction. Revenue generated internally, mainly from tourism, from 2006 to 2010 showed a positive trend that predicted a rise in revenue in future years, especially when the conservation area is marketed appropriately. However, we found need for an intervention from the donor world in view of the high cost of initial investment in infrastructural development; we are sure that promoted tourism will increase internal-generating funds to make KCA self-funding subsequently.

Key words: Kakum Conservation Area (KCA), big tree, canopy walk-way, hiking, observation platform, rainforest, tourism, virgin forest, waterfalls, self-funding, donor sources,.

INTRODUCTION

Without doubt, biodiversity is under threat globally (Smith and Walpole, 2005); and almost all countries have set aside areas for conservation of species (Cullen and White, 2013). With over 180 countries being signatories to the International Convention on Biological Diversity (UNEP, 1992), now it is the means of attaining conservation of biodiversity that is the preoccupation of policy makers (Gadgil, 1992; Terborgh et al., 2002). The designation and management of protected areas have become principal elements in the development planning of many nations (Pimbert and Pretty, 1997). But whereas the concept of protected areas has existed in Europe for several thousand years (Jones-Walters and Čivić, 2013), the concept seems quite recent in tropical Africa.

*Corresponding author. E-mail: dakb92@yahoo.com.

For example by 1967 Ghana had 13 wildlife reserves comprising five National Parks (with emphasis on tourism), one strict Nature Reserve (with emphasis on research), five Game Production Reserves (with emphasis on meat production and multiple land use programmes); and two Wildlife Sanctuaries (with emphasis on education and research) (Manu, 1984). After various re-organizations and necessary arrangements, Ghana currently has 16 Wildlife Protected Areas (WPAs) comprising seven National Parks, six Resource Reserves, two Wildlife Sanctuaries and one Strict Nature Reserve. Collectively, the WPAs total about 12,585 km^2 that is, about 5.5% (Jachmann, 2008) of the country's nearly 239,000 km^2 land area. In addition, there are five coastal wetlands (RamsarSites) and about 300 scattered forest reserves. In all the protected areas, comprising the forest reserves, WPAs and wetlands represent about 16% of Ghana's total land area. The official WPAs of Ghana are generally modeled on the Yellowstone Park of Category II of IUCN classification (Mckinnon and Thorsell, 1986) in which the usual practice is to greatly restrict extractive human activity to the point of complete halt with the exception of tourism and research.

The wildlife protected areas are managed by the Wildlife Division; one of the four arms under the Forestry Commission, which was previously known as Game and Wildlife until 1994 and Wildlife Department later on. Ghana, formerly called Gold Coast, gained its political independence from British colonial rule in 1957. Before then, the desire to exert sustainable trade supremacy over other European competitors urged the British to set aside some forests for logging as the indigenes cleared the land to cultivate cash crops such as oil palm and cocoa; and food crops e.g. maize and cassava. Towards the end of the 19^{th} century, the then Kakum Forest was among the various reserves set aside as the "*Celtis-Lophira* hardwood Ghana's Production Resource Reserve". However the boundaries were not demarcated until 1925. In 1940 the Assin Attandanso forest was added to make a total of about 400 km^2. Timber exploitation especially of *Khayaivorensis* (mahogany) escalated from the 1950s until 1989 when the reserve was placed under Ghana Wildlife Department (GWD) to extend emphasis on protection and conservation beyond the trees to cover wild animals. Over the years several laws e.g. the 1961 Wild Animals Preservation Act and the legislative Amendments of 1971 had to be passed to make the existence of the Park a reality. The KCA was finally gazetted as a national park and resource reserve by Legislative Instrument 1525 of 1992 under the administrative jurisdiction of the GWD. By that time there had been reduction in the size of the original 400 km^2 due to unauthorized encroachment by farmers over the years when various legal arrangements were being made to wrestle the area out of Ghana's complex land tenure system. Now, known as a conservation area, Kakum combines the national park with the hitherto Assin Attandanso resource reserve (Jachmann et al., 2011).

Historically the indigenes have been generally and heavily dependent on forests for their livelihood. Apart from clearing the land for subsistence farming and cash crops, forest products have provided fuel, food including bush meat, medicinal herbs, and raw materials for construction of houses, furniture and many other items. On the other hand, the current status of KCA has been achieved through the combined efforts of the Government of Ghana, United Nations Development Programme (UNDP), United States Agency for International Development (USAID) supported by Central Region Development Commission (CEDECOM), Conservation International (CI), Mid-West Universities Consortium for International Activities (MUCIA) and Shell Company Ghana Ltd. Even though much more financial support is required, it cannot be overemphasized that positive attempts were made to keep KCA in undisturbed state as much as possible. Undeniably, the KCA is a remnant of the Upper Guinea Forest which used to be a strip of tropical moist forest that ran parallel to the coast from Guinea to the Cameroons (FAO/ECOWAP, 2005).

Over the last two decades, tourism has increasingly been projected as a key rationale and as an instrument for maintaining protected areas (Balmsford et al., 2009). The challenges on the prospects of KCA, for sustainable conservation of the remnant Upper Guinea Forest in this regard, is a major concern. Against a lot of odds, such as local people's unawareness of the importance of conservation, and being poorly funded, every effort is being made in the KCA to make it one of the most sustainable functional conservation zones in the country. Whether KCA has the potentials for increasing tourism drive as a means of self-funding in the long term is the main concern of this study. Therefore, it is our aim in this paper to highlight the main features of KCA that present enviable opportunity to promote tourism and increase internal-generating funds as well as appealing to donor sources, and set it apart as one of the most successful attempts at management, protection and conservation of biodiversity in a developing country. We have basically used an analytical - descriptive approach to provide information which is expected to sustain interest of the international community and provide an understanding for any call of support from any world conservation institution.

MATERIALS AND METHODS

Study area

The 210 km^2 Kakum National Park (KNP) and its twin 150 km^2 Assin Attandanso Resource Reserve (AARR) form the Kakum Conservation Area (KCA) (Figure 1). It spans the TwifoPraso, Assin and Abura districts of the Central Region of Ghana (1°30′′-1°51′′W; 5°20′′-5°40′N)′. It consists of variations of a moist evergreen forest. The KCA protects the headwaters of River Kakum (which is the source of its name) and two rivulets, Obuo and Nemini. Other

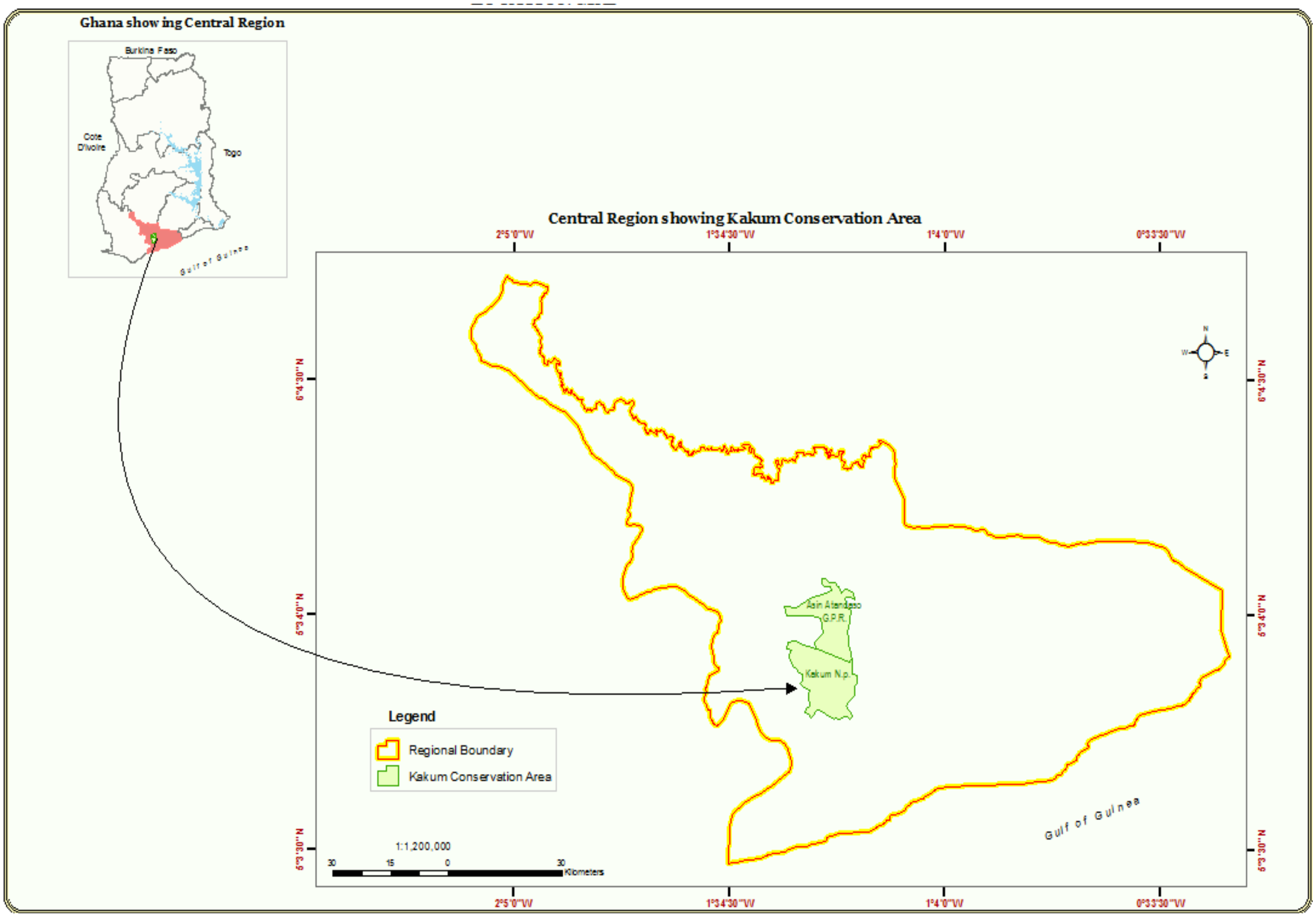

Figure 1. Location map of Kakum Conservation Area in the Central Region of Ghana.

drainage basins are formed from Nchemna which flows out to the south-east towards the sea; and Sukuma and Afia streams flowing west to the River Pra. Some other smaller streams are Ajueso to the east and Benebene and Aboabo to the north which may all dry up at the peak of the dry season in late February to early April. About a kilometer stretch of the main Cape Coast - TwifoPraso road forms part of the southern boundary of the KCA.

The average relative humidity is about 80% while the temperature ranges from19-32°C. The terrain is flat to slightly undulating with an elevation of between 150-250 m asl (Forestry Commission, 2007), mostly at the south-western portion of the Park.

Data collection

We used a thorough search method and an analytical - descriptive approach to provide information. A systematic approach was adopted in which evidence was obtained from individual indigenes through interactions and from the grey literature at the Park's headquarters and these were confirmed or otherwise by field survey.

The Area is fringed by about 50 communities and for the field survey, carried out from March 2010 to December 2012, the study area was divided into nine study sites, Abrafo, Kruwa, Briscoe II, Adiembra, Homaho, Aboabo, Afiaso, Antwikwaa and Mfuom all of which are also park posts for guards (Figure 2). The study took into consideration adequate rainy season and dry season months. Some already existing trails were followed usually from 0700-1000 and 1500-1800 GMT to sight any large mammal that may not have been reported. Also, each site was scouted over the period of study in order to locate features that have tourism potential such as sceneries which have not been reported, areas that can be developed for tourists' attraction, and to generate new ideas for boosting up tourism promotion in KCA. Particularly for a confirmation of what may be the biggest tree in Ghana, a tape and a SUUNTO height meter (Clinometer), were used to measure parameters like circumference, diameter and height of each of two big trees (Figure 3), one at KCA which our study identified and another at the Esuboni Forest Reserve (EFR), near AkimOda in the Eastern Region of Ghana), which hitherto has been dubbed the "Big Tree" and declared from time past to current as the biggest tree in the sub-region for years. Calculation of tree height was based on the formula *Tan θ = opposite side (h) ÷ adjacent side (x)* (Figure 3) and the diameter (D) based on C = ΠD where C is the uniform circumference and Π is the constant 3.14. All other statistical analyses were done by using Microsoft excel and PAST (Hammer et al., 2001).

Benefits accrued to KCA from the existing tourism drives and sustainability of such tourists' attractions and corresponding gains,

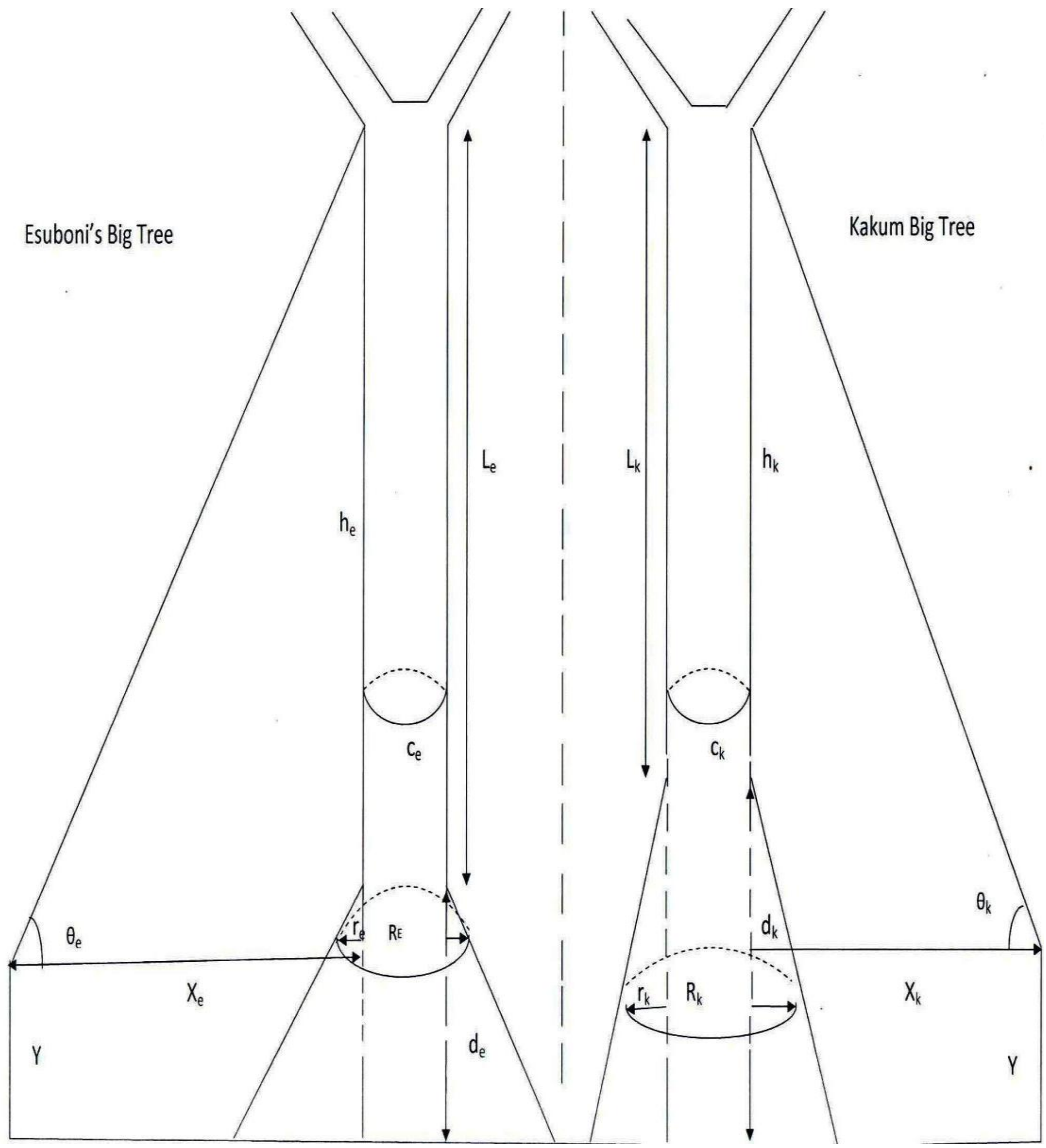

Figure 2. Measurement of height and circumference of big trees at Esuboni Forest Reserve near Akim Oda and Kakum Conservation Area near Cape Coast.

as well as trends of patronage of the various attractions were investigated by obtaining information from Management and analysis were made on available records from the Park's Headquarters. Threats to tourism drive at KCA were also investigated.

RESULTS AND DISCUSSION

The study reports some very interesting sceneries that offer potential for tourists' attraction. These include what may now be the biggest tree in Ghana, water falls, virgin forest, canopywalkway and observation platforms (Figure 2). Also included are the charismatic fauna, the jungle itself and its characteristic flora.

Tieghemella heckelii in the Esuboni Forest Reserve near AkimOda in the Eastern Region is named "The Big Tree". The impression is that, "The Big Tree" is the biggest tree in Ghana according to the Forest Services Division of the Forestry Commission; by consideration of width uniformity of the trunk between the base and the branches, the height as well as its accessibility. It means that many other trees may be bigger only at the base than "The Big Tree" or may not be high enough for the accolade; or, perhaps, bigger than the "Big Tree" by all standards but not accessible. This tree, located on the AgonaSwedru - AkimOda highway, has attracted many tourists, both local and foreign nationals to the Reserve. This study reveals a bigger tree in the KCA, about 30 km

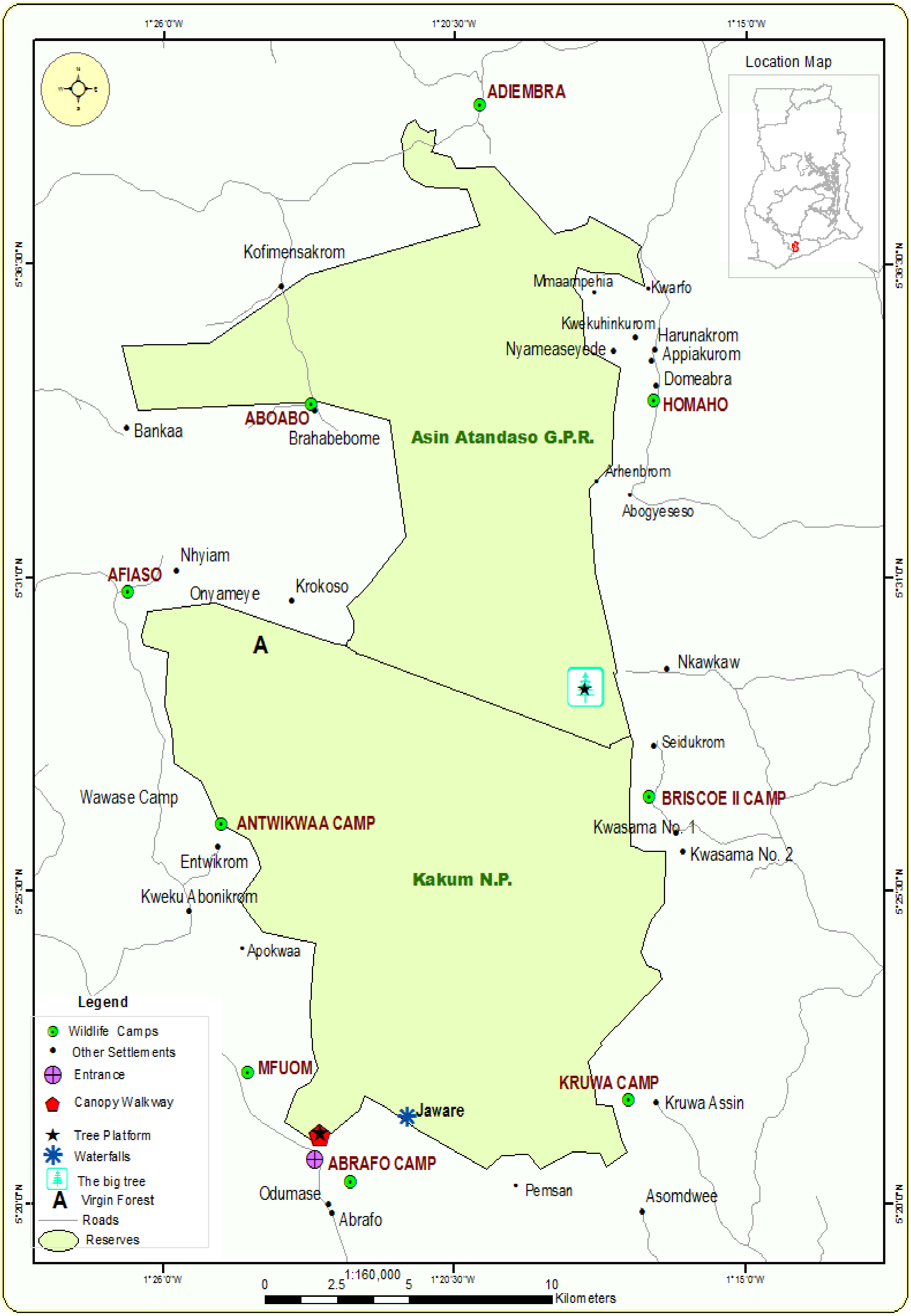

Figure 3. Location map of KCA showing landmarks and special features.

Table 1. Comparing parameters- height, circumference and diameter of two big trees.

Parameter	Kakum big tree	Esuboni big tree
Angle (s) of measurement to the point of trunk branching	59^0 , 84^0, 80^0, 58^0	50^0
Distance of measurement from tree (adjacent side, x)	x_k = 17.6 m, 3.17 m, 5.62 m, 18.4 m	x_e = 26.8 m
Height of measurement of tree (opposite side, h); average from 4 readings and 1 reading at Kakum and Esuboni Reserves respectively	17.6 m × Tan 59^0 3.17 m × Tan 84^0 5.62 m × Tan 80^0 18.4 m × Tan 58^0 = h_k = 30.211 m	26.8 m x Tan 50 ^{0} = h_e= 32.026 m
Height of reader's eye level above ground	= 1.52 m	1.52 m
Total height of tree excluding branches	30.211 m + 1.52 = **31.73 m**	32.026m + 1.52 m = **33.55 m**
Circumference at breast height, R Total distance round base-stem extensions at the breast height, Σr	R_k = 12.5 m Σr_k = 4.4 m	R_e = 11.4 m Σr_e = 4.6 m
Uniform circumference of tree, C	12.5 m - 4.4 m = **8.1 m**	11.4 - 4.6 m = **6.8 m**
Uniform diameter, D Height of tree above ground where uniform circumference begins	8.1 ÷3.14 = **2.6 m** d_k = 8.2 m	6.8 ÷ 3.14 = **2.2 m** d_e = 2.3 m
Length of Uniform circumference	L_k = 31.73 - 8.2 = **23.53 m**	L_e = 33.55 - 2.3m = **31.25 m**

from Cape Coast, which is 12.5 m wide at the base and 8.1 m wide at the trunk and thus about 1.1 m wider at the base and 1.3 m wider at the trunk than the hitherto "Big Tree" (Table 1). The two big trees measured impressive 2.6 and 2.2 m uniform diameter at KCA and Esuboni Forest Reserve (EFR), respectively (Table 1). It is only for the height that the big tree at EFR is taller, measuring 32.55 m as against 31.73 m (Table 1). At Esuboni the circumference and the diameter of the trunk become uniform for 31.25 m after only about 2.3 m height above ground which gives it a very good look (Figure 4). The sight makes it awesome. On the other hand the big tree at KCA (Figure 5) gives an impression of a beautiful huge tree at the base and its uniform circumference starts at a higher level, that is, 8.2 m from the ground for 23.63 m. Indeed both trees could qualify as "Big Trees" going by the criteria for the biggest tree in the Sub-Region but "who is who" between these two spectacular trees at EFR and KCA favours the latter. Foeline (1998), in excitement and ecstasy about the "Big Tree" at EFR near AkimOda quoted 396 cm (3.96 m) as its diameter and 90 m as its height though the newsletter did not indicate its methods of measurement. However, if one could imagine the speed of a sprinter to complete a 100 m race in about 10 s, it would be understandable as to how awesome the height of this tree only 10 m less is and with such a diameter. Though our study recorded a height of only a third of Foeline (1998) we are sure that our methodology is sound enough for an accurate estimate which height is still awesome to behold. In any case, the big tree at KCA is also *T. heckelii*and it is located at the Briscoe II area, approximately 3 km away from the nearest accessible village, i.e.Seidukrom (Figure 2). If one accesses the tree from another village, that is, Nkawkawit cuts down the walking journey to a shorter walking duration of about one hour.

It appears that the *T. heckelii* tree has the habit of growing big, high and uniformly wide along the trunk. The implication of this observation is not by way of toppling the recognition status of "The Big Tree" in the EFR and in consequence divert attraction to the newly found big tree at KCA, but to give tourists cause for comparison between the two by visiting both sites; to draw more tourists to KCA; to draw attention to the importance of

Figure 4. The big tree at Esuboni Forest Reserve, near Akim Oda.

Figure 5. The big tree at Kakum Conservation Area, near Cape Coast.

conservation viz-a-viz tree felling as many areas of the country have the opportunity for sighting big trees for sustained tourism drive in future; and to promote the autecology of *T. heckelii*. The occurrence of the big tree wherever in the country will attract tourists just the way each of the numerous waterfalls in the country have substantially good tourists' visitation.

The study also identified, at the Abrafo area, two water formations that appear like falls, and could attract tourists in their own fashionable ways but unlike any of the many popular waterfalls in Ghana. It is contended that the formation must be properly described and accorded the proper landmark formation for the necessary viewing. A proper classification may attract tourists to yield some income to Management. Perhaps local tourists will be more curious to see it as another form of spring water.

According to Management small pockets of primeval forest remain, at the KNP, as remnants of original forest being salvaged by timely adoption of the area as a National Park and continuous stewardship that has prevented further degradation of the area from various anti-conservation practices. The largest of these is what has been called "Virgin Forest" located in the Afiaso area (Figure 2). It covers a land area of 10,782.71 m^2 with a perimeter of 0.522 km according to our latest research (*in prep*). The small size of this Virgin Forest is an index of how heavy logging occurred at KCA. The spate of forest degradation that started several years ago makes primeval forests rare and amazing scenery today; albeit small as it may seem. Ecotourists especially visit places for three reasons; namely: wildlife, scenery and culture. This Virgin Forest will be attractive to many tourists if it is given proper exposure. The comfort of the micro-climate and the quest to satisfy one's curiosity about the rare Virgin Forest will make it attractive to tourists and also students and teachers.

The occurrence of about 69 species of mammals including large mammals like the *Loxodonta africana*, *Tragelaphus eurycerus*, *Hylochoerus meinertzhageni*, *Potamochoerus porcus* and some primate species (Sam, 1996) and about 234 species of birds (Dowsett-Lemaire and Dowsett, 2005) add to the attraction of KCA to both local and foreign tourists for hiking. However, the study found that the Conservation Area is not developed very well to enhance viewing of mammals and bird watching. Yet the potential for such facilities were observable. An observation platform each is located at Abrafo, Briscoe II (Figure 6) and Kruwa areas of KCA. Apart from the Kruwa's platform which needs rehabilitation, the others have been very useful for animal viewing. The Briscoe II platform was erected for viewing *L. africana* taking advantage of the proximity of the big *T. heckelii* which produces large quantities of fruits seasonally. *L. africana* in KCA have special preference to the *T. heckelii* fruit as food as we observed in another study currently in review.

The headquarters of the Area is situated in the south-western corner of the Park; about two kilometers from Abrafo-Odumase and 30 km from Cape Coast. The Area is sited about 165 km west of Accra, the national capital and therefore could be reached within a three-hour drive. Intercity transport to Cape Coast from Accra (140 km) is available from where one may hire a taxi or join public transport to the Area. From about one kilometer on the Abrafo-TwifoPraso road a 500 m branch road takes one through the main gate to the Visitor Centre. The Museum at the Centre consists of wooden African style buildings which serve as cultural attraction. Here visitors can get information about cultural and medicinal uses of the forest's vegetation. Visitors are educated about wildlife and conservation in general by paintings and posters which explain the complexity and web of life in a tropical forest. The sustainable use of wildlife, the economic and cultural connections that people have with the wild is emphasized during educational talks. An experience of the exhibits prepares the visitor for a reality of the scents, sights and sound of the forest community later. The canopy walk-way (Figure 7) is the most attractive component of KCA now and offers the only aerial walkway through the treetops in Africa. A journey along the 30 m suspended above ground canopy walk-way gives a bird's eye view and is another good opportunity for monkey-viewing and bird watching in addition to the experience and euphoria that make excitement. Three platforms on the canopy walkway serve as observation points for viewing the rainforest.

Considering the size of KCA, increase in number of viewing platform would be necessary to boost tourism and especially so by erecting one purposely for the viewing of the charismatic *T. eurycerus* and also for others like the *P. porcus* and the *H. meinertzhageni*. We propose in our latest study at KCA (*in prep*) for a research on habitat variability to be considered as it will help Management in monitoring and managing some animals well. We find that knowledge of habitat variability and habitat preferences of mammals can help identify appropriate locations for the erection of observation platforms to improve upon successes of hiking tourism in KCA, especially for those mammals that are secretive. It will also inform Management as to where access trails will be needed for the purposes of tourism and research.

Observation platforms near river bodies are expected to contribute to hiking successes in the dry season as mammals are viewed when they come to drink from the streams. Scats and spoors of most mammals are observable around river bodies. *P. porcus* is naturally distributed along rivers and streams and in marshes in the forest while *L. africana* need to drink large quantities of water and cool their bodies with water baths. However, the distribution of most mammals in the rainforest are naturally not very much influenced by water bodies even in the dry season since they obtain fresh succulent food materials throughout the year and can afford long distance locations to drink water. Moreover, while the nocturnal mammals can drink from the streams at night,

Figure 6. Observation platform at the Briscoe II area of Kakum Conservation Area near the big tree.

Figure 7. Students of University of Cape Coast enjoying the canopy walk-way at Kakum Conservation Area, near Cape Coast.

Figure 8. Some of the likely encounters and attractive scenes on your way to the big tree at Kakum conservation area.

secretive mammals like *T. eurycerus* will prefer to drink very early in the morning and all these can elude the observation of a tourist. What this means is that viewing mammals along river bodies in KCA is by chance or by determination to stay long in a hideout in the comfort of an observation platform. Hilly areas can also be developed in ways that will suit bird watching without serious disturbances to the ecosystem.

The boundary between the two reserves, KNP and AARR exists as a trail linking Briscoe II and Afiaso areas (Figure 2) and named “dividing line”. This dividing line can be constructed to make KCA motorable to facilitate deployment of staff and to commute visitors and researchers. It would be interesting for Management to establish another entrance to KCA. The Briscoe II area, occurring at one end of the dividing line, and considering the location of the big tree, seasonal visits to the area by elephants and presence of an observation platform, would be most ideal for a new entrance point to the Conservation Area. This will give tourists the opportunity to start from one end of KCA to the other and to enjoy other sceneries. Some tourists might not want to revisit the old recreational areas of KCA again but might wish to revisit the Conservation Area for new sceneries.

Our study found that the Conservation Area would be useful for field studies by pupils and students and their teachers alike. Our journey from the Briscoe II camp to the Big Tree started from a nearby settlement, Seidukrom, where we parked our vehicle and ended after a 2.67 km slow and gentle walk. After a 1 km-walk from Seidukrom we got to the boundary line and entered the Conservation Area. We covered a distance of 1.67 km between the boundary line and the Big Tree. Buttress roots, prop roots, stranglers and their dead hosts, stranglers and their living hosts, lianas, epiphytes, climbers, epiphylls, drip tips and many more field practical related to plant morphology and ecology were observable even by the path. The occurrence of a big and beautiful *Miliciaexcelsa*, with a uniform circumference from the ground, measuring 3 m is particularly refreshing to see. The lucrative tree species has been logged severely and a big one like this is rare today. One prop root formation was especially spectacular (Figure 8). Snails (Figure 8) were encountered even in the dry season and some mammalian activities were also observable.

Available records indicate very high patronage of KCA by tourists of both local and foreign nationals and these tourists mainly visit to experience a walk over canopies of trees along the canopy walk-way or for a hiking experience deep inside the Conservation Area to view fauna, forest structure or for the joy, pleasure and experience of being in a cool rare rainforest. Not much was in the records for camping visitations. In all a total of 455,886 tourists (Table 2) comprising 348,452 Ghanaians (Table 3) and 107,434 foreigners (Table 4) visited KCA for the past 5 years from 2006 to 2010. The study revealed that for the past five years Ghanaian students recorded the highest frequency of visit of 32.7% of all the visits and Ghanaian children/ pupils follow with 28%; 15.8% by Ghanaian adults; 11.3% by adult foreigners; 10.9% by adult students and 1.4% by foreign children (Figure 9). There was no significant difference among the age categories of visitors ($H=5.82$, $p=0.548$) and thus all of the age categories should be given equal target status to market the Conservation Area for improved tourism. The canopy walk-way attracted far more tourists than hiking. The number of visitors to the site in all the months differed from one year to another (Kruskal-Wallis: $Hs=43.81$, $p<0.0001$) but the trend showed visitations were encouraging throughout the year and progressive over the 5 year period studied, barring few anomalies (Figure 10), and that seem to suggest high expectations in 2011 and subsequent years. The two peaks realized in March/April and December (Table 2) which coincide with Easter and Christmas festivities and troughs in May and

Table 2. Monthly visitations to KCA recorded over the last 5 years.

Month	Year					Total
	2006	2007	2008	2009	2010	
January	2407	4207	4303	7790	7164	25871
February	3285	4283	3987	8543	10572	30670
March	6804	5533	7422	16252	10697	46708
April	8493	3110	8668	12652	15220	48143
May	6346	5639	9173	11351	3108	35617
June	6982	7500	6527	8054	7351	36414
July	4510	9520	14458	16154	10055	54697
August	4019	6506	13888	12750	8589	45752
September	4957	3031	5403	7076	5958	26425
October	2607	4823	5331	8328	3235	24324
November	3385	3695	9239	11191	4498	32008
December	10039	8091	8463	14356	8308	49257
Total	63834	65938	96862	134497	94755	**455886**

Table 3. Number of tourists (Ghanaians) that visited KCA for the past 5 years.

Year	Total visitation	Adult			Student			Children/Pupil		
		Canopy walk	Hiking	Subtotal	Canopy walk	Hiking	Subtotal	canopy walk	Hiking	Subtotal
2006	45150	11241	59	11300	14221	3160	17381	15688	781	16469
2007	46068	10503	58	10561	15999	746	16745	17959	803	18762
2008	73196	15940	223	16163	24325	625	24950	30807	1276	32083
2009	107035	22973	176	23149	38996	375	39371	43670	845	44515
2010	77003	10495	259	10754	49522	989	50511	15523	215	15738
Total	**348452**	71152	775	71927	143063	5895	148958	123647	3920	127567

Table 4. Number of tourists (foreign nationals) that visited KCA for the past 5 years.

Year	Total visitation	Adult			Student			Children/Pupil		
		Canopy walk	Hiking	Subtotal	Canopy walk	Hiking	Subtotal	Canopy walk	Hiking	Subtotal
2006	18684	8985	338	9323	7863	163	8026	1326	9	1335
2007	19870	9168	173	9341	9111	306	9417	1066	46	1112
2008	23666	10544	533	11077	10167	571	10738	1581	270	1851
2009	27462	13523	624	14147	11135	602	11737	1528	50	1578
2010	17752	7187	446	7633	8854	753	9607	512	0	512
Total	**107,434**	49,407	2,114	51,521	47,130	2,395	49,525	6,013	375	6,388

January (Table 2) that follow the festive months respectively probably portray the effect of the two festivals on recreation and tourism trends in Ghana. These are the two major festivals in Ghana for ages and they present Ghana good holidays that are ideal for well planned activities including tours to various sceneries and celebrations in ways at various places including tourists' sites that largely contrast the essence of the festivals. People can afford to spend during Easter and Christmas and often entertainment and recreational centres take advantage of this and advertise their centres in this regard. We are hopeful that Management can increase revenue respectably during annual Easter and Christmas festivities and other national holidays with effective marketing strategies.

The study observed also that visitation to KCA is

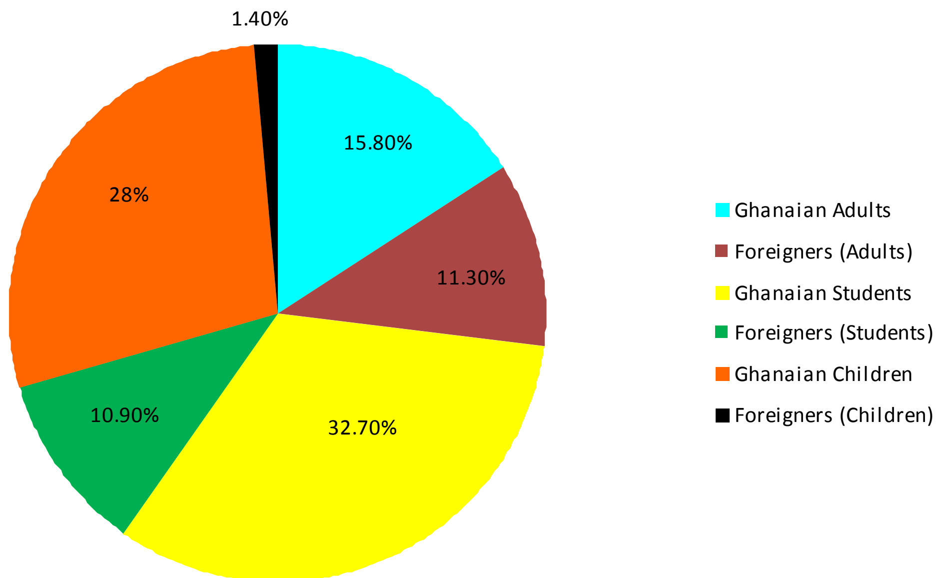

Figure 9. Categories of tourists and their visitations to KCA for the past 5 years.

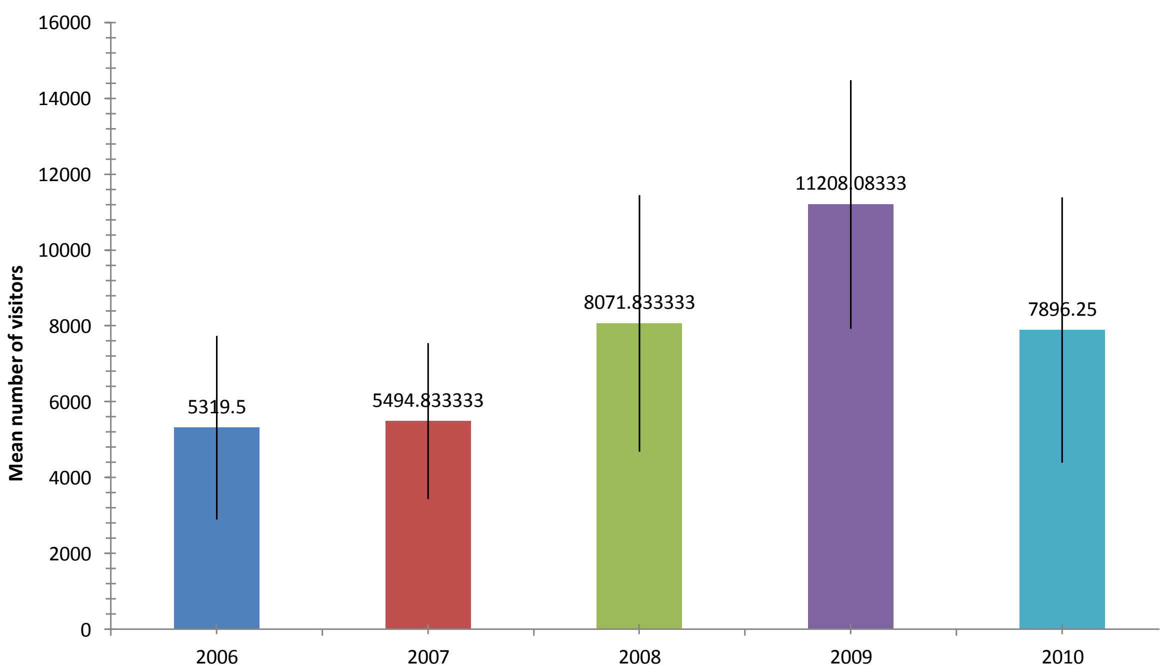

Figure 10. Mean number of visitors per each year from 2006 to 2010 with error bars showing standard deviations.

somehow reduced during the rainy seasons in May-June and September-October. Exception to this in 2006 is due to a shift in the weather pattern in Ghana, which has been erratic in some years; but the figures recorded during the rainy season still point to high attendance that defies the rains somehow.

A positive correlation emerged (*r=0.7, p=0.188; y = -13547x + 60000,* $R^2 = 0.849$) to indicate that the higher the number of visitors the higher the revenue. Revenue has been progressive over the five years studied (Figure 11) and this makes expectation for higher revenue in 2011 and subsequent years plausible and lends itself to credible forecast into the future for high revenues in the face of new attractive tourists' sites that have been unraveled by this study and Management cannot afford to disregard the recommendations and suggestions by this

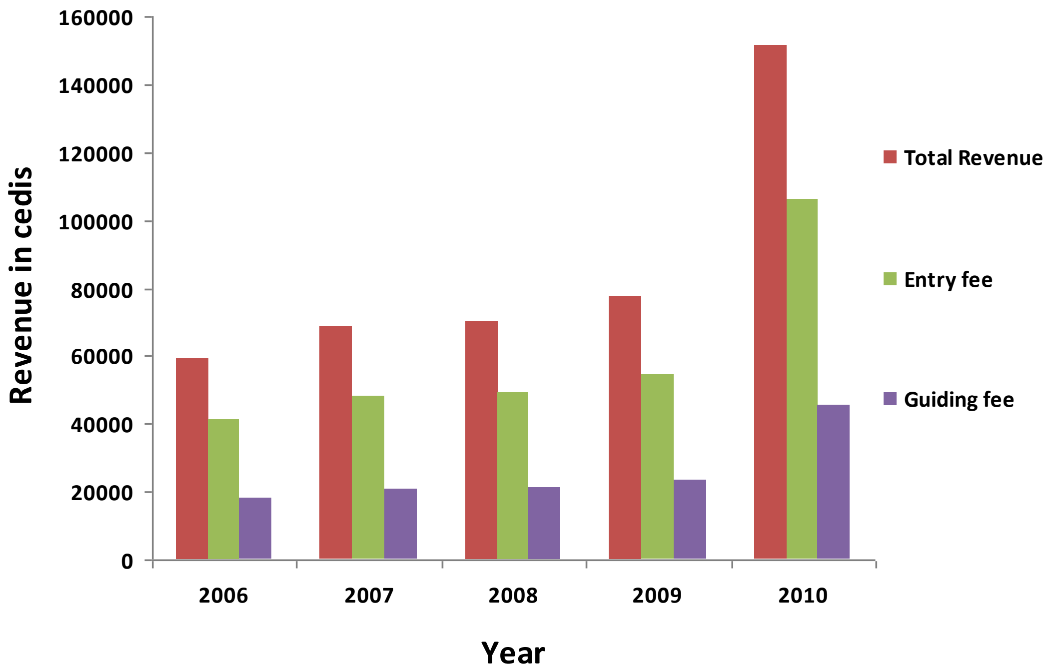

Figure 11. Yearly revenue from tourism at KCA for the past five years.

study. However, one wonders if all these infrastructure lined up by this study can be afforded without external aids considering their total capital requirement in relation to the total annual revenue obtainable from KCA as internal generating fund.How else will threats to tourism in KCA be addressed without funds.Human-wildlife conflicts, especially those from elephant raids (Monney et al., 2010) and poaching remain the major threats to tourism development at KCA. Occasional gunshots heard in the Conservation Area pose risks to visitors.

CONCLUSIONS AND RECOMMENDATIONS

In the light of the above, KCA has the potential to promote ecotourism that in the long term can ensure self-funding for sustainable conservation. However, for rapid results, this may require some initial investment to supplement internal-generating funds for some infrastructural development; and this is an appeal to the donor world. We recommend that a more serious effort to market KCA should be considered targeting both workers and students; and adults and children. All suggestions made earlier should also be considered. Management is entreated to find lasting solution to the major threats to tourism development at KCA identified by this study.

Conflict of interests

The author(s) have not declared any conflict of interests.

ACKNOWLEDGMENT

We are grateful to Management and staff of the Kakum Conservation Area for permitting us to carry out this research and the assistance given to us, particularly by Mr Annan-Riverson and Mr Tackie. We are also grateful to the Department of Entomology and Wildlife of the University of Cape Coast for supporting us with transport and our students, Miss Rose Macku-Sackey, Mr Samuel Kusi Ampofo and Mr Kwaku Frimpong for their invaluable assistance.

REFERENCES

Balmsford A, Beresford J, Green J, Naidoo R, Walpole M, Manica A (2009). A global perspective on trends in nature based tourism. Plos Biol. 7:1-6.

Cullen R, White PCL (2013). Prioritising and evaluating biodiversity projects. Wildl. Res. 40:91-93.

Dowsett-Lemaire F, Dowsett RJ(2005). Ornithological surveys in Kakum National Park. WDSP report No. 50-s. Unpublished.

FAO/ECOWAP (2005). Forest Policy developed in the Framework of ECOWAS common Agricultural Policy.

Gadgil M (1992). Conserving Biodiversity as if people matter: A case study from India. Ambio 21:266-270.

Hammer Ø, Harper DAT, Ryan PD (2001). PAST: Paleontological Statistics SoftwarePackage for Education and Data Analysis, Version 2.13.

Jachmann H (2008). Illegal wildlife use and protected area management in Ghana. Biol. Conserv. 141:1906-1918.

Jachmann H, Blanc J, Nateg C, Balangtaa C, Debrah E, Damma F, Atta-Kusi E, Kipo A (2011). Protected area performance and tourism in Ghana. South Afr. J. Wildl. Res. 41:95-109. http://dx.doi.org/10.3957/056.041.0112.

Jones-Walters L, Čivić K (2013). European protected areas: past,

present and future. J. Nat. Conserv. 21:122-124. http://dx.doi.org/10.1016/j.jnc.2012.11.006.
Manu CK (1984). Wildlife Conservation.The Mirror, Ghana: August 11, 1984, p.11.
McKinnon G, Thorsell J (1986). Managing Protected Areas in the tropics. Gland, Switzerland:IUCN
Monney KA, Dakwa KB, Wiafe ED (2010). Assessment of crop raiding situation by elephants (Loxodontaafricanacyclotis) in farms around Kakum Conservation Area, Ghana. Int. J. Biodivers. Conserv. 2:243-249.
Pimbert MP, Pretty JN (1997). Parks, people and professionals: putting 'participation' Protected-area management. In: Ghimire K and Pimbert MP (eds), Social Change and Conservation. EarthscanPublication limited, UK, pp.297-330.
Sam MK (1996). Zoological survey of Kakum National Park. Facing the storm: Five years of research in and around Kakum National Park. Washington D.C. 8-14.
Smith RJ, Walpole MJ (2005). Should conservationists pay more attention to corruption? Oryx 39: 251-256. http://dx.doi.org/10.1017/S0030605305000608.
UNEP (1992). Convention on Biological Diversity. Available from: http://www.biodiv.org/convention/articles.asp.

academicJournals

Vol. 6(5), pp. 154-163, May 2014
DOI: 10.5897/JENE2014.0438
Article Number: DF9C3F143792
ISSN 2006-9847

http://www.academicjournals.org/JENE

Journal of Ecology and the Natural Environment

Full Length Research Paper

Recent limnological changes and their implication on fisheries in Lake Baringo, Kenya

Omondi, R[1]*, Kembenya, E.[2], Nyamweya, C.[1], .Ouma, H[3]., Machua, S.K.[4] and Ogari, Z.[1]

[1]Kenya Marine and Fisheries Research Institute, P. O. Box 1881, Kisumu, Kenya.
[2]Kenya Marine and Fisheries Research Institute, P. O. Box 3259, Kisii, Kenya.
[3]Department of Zoology, Maseno University, P. O. Box 333, Maseno, Kenya.
[4]State Department of Fisheries, P. O. Box 48, Kampi Ya Samaki, Kenya.

Received 10 January, 2014; Accepted 31 March, 2014

Water samples for physico-chemical analysis for this study were collected monthly for five years between April 2008 and March 2013. Conductivity, temperature, dissolved oxygen and pH was measured *in situ* using a Surveyor II model hydrolab. Chlorophyll-*a* concentration was determined using a Genesys 10S Vis spectrophotomer. Nutrients were determined using standard methods and procedures. Analysis of Variance (ANOVA) was used to determine spatial and temporal variation in physico-chemical and biological factors. Principal components analysis (PCA) was performed to establish the correlation of the physico-chemical and biological parameters among sampling stations and to group stations with similar physico-chemical parameters. Both spatial and temporal significant variations ($P < 0.05$) were detected in the concentrations of the nutrients measured during the study.

Key words: Limnological changes, parameters, Lake Baringo, Kenya.

INTRODUCTION

Lakes are said to be ephemeral features of the land-scape. They show remarkable variability with time in their morphometry, physical, chemical and biological factors. Such variations are mainly induced by climatic changes and anthropogenic activities in the catchment area. In the last half of the 20th century there have been remarkable variations in climatic patterns, which have impacted negatively on the lake ecosystems (Ngaira, 2006). Such effects include frequent fluctuation in water levels, increased salinity and turbidity, among others. In the tropics, rainfall remains the major weather factor affecting the aquatic ecosystems in arid and semi-arid areas such as that of Lake Baringo. Lake Baringo in Kenya (East Africa) is a RAMSAR site, famous for its high bird diversity, hippopotamus and crocodile populations. The lake once supported a substantial fishery, and it also represents a precious source of fresh water in a semi arid area (Hakan et al., 2003). The lake has changed fundamentally in recent years; its ecosystem has become degraded and the fishery has dwindled. The deterioration is thought to be related to irrigation agriculture that reduces water inflow, and to excessive grazing by livestock in the lake catchment, which has led to increased erosion of soils (Bryan, 1994).

Lake Baringo is a highly variable system, governed primarily by changes in lake levels. These changes are

*Corresponding author. E-mail: reubenomondi@yahoo.com. Tel: +254 733 817711.

well correlated with changes in water quality, lake vegetation, and in the composition of plankton community (Hakan et al., 2003). The lake is characterized by high turbidity caused by erosion of fine volcanic soils in the catchment. The sediment consists of fine silt and clay, which settle slowly and is easily re-suspended by wave action (Anon, 2003). The suspended solids influence the Secchi depth, euphotic zone and light attenuation coefficient. Turbidity indirectly affects the level of dissolved oxygen by limiting photosynthesis by reducing light penetration in water (Omondi et al., 2011).

Physical chemical properties of any water body play a significant role in various aspects of hydrobiology. The interactions of physico-chemical properties of water have a significant role in the composition, distribution and abundance of aquatic organisms. It gives an insight into the relationship between organisms and their environment. Both physico-chemical properties and aquatic organisms are therefore used to determine the water quality and the structural composition of aquatic community (Sidneit et al., 1992). However these characteristics can be altered by anthropogenic activities in the lake as well as natural dynamics. The changes in physico-chemical properties affect water quality and quantity, species distribution and diversity, production capacity and causes ecological imbalance (Sidneit et al., 1992).

MATERIALS AND METHODS

Study area

Lake Baringo is a freshwater lake in the eastern arm of the Great Rift Valley in Kenya (Figure 1). It is located between latitude 0˚30' N and 0˚45' N and longitude 36° 00' E and 36° 10' E and lies approximately 60 Km north of the equator at an altitude of 975 m above sea level (Kallqvist, 1987). The lake has a surface area of approximately 130 Km^2 and a catchment of 6,820 Km^2. It has a mean depth of 3 m with the deepest point being about 7 m at high water levels.

Lake Baringo waters remain fresh despite lack of surface outlet, shallow depth and high net evaporation that characterizes the rift floor. Recent hydrogeological evidence confirms the original assumption (Beadle, 1932) that some lake water is lost by underground seepage through the fractured lake floor (Onyando et al., 2005). Dunkley et al. (1993) estimated that this outflow could exceed 108 m^3 year $^{-1}$. Lake Baringo has five islands, the biggest being the volcanic Kokwa. The island is a remnant of a small volcano that belongs petrogenetically to the Korosi volcano. This erupted during the Middle Pleistocene, approximately 2.6 million years ago (Cl'ement et al., 2003).

This area is characterized by dry and wet seasonality with unpredictable timing. The dry season usually starts from September to February while wet season occurs between March and August. Rainfall ranges from about 600 mm on the east and south of the lake to 1500 mm on the western escarpment of the Rift Valley. Lake Baringo experiences very high annual evaporation rates of 1650-2300 mm (Odada et al., 2006) and its survival depends on the inflows from rivers originating from the hilly basin where rainfall varies from 1100 to 2700 mm. The lake is fed by several seasonal rivers including Ol Arabel, Mukutan, Endao and Chemeron while Molo and Perkerra are perennial.

Global positioning system (GPS) navigational unit (Garmin II model) was used to locate the sampling stations. The stations S2, C2 and N2 lies on the South-North transect (Figure 1). Station S2 has the influence of rivers Molo and Perkerra. Station C2 is at the centre of the lake, while N2 lies in the north.

Sampling protocol

Samples were collected monthly for five years from April 2008 to March 2013. Depth was determined using a marked rope weighted at one end while a 20 cm diameter black and white Secchi disc was used to determine transparency. Turbidity was measured *in situ* using a HACH 2100P turbidimeter. 500 ml lake water samples for nutrients and chlorophyll *a* analyses were collected using a four litre Van Dorn sampler. These were kept in a cool box at 4°C and transported to the laboratory. In the laboratory, samples were filtered into 250 ml glass flasks using 0.45 μm pore size filter papers to remove phytoplankton before analysis.

Conductivity, temperature, dissolved oxygen and pH was measured *in situ* using a Surveyor II model hydrolab. The concentrations of ammonium nitrogen (NH_4-N) was analysed using the indophenol method while soluble reactive phosphorus (PO_4-P) was analysed using the ascorbic acid method. Nitrates nitrogen (NO_3-N) was determined by first reducing the nitrate-nitrogen to nitrite-nitrogen by passing the water sample through cadmium reduction column before adopting the sulfanilamide method to determine the nitrite-nitrogen concentrations. Silicate (SiO4) was determined by using the heteropoly blue method while Chlorophyll-*a* concentration was determined using a Genesys 10SVis spectrophotomer using acetone method (APHA, 2000).

Data analyses

Statistical computing language and environment R 2.15.0 (R Development Core Team, 2012) package was employed in data analyses and The R package ggplot2 (Wickham, 2009) was used for graphics. Analysis of Variance (ANOVA) was used in determining significant differences between spatial and temporal variation in physico-chemical and biological factors. Values with α < 0.05 were considered significant. In cases where there were significant differences, Tukey's Multiple Range Test was used to separate the means. Principal Components Analysis (PCA) was performed to establish the correlation among the physico-chemical and biological parameters among sampling stations. Principal Components Analysis (PCA) was performed using PAST programme (Hammer et al., 2001) to establish the correlation of the physico-chemical and biological parameters among sampling stations and to group stations with similar physico-chemical parameters.

RESULTS

The mean (± SE) spatial values of physico-chemical factors measured during the study are shown in Table 1. The mean depth of the lake was 5.7 ± 0.30 m. Spatial values ranged from 5.2 to 6.2 m at S2 and N2, respectively. The depth increased from south to north of the lake. There were significant differences in depth among stations (F = 14.18, P < 0.05). Temporally the depth of the lake ranged from 2.95 in December 2009 to 9.55 m in September 2012 (Figure 2). There were significant differences in mean lake depth among months (F =350.22, P < 0.05). The spatial mean Secchi depth for

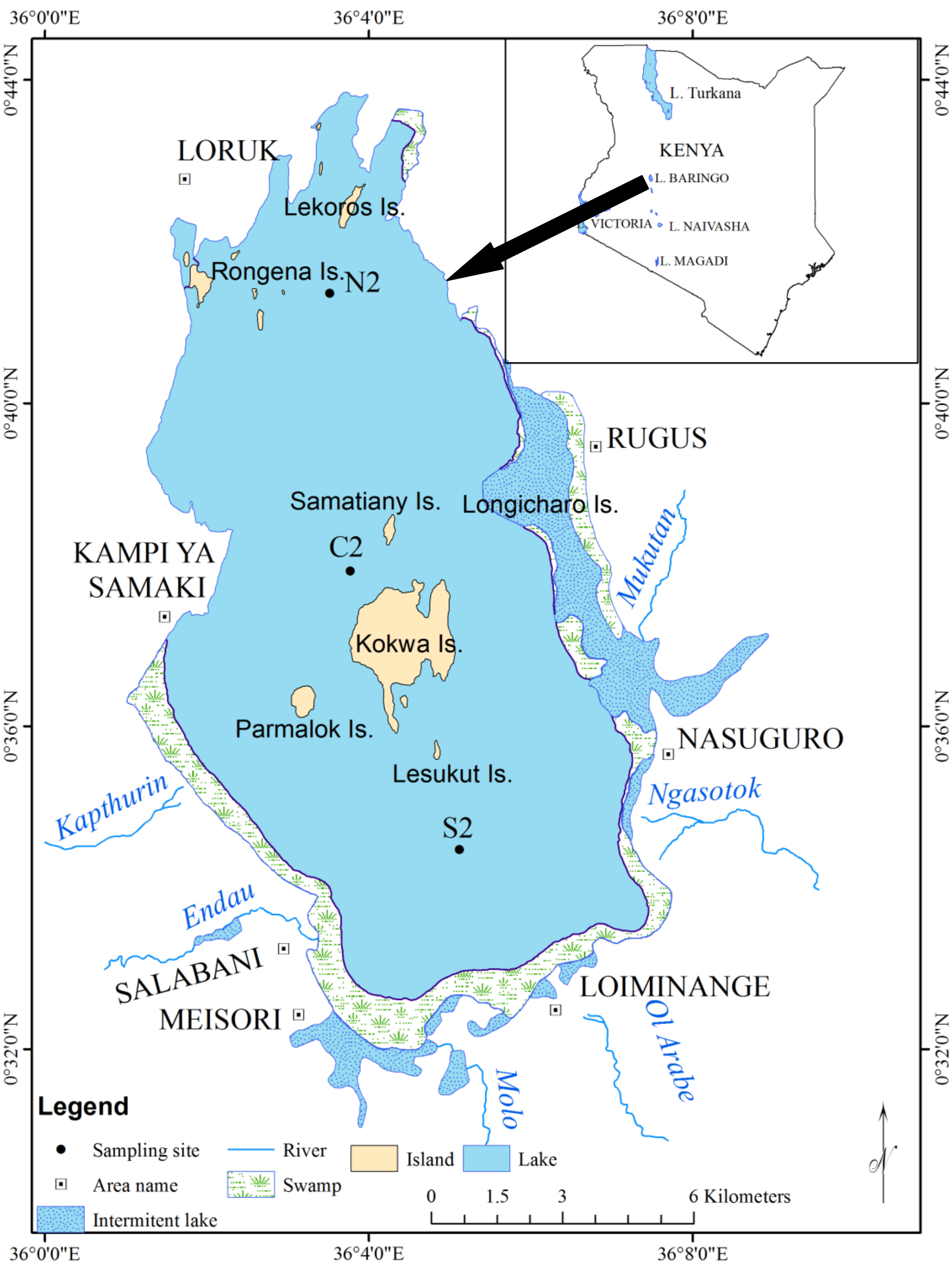

Figure 1. A map of Lake Baringo showing the stations, S2, C2, and N2, sampled during the study from April 2008 to March 2013.

the lake was 34.6 ± 1.4 cm. Values ranged from 32.0 to 36.8 cm at S2 and N2, respectively (Table 1). The mean spatial Secchi depths were not significantly different among stations ($F = 1.82$, $P > 0.05$).

Water transparency increased from south to north. Temporally, Secchi depth values ranged from 7 cm in March, 2010 to 146 cm in December, 2012. It was noted that the lowest Secchi depth coincided with the rainy season whereas the highest coincided with the dry season. There were significant variations in mean Secchi depth between months ($F = 45.91$, $P < 0.05$).

Turbidity of the lake ranged from 68.51 to 80.24 NTU at

Table 1. Mean (± SE) physico-chemical parameters and Chlorophyll *a* recorded at the sampling stations between April 2008 and March 2013.

Parameter	Station		
	C2	**N2**	**S2**
Alkalinity	199.93 ± 2.66	196.95 ± 3.10	199.20 ± 2.73
Chl a	12.27 ± 0.52	10.91 ± 0.51	13.84 ± 0.86
Conductivity	577.76 ± 9.47	581.97 ± 9.37	573.36 ± 10.02
Depth	5.98 ± 0.12	6.35 ± 0.12	5.31 ± 0.13
DO	6.73 ± 0.09	6.55 ± 0.08	5.93 ± 0.08
Hardness	68.86 ± 1.24	70.90 ± 3.51	69.33 ± 1.21
NH4	50.28 ± 2.44	47.57 ± 2.43	53.13 ± 4.88
pH	8.59 ± 0.42	8.51 ± 0.44	8.56 ± 0.42
Secchi	38.14 ± 1.90	40.24 ± 2.03	35.05 ± 1.87
Silicates	24.91 ± 0.37	25.58 ± 0.36	24.59 ± 0.36
SRP	32.99 ± 4.39	30.60 ± 4.27	39.23 ± 4.78
Temperature	26.68 ± 0.12	26.20 ± 0.13	24.84 ± 0.11
Turbidity	73.88 ± 3.89	68.58 ± 3.48	80.26 ± 4.26
Nitrates	8.13 ± 0.80	7.02 ± 0.72	11.29 ± 0.66
TDS	207.58 ± 3.8	215.78 ± 4.02	216.70 ± 4.34
Nitrites	3.60 ± 1.11	2.38 ± 0.66	5.30 ± 2.11
TP	104.32 ± 31.75	76.52 ± 20.57	99.56 ± 25.09
TN	1198.9 ± 219.88	1072.71 ± 220.9	1219.3 ± 191.15
TSS	12.44 ± 2.38	10.67 ± 1.89	13.78 ± 2.17

N2 and S2, respectively with a mean spatial turbidity of 74.24 ± 2.25 (Table 1). There were significant differences among stations (F= 2.26, $P > 0.05$). Tukey's Multiple Range test indicated significant differences in stations S2, C2 and N2. Turbidity decreased from south to north in the lake. The temporal turbidity ranged from 4.67 NTU in December, 2012 to 258 NTU in May, 2010. There were significant temporal differences (F = 7097.13, $P < 0.05$). The lowest turbidity coincided with the rainy season whereas the highest occurred in dry season. Spatial water temperatures ranged from 24.9°C at S2 to 26.2°C at N2 with a mean temperature of 25.9 ± 0.77°C. There was significant difference in the mean temperature between stations (F = 62.75, $P < 0.05$). Temporally temperature ranged from 22.1°C in May, 2010 to 31.8°C in August, 2008. There was significant difference in the mean temperature between months (F = 160.26, $P < 0.05$).

Dissolved oxygen concentration in the lake ranged between 5.89 mg l^{-1} and 6.7 mg L^{-1} at stations S2 and C2, respectively (Table 2) with a mean of 6.40 ± 0.05 mg L^{-1}. There was significant difference between the sampling stations (F = 25.79, $P < 0.05$). Further analysis showed that there were only significant difference in mean dissolved oxygen concentration in two pair of stations S2 and C2 ($P < 0.05$) and S2 and N2 ($P < 0.05$). Temporally, dissolved oxygen concentration ranged from 3 mg l^{-1} in February 2010 to 8.8 mg l^{-1} in March 2010. There were significant differences in the mean dissolved oxygen concentrations between the sampling months. (F = 81.03, $P < 0.05$). Spatially pH ranged from 7.2 at station N2 to 9.9 at station S2 while temporally this varied from 7.18 to 9.93 in September 2009 and March 2010, respectively. There was no significant difference between the sampling stations (F = 1.59, $P = 0.205$). Temporally there was no significant difference observed between the months (F = 0.86, $P > 0.05$).

Electrical conductivity values during the study fluctuated between 573.36 µScm^{-1} at S2 and 581.97 µScm^{-1} at N2, with a mean of 577.69 ± 5.55 µScm^{-1}. There was a decreasing trend in conductivity values from south to north. There was a significant difference in mean conductivity between sampling stations (F = 0.20, $P < 0.05$). Temporally conductivity values ranged from 486 µScm^{-1} to 867 µScm^{-1} in December, 2009 and April 2010, respectively. Significant difference was recorded in the mean conductivity between sampling months (F = 8420.59, $P < 0.05$). Both spatial and temporal significant variations were detected in the concentrations of the nutrients measured during the study (Figure 3). Between stations the highest concentrations of all the nutrients, except silicates, were realized at S2 with a decreasing trend from south to north. Ammonium concentrations fluctuated between 15.1 and 134.1 µg L^{-1}, nitrates between 2.1 and 15.3 µg L^{-1}, SRP from 4.5 to 73.4 µg L^{-1} and silicates from 22.4 to 33.6 mg l^{-1}.

Spatially, the amount of Chlorophyll *a* ranged from 11.91 at N2 to 13.8 4 µg L^{-1} at S2 with a mean of 12.4 ±

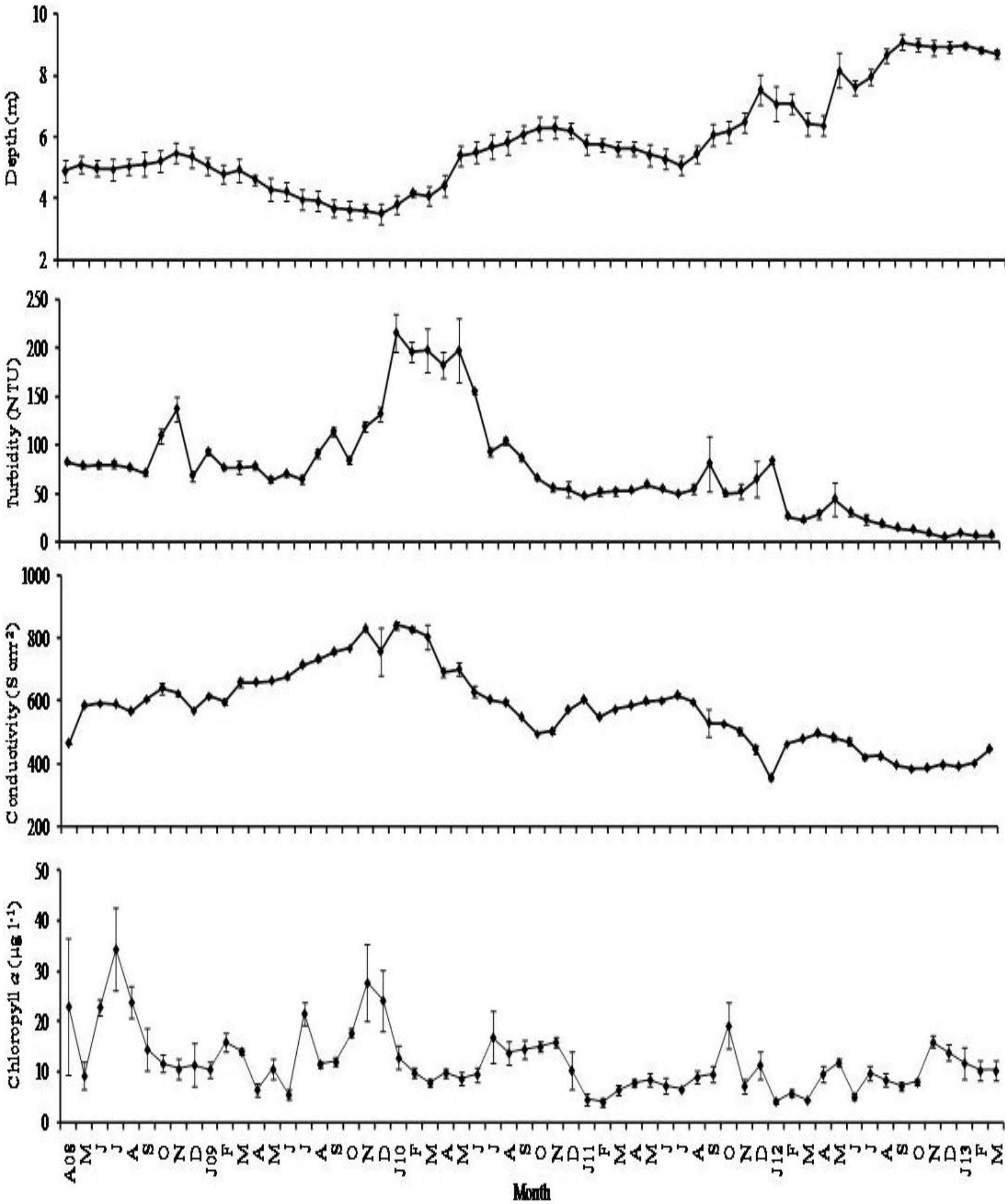

Figure 2. Monthly mean (± SE) of depth, turbidity, conductivity and chlorophyll *a* recorded at the sampling stations between April 2008 and March 2013.

0.8 µgL^{-1}. There was a significant difference in the mean Chlorophyll *a* concentration between stations (F = 4.79, *P* < 0.05). Temporally, Chlorophyll *a* concentration ranged from 2.6 µg L^{-1} in February, 2011 to 51 µg l^{-1} in July 2010

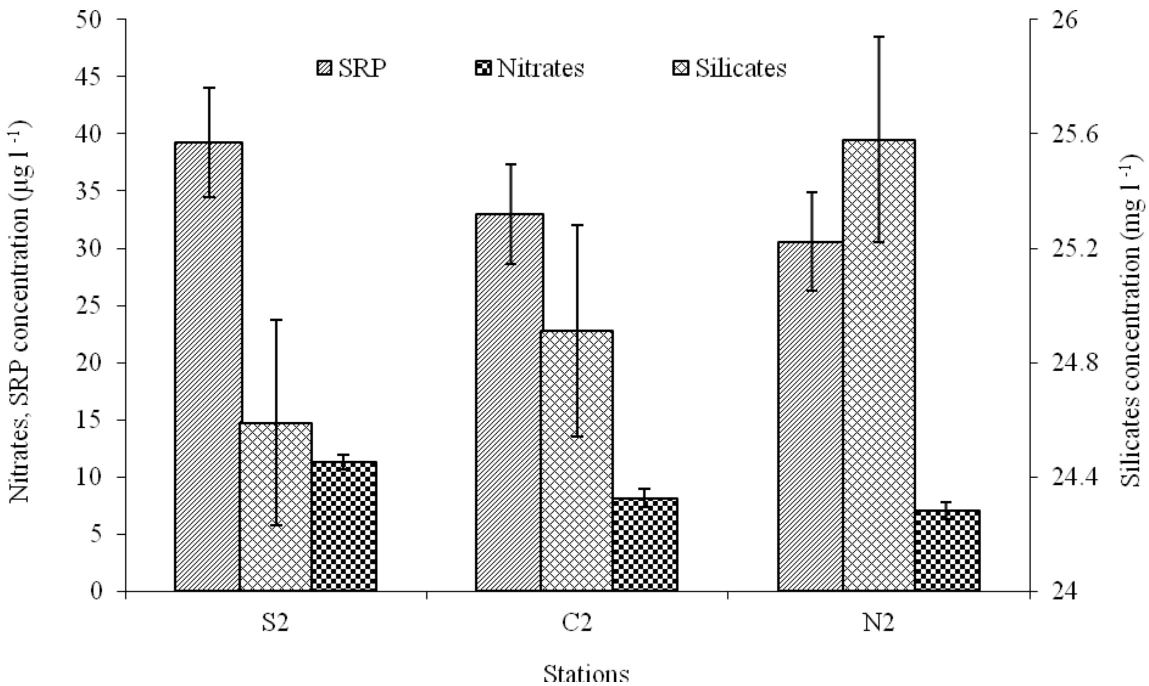

Figure 3. Spatial mean (± SE) of silicates, nitrates and SRP values recorded at the sampling stations between April 2008 and March 2013.

(Figure 2). There was also a significant difference in the mean Chlorophyll *a* concentration between the sampling months (F = 665.43, $P < 0.05$).

The PCA showed that the important environmental factors in the characterization of Station S2 are turbidity, nitrates, SRP, ammonium and Chlorophyll *a*. Sampling station C2 was characterized by alkalinity, dissolved oxygen and temperature while N2 was characterized by conductivity, hardness and silicates (Figure 4).

Euclidean clustering of the sampling stations based on the physico-chemical parameters showed that station S2 was separated from the other two stations (Figure 5).

DISCUSSION

The small difference in environmental variables across the sampling stations in the lake can be attributed to its small size and shallowness and also to the daily mixing of the lake water by wind action. Similar results have been reported for other lakes in the region (Burgis, 1971). Difficulty in establishing large-scale spatial heterogeneity in tropical lakes has also been attributed to their small size and shallowness (Sarma et al., 2005). The general variation of physical and chemical parameters observed in the south-north transect in this study was due to the effect of the affluent rivers and streams.

In this study, the depth of Lake Baringo was variable spatially and temporally. The temporal variations were more pronounced with the highest depth coinciding with the rainfall season and the lowest with the dry season. Reduced depth may have been due to reduced rainfall, high evaporation rate, water abstraction from incoming rivers and the lake. On the other hand, high water levels were associated with high rainfall, increased inflows and reduced evaporation. This is attributed to flash floods, which are common in arid areas due to lack of vegetation cover. These observations have also been reported by other authors. For example, Gregory (1921) and Worthington and Riccardo (1936) reported that water level of the lake fluctuates with time and responds to alternating wet and dry periods (Kallquist, 1987; Aloo, 2002). The high water temperatures recorded in the study were mainly due to the high intensity of solar radiation in the area with air temperatures ranging between 35 to 39°C (Ngaira, 2006). The high concentration of suspended solids also enhances absorption of solar energy (Wetzel, 2001). Patterson and Kiplagat (1995) attributed the high temperatures in Lake Baringo with ranges of 21.2 to 33.3°C to dissolved and suspended materials. The significant variation in temperatures at different stations was due to the different times of sampling with stations sampled early in the morning recording lower temperatures than those sampled later in the day. Temporal variations of water temperatures were due to changes in seasons and water levels of the lake. Reduced depth due to decreased rainfall and increased evaporation led to high water temperatures.

Siltation from the deposition of allochthonous materials carried by River Molo and River Perkerra to the south and Mukutan stream to the west probably account for the

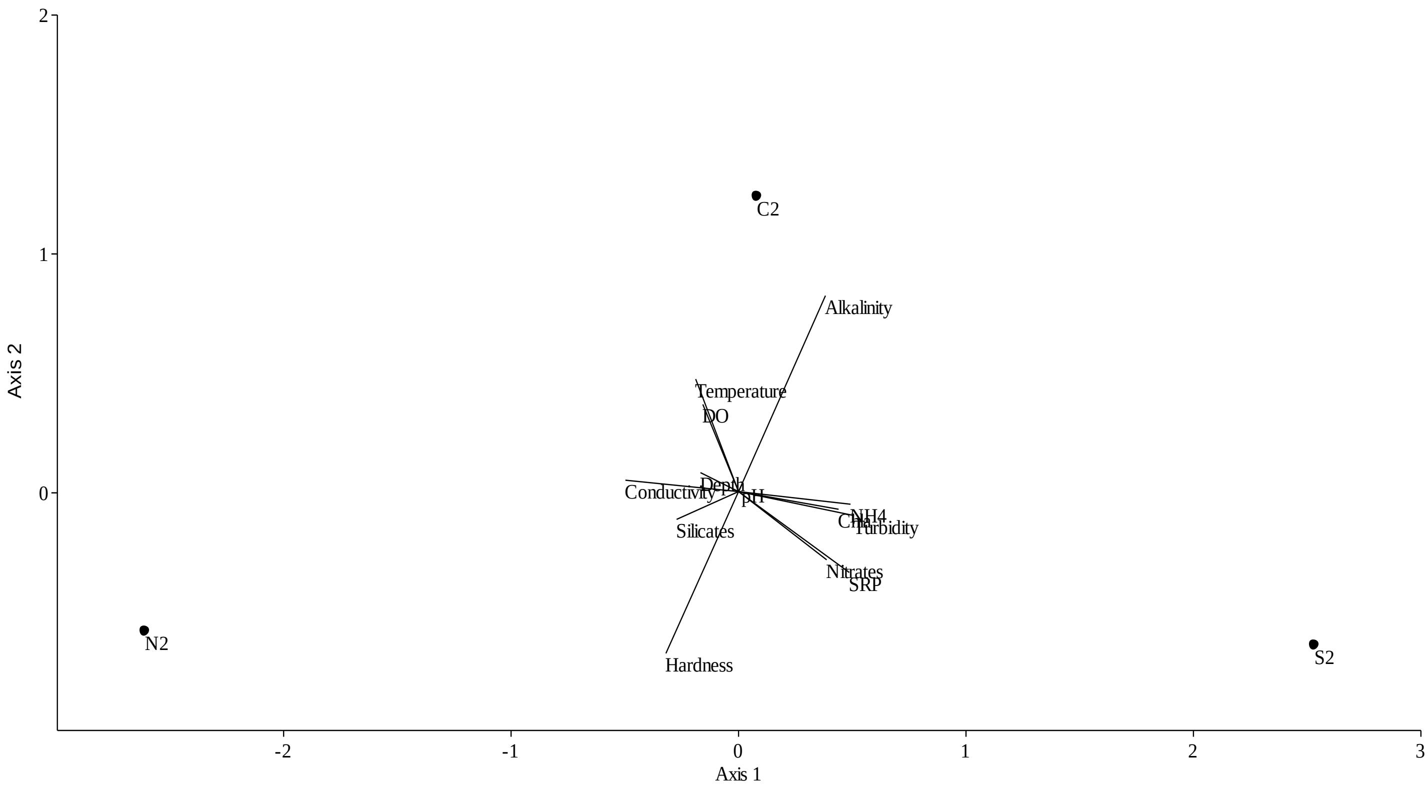

Figure 4. Principal component analyses (PCA) for sampling stations (dots) and environmental variables (arrows) in Lake Baringo between April 2008 and March 2013.

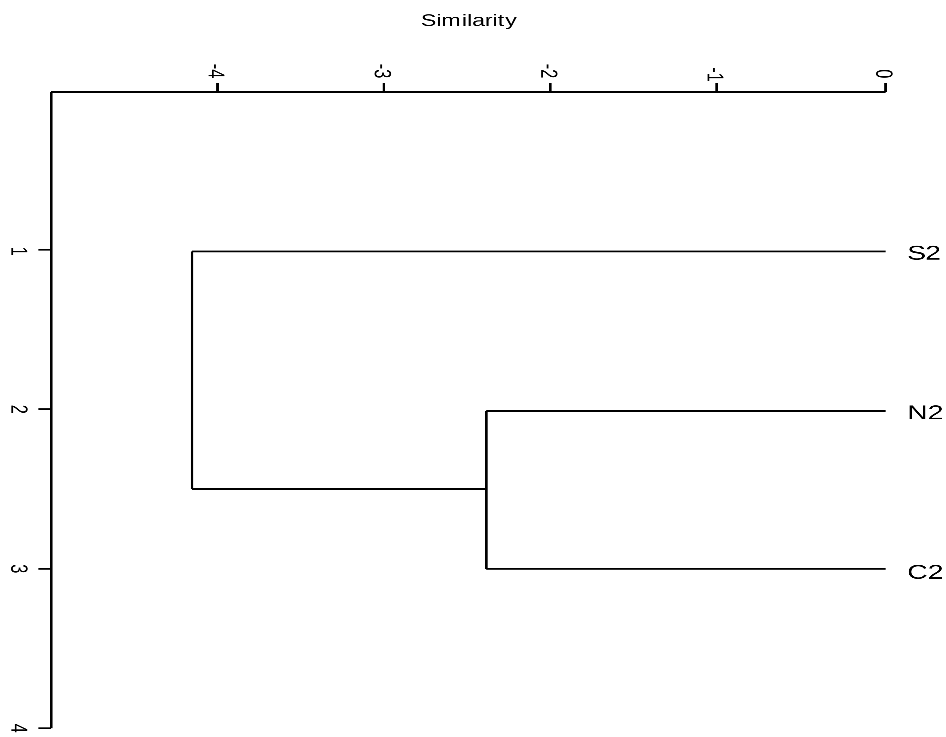

Figure 5. Dendogram clustering (Agglomerative) of sampling stations according to physico-chemical parameters in Lake Baringo between April 2008 and March 2013.

low lake depths recorded in these areas. Furthermore, established macrophytic communities in the two zones contribute to accumulation of silt by acting as traps for the incoming materials. The type of local geology, topography and meteorology (Onyando et al., 2005) coupled with anthropological activities, especially overgrazing and deforestation expose the Lake Baringo catchment to high erosion. The resulting sediments and suspended solids in turn influence the lake's depth and substratum. The muddy substratum in south of the lake is not suitable for benthopelagic pota- modromous *Labeo cylindricus* that prefers rocky habitats (Nyamweya et al., 2012). This explains the absence of the species in such areas that are dominated by *Protopterus aethiopicus* (Dipnoi) and *Clarias gariepinus* (Clariidae). The shallow soft sediments in these areas make them suitable for the spawning of *O. niloticus* while the swamps forms refuge for the larval and fingerling fishes. Sedimentation and turbidity have been found to be significant contributors to declining populations of aquatic organisms (Henley et al., 2000).

The low Secchi depths close to the mouths of rivers Molo/Perkerra and Mukutan were attributed to suspended solids brought into the lake by the rivers which reduce transparency. Turbidity results from the scattering of light in water by organic and inorganic particles. The amount of deposited suspended solids diminished with distance from the river mouths, explaining the increase in transparency from south to north. Oduor (2000) and Wahlberg et al. (2003) attributed the low transparency in the lake to resuspension of sediments by wind action. Shallowness in lakes have been reported to lead to unpredictability of seasonal events especially in windy, unstratified water bodies where resuspension of bottom sediments results in reduced water transparency (Sommer et al., 1986). The resuspension of the bottom sediments into the water column which is a common feature in such ecosystems represents a major physical factor which can impact on other abiotic and biotic variables. Low water transparency inhibits light penetration consequently reducing the euphotic zone. As a result primary production is minimal in turbid waters which has cascading effects up the food web and ultimately on fisheries production. A number of fish species have been noted to depend on sight for their feeding and reproduction. Indeed *O. niloticus* endemic to the lake feeds by sight and identifies spawning partners through secondary reproductive characteristics. This explains the reducing catches of the species with increase of turbidity of the lake over time. In contrast the catches of the introduced *P. aethiopicus*, which feeds by groping, has risen and presently dominates the lake's fishery.

The relatively high mean of dissolved oxygen concentration of 6.4 mg L^{-1} in Lake Baringo showed that the lake is well aerated. Dissolved oxygen in water is greatly influenced by the process of photosynthesis thus light intensity. This explains why dissolved oxygen values measured in the lake increased with time of sampling with areas sampled early in the morning, when there was low light intensity, having lower dissolved oxygen concentration. Turbidity also indirectly affects the level of dissolved oxygen by limiting photosynthesis through reduction of light penetration in water and this could partly explain the low concentrations of dissolved oxygen at the river mouth where turbidity were the highest. Furthermore, decomposition of allochthonous materials would also consume oxygen in such localities. The high pH in the lake can be attributed to the domination of the algal community by the *Microcystis aeruginosa* (Oduor, 2000). Blooms of this use carbon dioxide for their photyosynthetic activity and removal of the gas results in increased pH as have been reported by Purandara et al. (2003). Oxygen depletions are the most common cause of fish kills. Fish kills from oxygen depletions can range from "partial" to "total". In a partial kill the dissolved oxygen level gets low enough to suffocate sensitive species and large fish, but many small fish and hardy species survive.

In an earlier study, Kiplagat et al. (1999) attributed fluctuation in conductivity values in Lake Baringo to the nature of inflowing river waters. Therefore, high values of conductivity at the river mouths to the south and east may be attributed to high ion loads in the incoming river water. Arle (2002) reported that mineral concentrations and dilution affect the value of conductivity. The onset of rains has been observed to signal radical changes in physical and chemical variables in tropical rivers (Lowe-Connell, 1987; Chapman and Kramer, 1991). The high temperatures in Lake Baringo area accompanied by the high evaporation rates could also contribute to the fluctuations in conductivity values in the lake. During rains there is dilution of lake water resulting in decreased ion concentrations while during drought and low water levels there is an increase of these thus high conductivity levels. This was supported by the negative correlation between conductivity values and lake depth.

The frequent peaks of nutrients realized during the study were probably caused by flushing of ions into the lake after rains in the catchment. River inflow has been observed to shape chemical gradients in other lakes (Patalas, 1969) through nutrient and organic matter input. On the other hand during dry periods high concentrations of ions observed could be due to reduced water volume in the lake by evaporation. Increased concentrations of ions, due to evaporation, in shallow lakes following dry periods have been reported by Swaine et al. (2006).

Chlorophyll *a* is a measurement frequently used to estimate phytoplankton biomass and to predict eutrophication levels of freshwater aquatic ecosystems (Wetzel, 2001; Dodds, 2002). The low Chlorophyll *a* concentrations recorded in Lake Baringo can be attributed to the high turbidity resulting in low light penetration leading to low photosynthetic activity. This is shown by the increase in the Chlorophyll *a* concentration during periods of low water levels in the lake. From the results of the study, increase in depth results in the increase in light transparency which culminates in higher production, thus increasing chlorophyll *a*. However, this was not the case in this study showing that probably the water turbidity arising from the silt brought in by rivers suppressed photosynthesis.

PCA results confirmed that most nutrients enter the lake through the rivers since these were the factors that characterized station S2, a river mouth station. Characterization of station C2 by dissolved oxygen and temperature is due to the fact that this was the station which was always sampled last when temperatures and light intensity were high.

RECOMMENDATIONS

The present study provides evidence that the incoming water through rivers is the source of pollutants in form of silt, nutrients and ions. These come from the catchment and are as a result of anthropogenic activities which induce soil erosion especially farming, deforestation and keeping of large number of livestock. Increased nutrients in the lake have led to the domination of the algal community by *M. aeruginosa,* a species known to be inedible for most zooplankton and fish. Increased turbidity, worsened by frequent winds and resuspension of sediments in the lake depress photosynthesis and also reduces feeding efficiency in fish that feed by sight. Indeed the increasing turbidity in the lake water could be one of the reasons for the decreasing catches of the once dominant *O. niloticus*. Considering that the lake has no outlet, the concentration of most of these pollutants would be cumulative and remain in the lake for a long time and will worsen unless the situation is contained. There is need for restoration of the lake by addressing the problem of soil erosion and siltation in catchment so as to reduce the amount of allochthonous materials entering the lake. This can be alleviated through afforestation programmes and reduction of the number of livestock in the area. The areas around the lake should also be protected by fencing and planting suitable grasses like vetiver which can withstand water logging and drought.

Conflict of Interests

The author(s) have not declared any conflict of interests.

ACKNOWLEDGEMENT

We wish to thank Kenya Marine and Fisheries Research Institute for providing funds for the study.

REFERENCES

Aloo PA (2002). Effects of climate and human activities on the ecosystem of Lake Baringo. P 335-347. In ‘The East African Great Lakes: Limnology, Paleolimnology and Biodiversity, Odada E.O and D. O Olago (eds) Kluwer Academic, London.

Anon (2003). Lakes of the Rift Valley, Project Briefing. http://www.earthwatch. org/expeditions/harper/harper_03.pdf; accessed September 15, 2013.

APHA (2000).Standard methods for the examination of water and wastewater.20th edition.American Public Health Association Inc., New York, USA.

Arle J (2002). Physical and chemical dynamics of temporary ponds on a calcareous plateau in Thuringia Germany. Limnologia 32:83-101.

Beadle LC (1932). Scientific results of the Cambridge Expedition to the East African lakes in relation to their fauna and flora. J. the Linnean Soc. Zool. 38:157-211.

Bryan RB (1994). Land degradation and the development of land use policies in a transitional semi-arid region. In Soil Erosion, Land Degradation and Social Transition – Geoecological analysis of a semi-arid tropical area, Kenya, ed. R. B Bryan, pp. 1-30. Catena-Verlag, Cremlingen-Destedt.

Chapman LJ, Kramer DL (1991). Limnological observations of an intermittent tropical dry forest stream. Hydrobiologia 226:153-166.

Cl’ement JP, Caroff M, H’emond C, Bollinger JJC, Guillou H, Cotton J (2003). Pleistocene magmatism in a lithospheric transition area: Petrogenesis of alkalins lavas from Baringo- Bogoria basin, central Kenya Rift. Can. J. Earth Sci. 40:1239-1257.

Dodds WK (2002). Freshwater Ecology: Concepts and environmental applications. Academic Press. San Diego. 569 pp.

Dunkley PN, Smith M, Allen DJ, Darling WG (1993). The geothermal activity and geology of the northern sector of the Kenya Rift Valley. British Geological survey Research Report SC/93/1, Keyworth, Norttingham.

Gregory JM (1921). The Rift Valleys and Geology of East Africa. Seeley Service: London.

Hammer O, Harper DA T, Ryan PD (2001). PAST: Paleontological Statistics Software Package for Education and Data analysis. Palaeontologia Electronica. 4(1):1-9.

Henley WH, Patterson MA, Neves RJ, Lemly AD (2000). Effects of sedimentation and turbidity on lotic food webs: A concise review for natural resource managers. Review Fish. Sci. 8:125-139.

Kallqvist T (1987).Primary production and phytoplankton in Lake Baringo and Naivasha, Kenya. Norwegian Institute for Water Research Report, Blinden, Oslo, 59pp.

Kiplagat WK, Njuguna SG, Francis MM, Lothar K (1999). The physico-chemical conditions of Turkwel gorge reservoir, a new man-made lake in northern Kenya. Limnologia 29:377-392.

Lowe-McConnell RH (1987). Ecological studies in fish communities. Cambridge. 33 p.

Ngaira JK (2006). Implications of climate change on the management of Rift Valley lakes in Kenya. The case of Lake Baringo.pp 133-138. In Odada EO, DO Olago, W Ochola, M Ntiba, S Wandiga, N Gichuki, H Oyieke (eds) Proceedings (Vol. 2) of 11th World Lakes Conference, 31st October to 4th November 2005, Nairobi Kenya. 623 pp.

Nyamweya CS, Mlewa CM, Ngugi CC, Kaunda-Arara B, Njiru M, Gichuki JW, Ojuok JE (2012). Aspects of the biology of *Labeo cylindricus* (Pisces: cyprinidae) in Lake Baringo, Kenya. Lakes and Reservoirs: Research and Management. 17(3):225-229. doi:10.1111/lre.12002

Odada EO, Onyando JO, Obudho PA (2006). Lake Baringo: Addressing threatened biodiversity and livelihoods. Lakes and Reservoirs: Research and Management. 11:287-299.

Oduor SO (2000). Physico-chemical Dynamics, Pelagial Primary Production and Algal Composition in Lake Baringo, Kenya. MSc. Thesis, IHE, Deft, Austria. 83 pp.

Omondi R, Yasindi AW, Magana A (2011). Spatial and temporal variations of zooplankton in relation to some environmental factors in Lake Baringo, Kenya. Eger. J. Sci. Technol. 11:29-50.

Onyando JO, Kisoyan P, Chemelil MC (2005).Estimation of potential soil erosion for River Perkerra catchment in Kenya. Water Res. Manag. 19:133-143.

Patalas K (1969). Composition and horizontal distribution of crustacean plankton in Lake Ontario. J. Fish. Res. Board Can. 26:2135-2164.

Patterson G, Kiplagat KW (1995).The influence of the diel climate cycle

on the depth-time distribution of phytoplankton and photosynthesis in a shallow equatorial lake (Lake Baringo, Kenya). *Hydrobiologia* 304:1-8.
R Development Core Team (2012). R: A Language and Environment for Statistical Computing. (R. D. C. Team, Ed.). *R Foundation for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. doi:10.1007/978-3-540-74686-7.
Sarma SSS, Nandini S, Gulati RD (2005). Life history strategies of cladocerans: comparisons of tropical and temperate taxa. Hydrobiologia 542:315-333.
Sidneit MT, Fakio ALT, Maria CR, Francises AE, Adaunto F (1992). Seasonal variation of some limnological factors of Lagoa do Guarana, a varzea lake of the Rio Parana State of Mato Groso do Sul. Braz. Rev. Hydrobiol. 25:269-276.
Swaine MD, Adomako J, Ameka G, De Graft-Johnston KAA, Cheek M (2006). Forest river plants and water quality in Ghana. Aquat. Bot. 85:299-308.
Wahlberg HT, Harper D, Wahlberg NT (2003). A first limnological description of Lake Kichiritith, Kenya: a possible reference site for the freshwater lakes of the Gregory Rift Valley. South Afr. J. Sci. 99:494-496.
Wetzel RG (2001). Limnology: Lake and rivers ecosystems. Academic press. San Diego. 1006p.
Wickham H (2009). ggplot2: elegant graphics for data analysis. New York: Springer. Retrieved from http://had.co.nz/ggplot2/book
Worthington EB, Ricardo CK (1936). Scientific results of the Cambridge expedition to the East African lakes, 1930-1 No.17. The vertical distribution and movement of the plankton in Lake Rudolf, Naivasha, Edward and Bunyonyi. J. Linnean Soc. Zool. 40:33- 69.

academicJournals

Vol. 6(5), pp. 164-169, May 2014
DOI: 10.5897/JENE2014.0439
Article Number: AF008D843793
ISSN 2006-9847

http://www.academicjournals.org/JENE

Journal of Ecology and the Natural Environment

Full Length Research Paper

Exploration of climate influences on the abundance of galls on red willow (*Salix laevigata*) across two riparian communities in Southern California

Tauras Vilgalys[1], Rachael Sears[2], Emily Hand[3], Sara Morledge-Hampton[1] and Víctor D. Carmona-Galindo[1]*

[1]Biology Department, Loyola Marymount University, 1 LMU Dr. MS 8220, Los Angeles, CA 90045, United States.
[2]Environmental Science Program, Loyola Marymount University, 1 LMU Dr. MS 8220, Los Angeles, CA 90045, United States.
[3]Natural Science Department, Loyola Marymount University, 1 LMU Dr. MS 8220, Los Angeles, CA 90045, United States.

Received 14 January, 2014; Accepted 7 March, 2014

In Southern California, the red willow (*Salix laevigata* Bebb) hosts a variety of gall-inducing parasitic insects. However, little is known about the ecology of these parasites, particularly the characterization of their microclimate preferences. This study explores the relationship between microclimate and gall frequencies in *S. laevigata* in the Ballona Wetlands and Temescal Canyon, and gall count correlated with biotic and abiotic factors such as soil pH, soil moisture and willow density. Significantly more galls per leaf were found at Temescal Canyon than Ballona Wetlands. Although the number of galls per leaf correlated negatively with soil pH, soil moisture content and canopy openness, only site and gall location were found to significantly predict the number of galls. These results suggest that additional or interacting microclimate factors may influence gall frequencies between Temescal Canyon and the Ballona Wetlands.

Key words: Insect galls, microclimate, plant vigor hypothesis, self-thinning rule.

INTRODUCTION

Willows (*Salix* spp.) are the host of parasitic interactions with a variety of other organisms. Some of these interactions produce abnormal plant growths, more commonly known as galls, which are formed as parasites manipulate the hormone levels of the host plant. Typically, gall formation relies on a mix of environmental and chemical signals that assist the parasite in identifying and infecting the host plant. More than 15,000 organisms can produce stem and leaf galls (Hartley and Lawton, 1992) and the identification of willow galls poses a monumental taxonomic challenge (Russo, 2006). Among willows, it is know that sawflies, midges, mites and fungi can cause galls although the complete number of species is unknown and the current list is far from exhaustive

*Corresponding author. E-mail: vcarmona@lmu.edu. Tel: +13103381968.

(Russo, 2006). Additionally, little is understood regarding the environmental requirements of gall-producing organisms (Russo, 2006). Gall formation is an important form of plant-herbivore interaction in that gall inducing insects affect the developmental pattern of plant organs (Larson and Whitham, 1991) and the physiology of the plant tissue surrounding the developing insect (Kopelke et al., 2003; Nymen and Roininen, 2000).

According to the plant vigor hypothesis, plants with optimal resource availability are most suited for gall formation (Price, 1991). Having a large amount of available energy, they create a nutrient-rich environment for the formation of galls that makes them ideal targets for parasitism (Price, 1991). Many factors can contribute to the distribution of gall-forming insect larvae, such as the distribution of secondary chemistry within or between host plants, environmental conditions, and weather-related factors (Kopelke et al., 2003). As such, characterizing the surrounding microclimate is an important tool in understanding the variability of gall formation between a singular plant species growing in various localities.

The main objective of this study was to evaluate the relationship between gall frequencies and microclimate in red willows (*Salix laevigata* Bebb) growing in two riparian communities in Southern California, Temescal Canyon and Ballona Wetlands. We hypothesized gall count would correlate with biotic and abiotic factors such as soil pH, soil moisture and willow density. Based on previous studies, we predicted that higher soil pH would correlate with higher stem gall count and a lower leaf gall count in *S. laevigata*. We also expected gall count would increase with soil moisture and canopy openness, but decrease as willow density decreases.

METHODS

Site description

Temescal Canyon is a protected chaparral area that experiences regular drought conditions. Alternately, Ballona Wetlands is a complex habitat comprising of estuarine and brackish marshes, freshwater marsh, and riparian corridor with a managed fresh water and tidal inputs (Carmona-Galindo et al., 2013). Additionally, the two communities are in different successional stages with Temescal Canyon being an unmanaged ecosystem and Ballona Wetlands having been restored and planted in 2003 (Friends of Ballona, personal communication). Temescal Canyon annually receives 18 to 28 cm of rain (Santa Monica Mountain Conservancy, personal communication) and Ballona Wetlands 18 to 38 cm of rain (Friends of Ballona, personal communication).

Gall counts

Thirteen (13) *S. laevigata* samples were collected at Ballona Wetlands and 12 at Temescal Canyon in Los Angeles, CA during November. Focal plants throughout each environment were randomly selected from both solitary plants and groups of trees. No more than a single tree from any cluster was selected. For each focal plant, a stem approximately 1.3 m from the ground was randomly selected and the galls on the last 50 cm of the stem were counted. Twenty leaves were selected from each stem and the number of galls per leaf were counted. The area of each leaf was measured via digital image analysis using Sigma Scan Pro (v5).

Environmental characterization

While collecting data, soil samples were taken from the base of each plant and stored in a cold room at 5°C until the time of analysis. Soil pH was measured by suspending 15 g of soil in 30mL of deionized water. Soil suspensions were agitated for 30 s and allowed to settle for 15 min. The pH of the supernatant was then measured using a Multi-Parameter Tester 35 pH meter. Soil moisture was measured by taking an initial wet soil weight for 10-20 g of soil, desiccating the soil in the Labconco FreeZone 4.5 L freeze dryer for 48 h, and weighing the soil again to obtain a dry weight.

Willow density was measured by counting the number of *S. laevigata* within a 2 m radius of each focal plant. Distance to the nearest woody-plant neighbor was also measured, as well as the base diameter of each focal tree. Canopy openness was measured by averaging four densiometer readings taken at the base of each focal plant.

Statistical analysis

Soil pH, soil moisture content, canopy openness, galls per leaf, galls per leaf area, stem galls, base diameter, distance from the nearest willow, distance from the nearest woody plant and willow density were tested for normality using a Shapiro-Wilks test. Correlations between these variables were also determined using Spearman Rank tests. Additionally, character traits were compared between the Temescal Canyon and Ballona Wetlands sites using Mann-Whitney U tests. The influence of variables on gall abundance was calculated using a general linear model. All analysis were conducted in Statistica (v9.1).

RESULTS

Data distribution

Soil pH ($W=0.909$), soil moisture content ($W=0.891$), canopy openness ($W=0.890$), galls per leaf ($W=0.714$), leaf gall density, stem galls ($W=0.712$), base diameter ($W=0.812$), nearest willow ($W=0.581$), nearest woody plant ($W=0.764$), and willows within two meters ($W=0.641$) followed a non-normal distribution ($p<0.05$).

Correlations

The number of galls per leaf correlated positively with leaf gall density and negatively with soil pH, soil moisture content and canopy openness (Table 1). Leaf gall density also correlated negatively with pH and canopy openness (Table 1).

The number of willows within a 2 m radius correlated negatively within the distance to the nearest woody plant, distance to the nearest willow, and willow base diameter (Table 1). The distances to the nearest woody plant and the nearest willow correlated positively and soil moisture correlated positively with soil pH (Table 1). The number

Table 1. Correlational relationships between biotic and abiotic microclimate variables and gall abundance. N.S. is used to designate insignificant relationships and r-values are given for significant correlations (p<0.05).

	Gall density per leaf	Willow density	Nearest woody plant	Nearest willow	Soil pH	Percent moisture	Stem galls	Canopy openness	Base diameter
Galls per leaf	0.98	N.S.	N.S.	N.S.	-0.61	-0.43	N.S.	-0.80	N.S.
Gall density per leaf		N.S.	N.S.	N.S.	-0.63	N.S.	N.S.	-0.78	N.S.
Willow density			-0.67	-0.69	N.S.	N.S.	N.S.	N.S.	-0.58
Nearest woody plant				0.75	N.S.	N.S.	N.S.	0.52	N.S.
Nearest willow					N.S.	N.S.	N.S.	N.S.	N.S.
Soil pH						0.43	N.S.	0.65	N.S.
Percent moisture							N.S.	0.51	N.S.
Stem galls								N.S.	N.S.
Canopy openness									N.S.

Table 2. Analysis of covariance for the number of gall with respect to main effects and interaction terms. Asterisk (*) denotes covariate variables. Double asterisks (**) denotes significant effect on gall abundance (p<0.05).

Source of variation	DF	MS	F	p
*Soil pH	1	30.1932	2.4244	0.1267
*Moisture	1	2.3976	0.1925	0.6630
*Canopy openness	1	11.0762	0.8893	0.3509
Site	1	107.8604	8.6609	0.0052**
Gall location	1	106.6338	8.5624	0.0055**
Site x gall location	1	207.4338	16.6564	0.0002**
Error	43	12.4537		

of stem galls did not correlate with any other measured variable (Table 1).

Analysis of covariance

A general linear model identified the site (Ballona or Temescal), gall location (leaf or stem), and the interaction between site and gall location as the only factors that predicted a significant amount of the variance in gall count (Figure 1; Table 2; p<0.01). At Ballona Wetlands, there was no difference in the number of stem and leaf galls with a mean of 0.65±1.72 galls per plant on both the stem and shoot. However at Temescal Canyon, there was a difference between leaf tissues with the leaves of a plant containing 9.06±6.64 galls and the stems containing 1.75±2.77 galls (Figure 1).

Site differences in gall densities and microclimate factors

Significant differences were detected in galls per leaf (U=0.5, p<0.0001; Figure 2a) and galls per leaf area (U=2.0, p<0.0001; Figure 2b) between the two sites. At Temescal Canyon, there were significantly more galls per leaf than at the Ballona Wetlands. Canopy openness was significantly greater at Ballona Wetlands than at Temescal Canyon (U=0.0, p<0.0001; Figure 2c). Soil moisture content (U=30.0, p<0.01; Figure 2d) and soil pH (U=7.0,p<0.001; Figure 2e) were both significantly greater at Ballona Wetlands.

DISCUSSION

The number of galls per leaf had a significant negative correlation with soil pH, soil moisture and canopy cover. Since the leaf gall density is strictly correlated to leaf area, the number of gall per leaf area behaved similarly to the number of galls per leaf. Additionally, among the environmental factors, it was positively correlated with soil pH and soil moisture while negatively correlated with base diameter and willow density. The analysis of covariance shows that site, location of the gall, and location by site interaction were found to explain

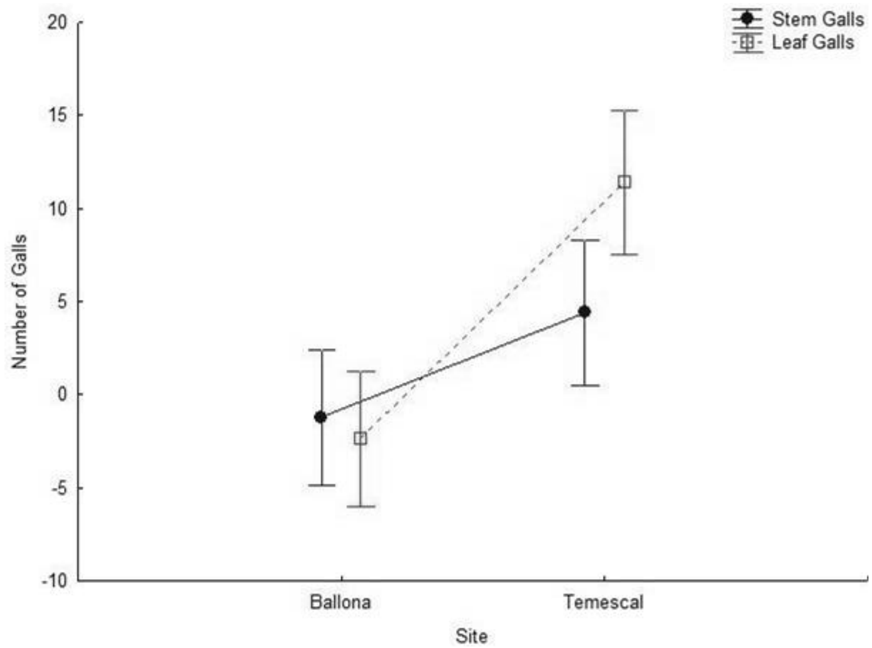

Figure 1. Average number of stem and leaf galls at the Ballona Wetlands and Temescal Canyon. The site, gall location and site x gall location each differed significantly (p<0.01). Bars denote 95% confidence intervals.

variations in the quantity of galls. As covariates, soil pH, soil moisture and canopy cover did not explain a significant proportion of the variation in the numbers of galls. Temescal Canyon had significantly more galls per leaf, greater canopy cover, less soil moisture and a lower pH than Ballona Wetlands.

Based on the analysis of covariance, none of the site differences had an effect independent of site. It is unclear what microclimate characteristics contributed the change in gall abundance between sites. However, it is possible that the interactions between biotic and abiotic factors that were measured may be more important than individual variables (Bollinger et al., 1991). For example, studies of soil moisture and gall formation have shown no relationship (Bauer, 2010) and a negative relationship (Sumerford et al., 2000), suggesting that the interactions of multiple factors may be important in explaining changes in gall abundance. Additionally, there may be alternate factors in the plant chemistry (e.g. semi-ochemicals) that influence gall formation between the two sites. Examining differences in semiochemicals and biochemistry of plants at the two sites may help further in explaining the variation in gall abundance and formation. Furthermore, additional variation may be explained by differences in the species of gall present.

An important difference between Ballona Wetlands and Temescal Canyon is their relative secondary success-sional stage. The Ballona Wetlands are a heavily ma-naged environment and was recently revegetated while Temescal Canyon is a preserved area of older riparian growth (Carmona-Galindo et al., 2013). Au (2013) found that successional changes influenced *Syzgium malaccense* gall formation as different biological communities dominated the landscape. Successional stages may influence gall dispersion and more established areas may be more likely to have resident gall forming insect populations that invaded in earlier successional stages.

There may be a possible tradeoff between plant vigor and insect distribution in that the number of galls did not correlate with either trunk diameter or willow density. According to the plant vigor hypothesis, galls should grow on the trees with the greatest amount of available energy. This hypothesis suggests that galls would be the most prevalent on older, healthier individuals. However, these more mature trees are often the result of a self-thinning process and decreased tree density may reduce opportunities for insect dispersion.

Consistent with self-thinning rule, we observed a significant inverse relationship between trunk diameter and willow density. This indicates there may be a tradeoff between willow size and tree density and an optimal intermediate condition that would promote the greatest amount of gall formation.

Conflict of Interests

The author(s) have not declared any conflict of interests.

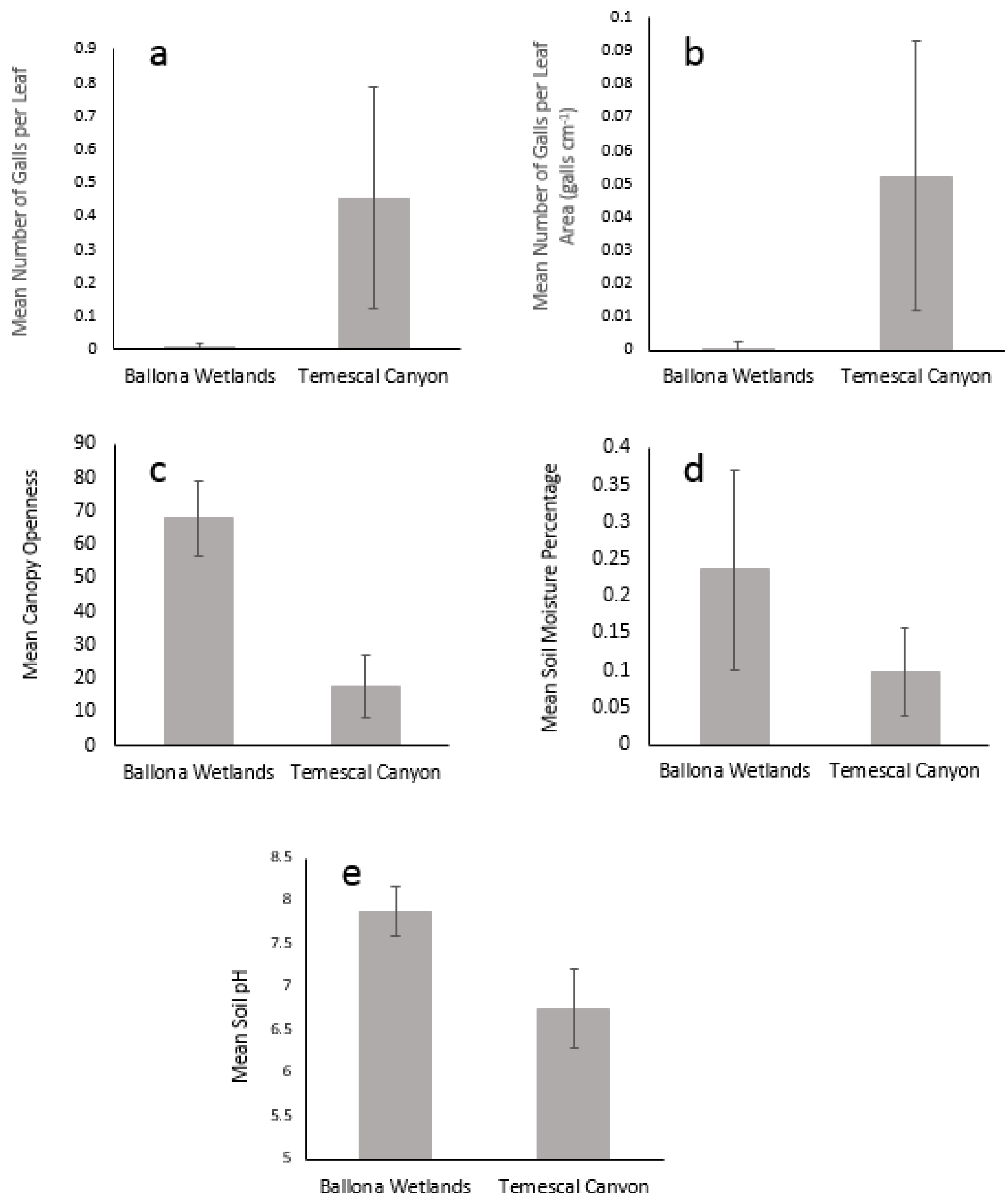

Figure 2. Site differences in microclimate and gall frequencies between the Ballona Wetlands and Temescal Canyon for a) the number of galls per leaf, b) the number of galls per leaf area, c) canopy openness, d) soil moisture and e) soil pH. Bars denote ±1 S.D.

REFERENCES

Au S (2013). Succession in galls on Syzygiummalaccense and their impact on leaf aging. UC Berkeley Library. Retrieved November 21, 2013 from http://escholarship.org/uc/item/847704sb.

Bauer T (2010). The densities of goldenrod galls (Eurostasolidaginis) and their goldenrod host plants (Solidagocanadensis) while directly related to each other, are not impacted by soil nitrogen or soil moisture. Deep Blue. Retrieved November 21, 2013 from http://deepblue.lib.umich.edu/bitstream/handle/2027.42/78445/Bauer_Tatia_2010.pdf?sequence=1.

Bollinger EK, HarperSJ, Barrett GW (1991) Effects of seasonal drought on old-field plant-communities. American Midland Naturalist 125: 114-125. http://dx.doi.org/10.2307/2426374.

Carmona-Galindo VD, Hinton-Hardin D, Kagihara J, Pascua MRT (2013). Assessing the Impact of Invasive Species Management Strategies on the Population Dynamics of Castor bean (Ricinuscommunis L., Euphorbiaceae) at Two Southern California Coastal Habitats. Nat. Areas J. 33(2):222-226. http://dx.doi.org/10.3375/043.033.0212

Hartley SE, Lawton JH (1992) Host-plant manipulation by gall insects: a test of the nutritition hypothesis. J. Anim. Ecol. 61: 113-119.http://dx.doi.org/10.2307/5514.

Kopelke JP, Amendt J, Schonrogge K (2003). Patterns of interspecific associations of stem gallers on willows. Divers. Distributions 9: 443-453. http://dx.doi.org/10.1046/j.1472-4642.2003.00037.x.

Larson KC, Whitham TG (1991) Manipulation of food resources by a gall-forming aphid: the physiology of sink-source interactions. Oecologia 88:15-21. http://dx.doi.org/10.1007/BF00328398

Nymen T, Widmer A, Roininen H (2000) Evolution of gall morphology and host-plant relationships in willow-feeding sawflies (Hymenoptera: Tenthredinidae). Evolution 52(2): 526-533.http://dx.doi.org/10.1554/00143820(2000)054[0526:EOGMAH]2.0.CO;2; http://dx.doi.org/10.1111/j.0014-3820.2000.tb00055.x

Price PW (1991). The plant vigor hypothesis and herbivore attack. Oikos 62:244-251. http://dx.doi.org/10.2307/3545270.

Russo R (2006). Field guide to plant galls of California and other Western states. University of California Press, Berkeley, pp. 20-22, 205-216.

Sumerford DV, Abrahamson WG, Weis AE (2000) The effects of drought on the Solidagoaltissima-Eurostasolidaginis-natural enemy complex: population dynamics, local extirpations, and the measures of selection intensity on gall size. Oecologia 122: 240-248. http://dx.doi.org/10.1007/PL00008852

academicJournals

Vol. 6(5), pp. 170-182, May 2014
DOI: 10.5897/JENE2014.0441
Article Number: F7F5ADC43794
ISSN 2006-9847

http://www.academicjournals.org/JENE

Journal of Ecology and the Natural Environment

Full Length Research Paper

Status of Hagenia forest in the Parc National des Volcans, Rwanda: A review of historical records

Seburanga J. L.[1]*, Nsanzurwimo A.[2] and Folega F.[3]

[1]College of Science and Technology, University of Rwanda, P.O. Box 117, Butare, Rwanda.
[2]Faculté des Sciences, Institut d'Enseignement Supérieur de Ruhengeri, P.O. Box 155 Ruhengeri, Rwanda.
[3]Faculté des Sciences, Université de Lomé, BP 1515, Lomé, Togo.

Received 18 January, 2014; Accepted 27 February, 2014

Hagenia-shaped habitat is an important element in conservation of world's only population of mountain gorillas surviving in the wild. In fact, in the Parc National des Volcans (henceforth PNV), gorillas spend most of their life time in the nutritious herbaceous habitats near or within the Hagenia-Hypericum zone. Unfortunately, populations of *Hagenia abyssinica* in this park have been reported to be ageing. Using information drawn from the statistical analysis of records in herbaria and the cross−examination of the literature, the status of Hagenia forest in PNV is discussed. The results show that *H. abyssinica* in PNV has an unusual pattern of population structure and distribution, seemingly since many decades. No record of *H. abyssinica* was collected from PNV, but patterns of collections of *H. abyssinica* are globally similar to those of a set of five control tree species, such that this absence of records from this park cannot be considered as due to collector or collection site-bound bias. The paper ends by giving insight on possible implications for conservation of the park's wildlife, chiefly the gorillas.

Key words: Tree regeneration, herbarium records, afromontane forest.

INTRODUCTION

Hagenia abyssinica is a typical example of an afro-montane tree endemism, now considered as endangered (Feyissa et al., 2007a). Not only it is among the rare dioecious tree species (Vamosi and Vamosi, 2005), but also is one of the few tropical rain forest tree species whose pollination and seed dispersal is mediated by wind (Turner, 2001). In the few remnant afro-montane forests where it occurs in Rwanda, *H. abyssinica* is associated with a rich and unique biodiversity such that any threat to its normal dynamics may affect the wellbeing of many wildlife species. Hagenia-shaped habitat is an important element in conservation of world's only population of mountain gorillas surviving in the wild (Sarmiento et al., 1996). According to McNeilage (2001), corroborated by Kayijamahe (2008), gorillas in PNV were found to spend most of their life time in the nutritious herbaceous habitats near or within the Hagenia-Hypericum zone. Unfortunately, Hagenia forests seem to have been declining since many decades.

In his analysis of the vegetation structure in Denkoro forest (Ethiopia), Ayalew (2003) noticed that *H. abyssinica* had fallen in the category of those tree species whose majority of individuals was in the highest DBH (diameter at breast height) classes, suggesting that the species was no longer reproducing effectively. This result can be viewed as a validation of early

*Corresponding author. E-mail: seburanga@yahoo.fr.

concerns in line with which this species was declared endangered in Ethiopia (Kibebew and Addis, 1996) and the Ethiopian forestry law prohibits its utilization in this country (FDRE, 1994). In another study, Lange et al. (1997) found thaton Mount Kenya, the regeneration of Hagenia was either decreased or abolished in areas suffering from a high herbivorous activity. Feyissa et al. (2007a) confirmed there was a reason to be concerned about the future of this species and insisted that it should be listed as endangered. *H. abyssinica* is missing on the list of 212 tree species recorded in four of the most important forests in Western Uganda [Bwindi Impenetrable National Park (BINP), Kasyoha-Kitomi Forest Reserve (KKFR), Kibale National Park (KNP) and Budongo Forest Reserve (BFR)], perhaps implying that it was too rare to be easily encountered during the survey (Eilu et al., 2004). When Eilu and Obua (2005) listed the most dominant tree species in the disturbed sites of Bwindi Impenetrable National Park, *H. abyssinica* was not included. This suggests that this species had low occurrence. Lejju et al. (2001) came up with a similar result in Mgahinga Gorilla National Park, where *H. abyssinica* was never recorded in undisturbed sites and had so-called highest frequency lower than 0.05% (=0.03)

In PNV, park amputations, which culminated in 1970s when almost all the Neobutonia forest was lost to land reclamation by humans, forced gorillas to retreat back uphill to the mountains, exerting an increased pressure on vegetation and altering the course of succession within the bamboo and Hagenia forests (Murererehe, 2000; Nsanzurwimo, 2004; Plumptre, 1993). In addition, poaching activities further confine gorillas to the area between mounts Karisimbi and Sabyinyo, reducing their range to only a small portion of the originally suitable space. Indeed, gorilla density negatively correlates with total combined signs of human disturbance, and few gorillas are found in the area of Mikeno, south of Karisimbi and in the Eastern part of the Virunga Range (Gray et al., 2005; Kayijamahe, 2008). In fact, as it appears in the literature, Hagenia forest, which, unfortunately, seems to have been receding for decades, is critical to gorilla conservation in PNV and there is a reason to be concerned should this trend continue. However, due to budget constraints researchers in developing countries are inherently faced with, no other study has been so far dedicated to elucidating this problem. Not even a literature review.

This paper uses information drawn from the statistical analysis of records in herbaria and the cross-examination of the literature to discuss the status of Hagenia forest in PNV and some of its possible effects on the conservation of biological diversity in this park. It forms a baseline for future investigations on the causes and implications of Hagenia forest dynamics not only in des Parc National des volcans (Rwanda), but also in other afromontane forests of East Africa.

MATERIALS AND METHODS

Study area

The study was conducted Rwanda, a small landlocked country in central Africa, located around 2º00 South latitude and 30°00 East longitude. The areas concerned by this study are situated in the western and northern parts of the country, on both sides of the Congo-Nile ridge (1600-2900 m) and south to the crest line of the volcanic cones (2300-4500 m). The entire area of study is located in the Albertine Rift, a biodiversity hotspot with many endemic and endangered species (Plumptre et al., 2007). In particular, the virunga volcano range is home to world's only population of mountain gorillas surviving in the wild (Weber and Vedder, 1983). Because of high altitude, the temperature (11-18°C) and rainfall (1700-1800 mm) in the study area are more moderate than the surrounding hot and humid equatorial regions, even though the climate follows the same annual cycles.

Previously disturbed (and undisturbed) areas investigated here are located on the foothills of Muhabura Mountain, in the eastern part of des Parc National des Volcans (Figure 1). The presence of plowing or digging vestiges on the ground, burn tracks on trees or disturbance indicator species [either native (*Pteridium aquilinum*), exotic (*Eucalyptus maidenii*, *Erythrina abyssinica*, *Carica cundinamarcensis*, *Solanum tuberosum*, *Buddleja davidii*, *Setaria* sp.), or ruderal (*Galinsoga parviflora*, *Crotalaria recta*, *Solanum nigrum* and *Oxalis corniculata*)] have served as a convincing mark of disturbance (Seburanga, 2007). Undisturbed plots were defined within areas free of disturbance indicators.

Study material

Hagenia abyssinica (Bruce) Gmel. [Rosaceae] is the species of interest [or treatment, in the language of inferential statisticians] for this study. Five other tree species were selected to serve as a source of control data. These are: *Erica arborea* L. [Ericaeae], *Hypericum revolutum* Vahl. [Hypericaceae], *Dombeya goetzenii* K.Schum. [Sterculiaceae], *Arundinaria alpina* K. Schum. [Poaceae] and *Neoboutonia macrocalyx* Pax. [Euphorbiaceae]. *H. revolutum* was chosen because it is often associated with *H. abyssinica* (Table 1). *D. goetzenii*, *A. alpina*, and *N. macrocalyx* were picked for they are key tree species of the outer forest ring that envelops the Hagenia-Hypericum zone. *E. arborea* was selected as the most characteristic of the inner forest layer.

The Hagenia-Hypericum woodland, which lies between 2800-3200 m of altitude, forms the most striking forest formation. At lower altitude, it is buffered by a bamboo belt (the structure is very apparent on the western side of Karisimbi volcano and around Sabyinyo) or by a mixed forest dominated by Dombeya trees on the southern part of Bisoke or by a Neoboutonia-dominated forest on the western side of Mikeno volcano). At higher altitude (3200-3600 m), the Hagenia-Hypericum forest is replaced by a heather land, which forms the uppermost woody vegetation (Watts, 1983). In total, there are five to nine vegetation strata (Steklis et al., 2005). However, for the sake of simplicity, this study was limited to the description of those directly connected to the Hagenia forest, with their respective key tree species (Hagenia, on the one hand, and the five control tree species, on the other hand). The total number of vegetation formation in PNV varies with the research objectives and the methods used for classification.

Specimens whose collection dates were not specified [for example, Specimen No 2044 of *D. goetzenii* by Ewango and Specimen No 225 of *N. macrocalyx* by Nuyt C.] were removed from the analyzed sample. For any species represented by many copies of specimens, only one copy was retained for the analysis, if four conditions were fulfilled; that is, if all copies were collected (1) at the same location (2) during the same year and (3) by the same person

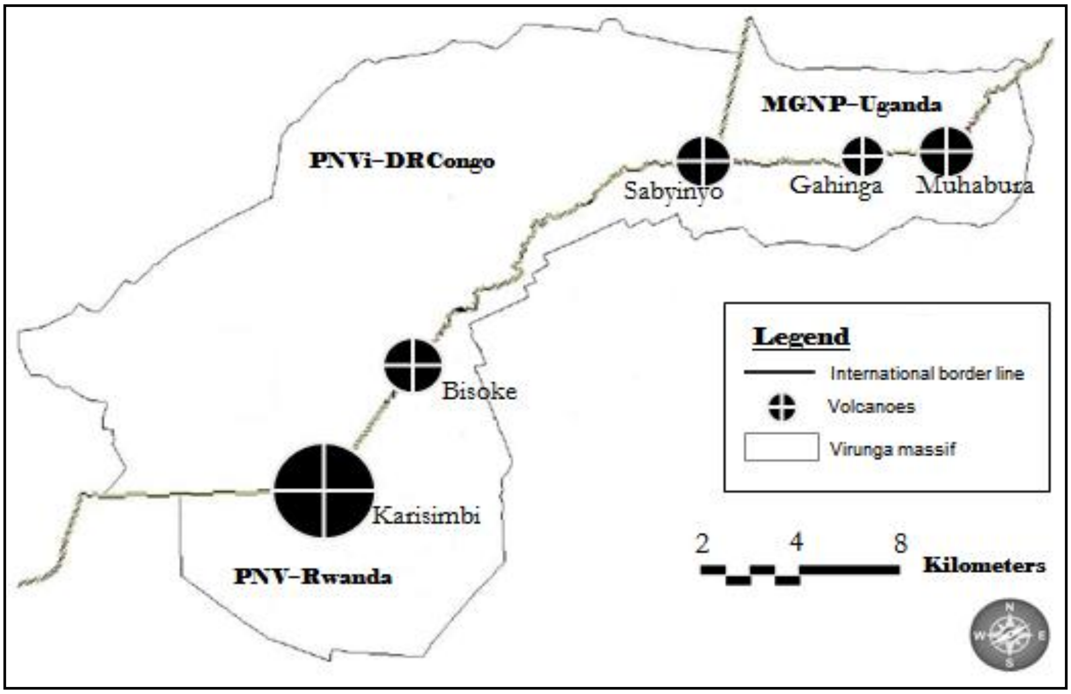

Figure 1. Location of the Parc National des Volcans (PNV) in the virunga massif.

Table 1. Sample species per Hagenia-associated vegetation zone.

Vegetation type	Characteristic tree species	Altitude (m)
Sub-Alpine	*E. arborea*	3200-3600
Hagenia-Hypericum woodland	*H. abyssinica*, *H. revolutum*	2800-3200
Bamboo forest	*A. alpina*	2500-2800
Mixed forest	*N. macrocalyx*, *D. goetzenii*	1600-2500

and (4) were assigned the same specimen number. This was the case for Specimen No 869 of *D. goetzenii* collected by Bouxin (1971) from Mayebe site and Specimen No 15385 of *D. goetzenii* collected by Troupin (1974) from Gikungu location, which had two copies each. With regard to the two duplicates of Hagenia record No 22, both taken at exactly same geographical coordinate (UTM 0758465/9724490) in 1990 from Rubyiro location by two different collectors [Ferdinand and Ngayabahiga], we suspected that there was inconsistency in recording the collector's name (one, the forename and, the other, the surname of same person) and presumed they were just two copies of same record by Ferdinand Ngayabahiga; thus treated as such.

Records of different infra-specific taxa that belong in a same species were grouped into one set and considered as mere copies of that species. This was the case for *H. revolutum* whose data comprised three different entries: *Hypericum revolutum*, *Hypericum revolutum* (trois), and *Hypericum revolutum* Vahl. They were treated as copies of a same species and assigned one entry name: *Hypericum revolutum* Vahl.

Spelling or nomenclatural errors were corrected based on our expert judgment. For instance, the entry name *Harundinaria alpina* of specimen no. 674 collected by Nzakizwanayo (2005) from Mukura forest was treated as another specimen of *A. alpina*. Except where indicated otherwise, taxonomic classification and species nomenclature used in the database were maintained, for the sake of easy comparison. Among taxa treated as such is *Arundinaria alpina*, a species whose nomenclature has evolved a lot since the time the first collections were made. It once was referred to as *Arundinaria alpina* K. Schum. (Owiunji et al., 2004), then as *Sinarundinaria alpina* (K. Schum.) C. S. Chao & Renvoize (Nsazurwimo, 2004; Karlowski, 2006), and since recently as *Yushania alpina* K. Schumann Lin. (Ohrn) (Seburanga, 2007). Only the name *Arundinaria alpin*a K. Schum., as used in the plant database at National Herbarium of Rwanda, is hereafter applied when referring to this taxon.

Data collection

The study builds upon raw data of three kinds: Field-drawn data (tree DBH data), herbarium records (historical occurrence data), and literature-extracted data (spatial occurrence maps).

Number of Hagenia trees per DBH class

Data on Hagenia tree distribution per DBH class were collected in 2007 on the foothills of Muhabura Mountain in the Parc National

Table 2. Number of Hagenia individual trees per DBH classes on Muhabura Mountain, Parc National des Volcans [data extracted from Seburanga (2007)].

Type of site	DBH (diameter at breast height) classes		
	≤ 10 cm	10 - 30 cm	≥ 30 cm
Disturbed forest	2	1	1
Undisturbed forest	2	2	4
Total	4	3	5

des Volcans, between 2500 and 3300 m of altitude (Seburanga, 2007). These data were collected along four transects, each passing across two neighboring areas (disturbed and undisturbed area), by the plot method and semi-stratified sampling. Circular plots of 20 m in radius were established at every 250 m interval along the reconnaissance trails. In total, 44 plots equitably distributed between disturbed and undisturbed areas were surveyed. Each pair of sites was characterized by comparable topography, altitude average, soil nature and vegetation type for valid comparison. Height and DBH (diameter at breast height) was measured for individual trees occurring in a plot.

Hagenia historical occurrence in Rwanda

To assess whether its arrested regeneration, as suggested by findings of contemporary studies, is not merely a recent trend or a temporary event with no lasting effects, we delved into herbarium records of Hagenia in Rwanda to analyze its historical patterns of occurrence [for the appropriateness of use of herbarium records in ecological studies please refer to Fuentes et al. (2013) and Antonovics et al. (2003)]. Species record counts and associated data, including collection dates and names of sites and collectors, were drawn from the plant database available at the National Herbarium of Rwanda, hosted at the Rwanda Institute of Scientific and Technological Research (IRST). Historical occurrence data were retrieved for five other tree species to serve as control data, to measure the likelihood that the observed trend is not simply due to a species or collector-bound bias that might originate from collectors' differential effort to take record of Hagenia in PNV as compared to other parks. Cross-references to the records were retrieved from databases of Botanical Garden Meise (Belgium) and Kew Gardens (UK).

Hagenia spatial occurrence in the virungas

To assess whether its reported arrested regeneration is just a PNV-bound problem or a transboundary issue whose fallouts extend to the entire virunga massif, data on Hagenia presence/absence in the virungas were extracted from Owiunji et al. (2004), Dondeyne et al. (1993), McNeilage (1995), Nsanzurwimo (2004), Steklis et al. (2005) and Seburanga (2007) in order to analyze patterns of its spatial occurrence in the three contiguous parks: Parc National des Volcans (Rwanda), Mgahinga Gorilla Nationa Park (Uganda), and Parc National des Virungas (Democratic Republic of Congo).

Data analysis

Number of Hagenia trees per DBH class

For both the disturbed and undisturbed forest, DBH data were stratified into three categories: ≤ 10, 10< × < 30 and ≥ 30 cm. Analysis was conducted through simple scree plotting, using filter and sorting tools of Microsoft excel applications.

Hagenia historical occurrence in Rwanda

Herbarium data were stratified into two data sets based on the parent material of the dominant soils under the forests from which the specimens were collected: [A] Collections taken from forests on both sides of the Congo-Nile ridge (shale, micaschist, micaceous granite, quartzitic or granitic rock) and [B] Collections taken from virunga massif forest (volcanic rock) (Verdoodt and Van Ranst, 2003).

Hagenia spatial occurrence in the virungas

Data on presence/absence of Hagenia (and of five control species) were selectively retrieved, noting whether the species was Albertine Rift Endemic (ARE) or IUCN-red listed as vulnerable. A data matrix was created based on a binary coding system in which "1" stands for species presence and "0" for species absence.

The normality of data was assessed using the Shapiro−Wilk test. Paired Sample Wilcoxon Signed Ranks Test was used to assess the level of significance of differences between record counts from the Congo-Nile ridge and virunga massif samples. Pearson Correlation Test allowed the quantification of co-variation observed between species record counts, number of collection campaigns (expressed in term of different years the specimens were collected) and number of collectors onboard.

RESULTS

Number of Hagenia trees per DBH class

The results show that Hagenia trees are very rare in Muhabura forest (Table 2), especially lager trees (DBH ≥ 30 cm) within previously disturbed areas. Sites combined, there are more trees within the ageing class (DBH ≥ 30 cm) than in younger categories.

Hagenia historical occurrence in Rwanda

All records of Hagenia were taken from areas beyond the virunga massif (from forests on both sides of the Congo-Nile ridge). Around 66.7% of the total number of the specimens were collected from Nyungwe National Park only (Table 3).

When records of *H. abyssinica* and those of control tree species were combined, statistical analysis showed a difference between record data series from Congo-Nile ridge forests or nearby and virunga massif or close areas ($W = 210.5; Z = 3.32; Prob > |W| = 3.233E-4$) (Figure 2a). The majority of specimens (84 %) were collected in areas

Table 3. Historical records of *H. abyssinica* in Rwanda.

Collector	Number	Location	Region	Date	Altitude	Habitat
Troupin G.	15268	Gikungu	Gisenyi	1974	2150	Disturbed forest
Troupin G.	10474	Uwinka	Cyangugu	1959	2300	Forest hillside
Troupin G.	10403	Unspecified	Cyangugu	1959	2360	Forest hillside
Bouxin G. & Radoux M.	830	Mugasare	Cyangugu	1969	2300	Riparian and roadside
Troupin G.	14735	Wisumo	Kibuye	1973	2200	Disturbed forest
Reynders	373	Rutovu	Gikongoro	1959	2400	Valley forest
Bouxin G.	1036	Mugasare	Cyangugu	1971	2400	Riparian forest
Nzakizwanayo E.	12	Uwasenkoko	Gikongoro	1999	2370	Open forest
Ngayabahiga	22	Rubyiro	Gikongoro	1999	2170	Open forest

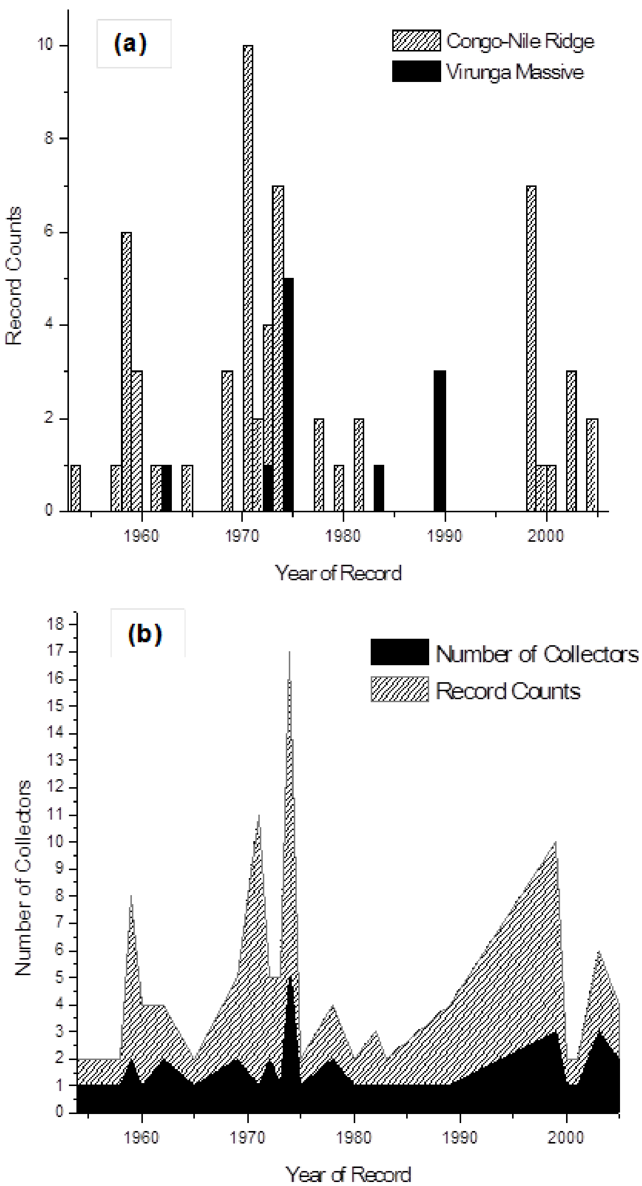

Figure 2. (a) Species record per sites and (**b)** per plant specimen collector.

areas beyond the virunga massif. On the other hand, record counts correlate with the number of collectors (*r^2 = 0.652; p<0.001*) (Figure 2b).

Roughly 67.14% of the specimens were collected by 1975. *H. revolutum* was as the most regularly collected, accounting for 31.4% of the records, with only 13.6% of its records taken from PNV or close areas. Both *H. abyssinica* and *N. macrocalyx* were never collected from PNV or close areas. For unknown reasons, records of *H. abyssinica* and the five control tree species occurred in a series of waves of collection [refer to the four in-phase collection peaks in 1959, 1971, 1974, and 1999, respectively (Figure 3b)] and the specimens taken in a given collection period appeared to be restricted to one or two collection sites (Table 3). A similar pattern of specimen collection was detected at the regional scale, suggesting that the earliest record of *H. abyssinica* in Rwanda was taken during late 1950s, more than 4 decades it was recorded in the Democratic Republic of Congo by Bequaert (in 1914) [note that an even earlier record was taken in this country by Schimper in 1838 (Botanical Garden Meise, 2014)]

There is an apparent similarity of trends for the two distributions, with four parallel peaks in 1959, 1971, 1974, and 1999. However, a paired Wilcoxon Signed Ranks Test revealed that the two distributions are significantly different (*W = 0, Z = - 4.04; Prob* > |*W*| = *9.536E-7*) (Figure 3a). When the test was performed using Hagenia record counts and Control species *yearly average* record count [total count for the group divided by the number of species in the group], the two distributions were found to be not significantly different (*W = 68.5, Z = - 1.88; Prob* >|*W*| = *0.056*) (Figure 3b), suggesting that the previously observed difference was due to the fact that the cumulative number of record counts for the group of control species was obviously higher than the record counts of a single species, Hagenia.

Roughly 2/3 of records were taken by not more than five specimen collectors. Only two collectors, Troupin G. and Bouxin G., accounted for 42.8% of the records (Table 4). Per collector intervention time ranges from one

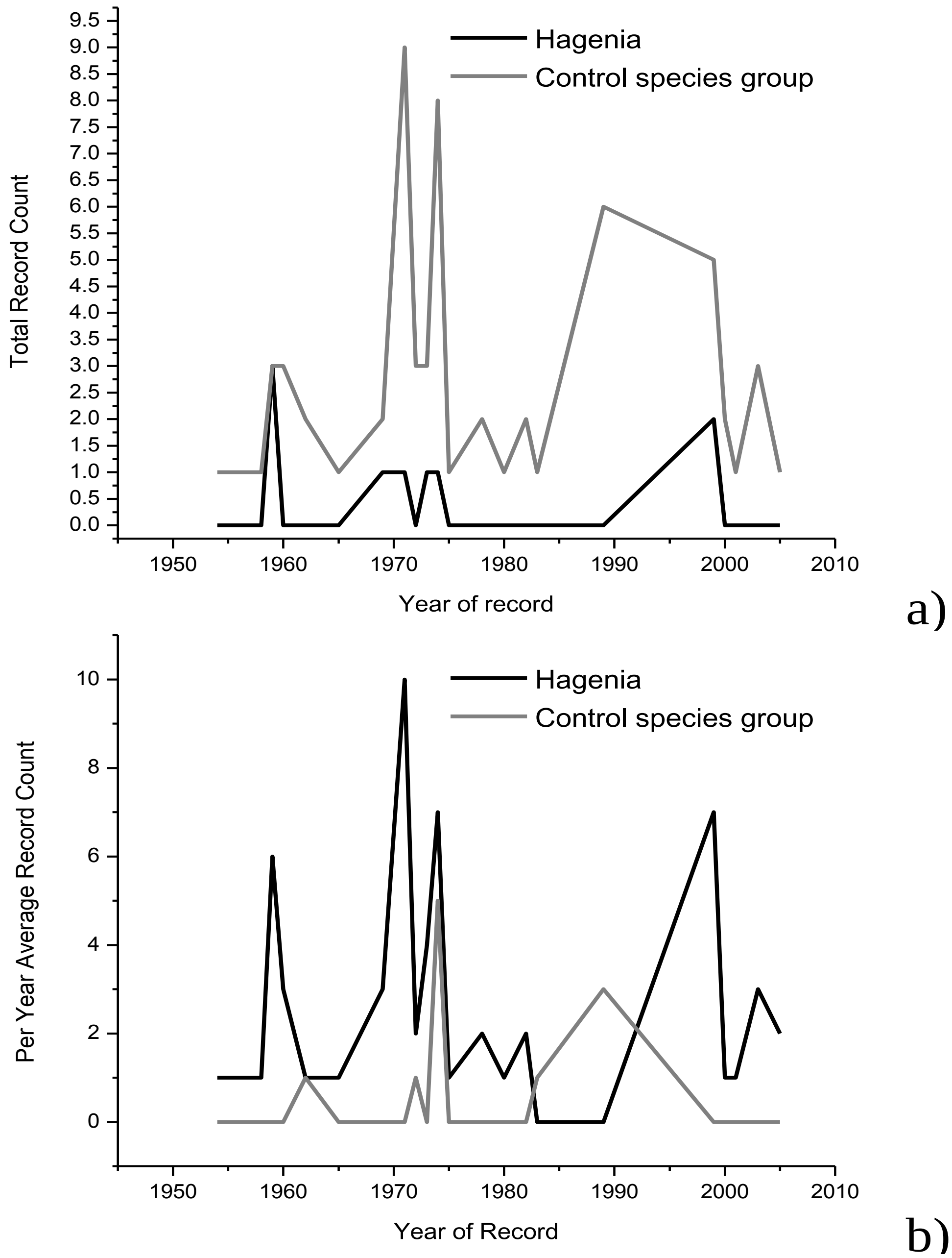

Figure 3 (a and b). Evolution of record counts per tree species (Hagenia) or group of species (the five control tree species combined).

to seven years. A strong relationship was observed between the number of records per collector and the number of concerned species (r^2 = *0.868; p<0.001*), on opportunity to make more records and collect a bigger number of different species.

Hagenia spatial occurrence in the virungas

Two species (*A. alpina* and *H. revolutum*) had regular occurrence in PNV as they were recorded in all sectors the one hand, and the number of collection campaigns (different years) (r^2 = *0.872; p<0.001*), on the other hand.

Collectors that took part in more campaigns had more that fall within the boundaries of this park [Figure 4c and d (compare with Figure 1)]. They are followed by *H. abyssinica*, which occurs in all parts of PNV, except in the area between mounts Sabyinyo and Gahinga, and *D. goetzenii*, which is missing only in the extreme west. *N. macrocalyx* has the same distribution as *D. goetzenii*, with the difference that, in addition, it is missing in the area around Mount Bisoke. *E. arborea* is the rarest

Table 4. Number of specimens and species collected per collector and per year of record.

Collector name	Record count	Number of species	Year of record
Auquier P.	1	1	1974
Auquier P.	2	2	1972
Bouxin G.	10	5	1971
Bouxin G. & Radoux M.	3	3	1969
Christiaensen A.R.	1	1	1954
Etienne C.	1	1	1972
Knox E.	3	3	1989
Lewalle J.	1	1	1965
Mulindahabi F.	1	1	1999
Munyaneza E.	1	1	2005
Musabe T.	1	1	2000
Mvukiyumwami J.	2	1	1982
Mvukiyumwami J.	1	1	1983
Ndiramiye G.	1	1	2001
Ngayabahiga F.	3	2	1999
Ngayabahiga F.	1	1	2003
Ntahumwe T.	1	1	2003
Nuyt C.	2	2	1974
Nzakizwanayo E.	3	3	1999
Nzakizwanayo E.	1	1	2003
Nzakizwanayo E.	1	1	2005
Rameloo J.	1	1	1974
Raynal J.	1	1	1978
Reynders M.	2	2	1959
Reynders M.	1	1	1958
Sita P.	1	1	1978
Troupin G.	1	1	1980
Troupin G.	7	4	1974
Troupin G.	4	3	1959
Troupin G.	3	2	1960
Troupin G.	1	1	1962
Troupin G.	4	2	1973
Troupin G.	1	1	1975
Van Der Veken P.	1	1	1962
Van Der Veken P.	1	1	1974

among the six.

DISCUSSION

Number of Hagenia trees per DBH class

Distribution of Hagenia individual trees within DBH classes does not show a reverse J size class distribution as expected of a properly regenerating species (White and Edwards, 2000). Instead there seem to be many more adults than saplings or seedlings [note that the number of Hagenia trees was too little to warrant a statistically unshakable conclusion, which requires us to interpret tree DBH results with reasonable caution]. Seburanga (2007) studied the regeneration of tree species in this part of the park. He found that, unlike Hagenia, the DBH profile of *Dombeya goetzenii* (one of the five control species used in this study) had a completely different shape, with more saplings than ageing trees. According to the same author, per species number of trees averaged at 106.2 and 8.2 trees for the ranges of ≤ 10 and ≥ 30 cm of girth diameter, respectively. In this study, Hagenia registered only 4 saplings with ≤ 10 of DBH and 5 individuals in the ageing class. However, this finding should be interpreted with caution because data are not presented in equal age classes. Passage time may vary a lot from size class to another. Indeed, if a tree is very long-lived, it could be perfectly sustainable to have a population with more

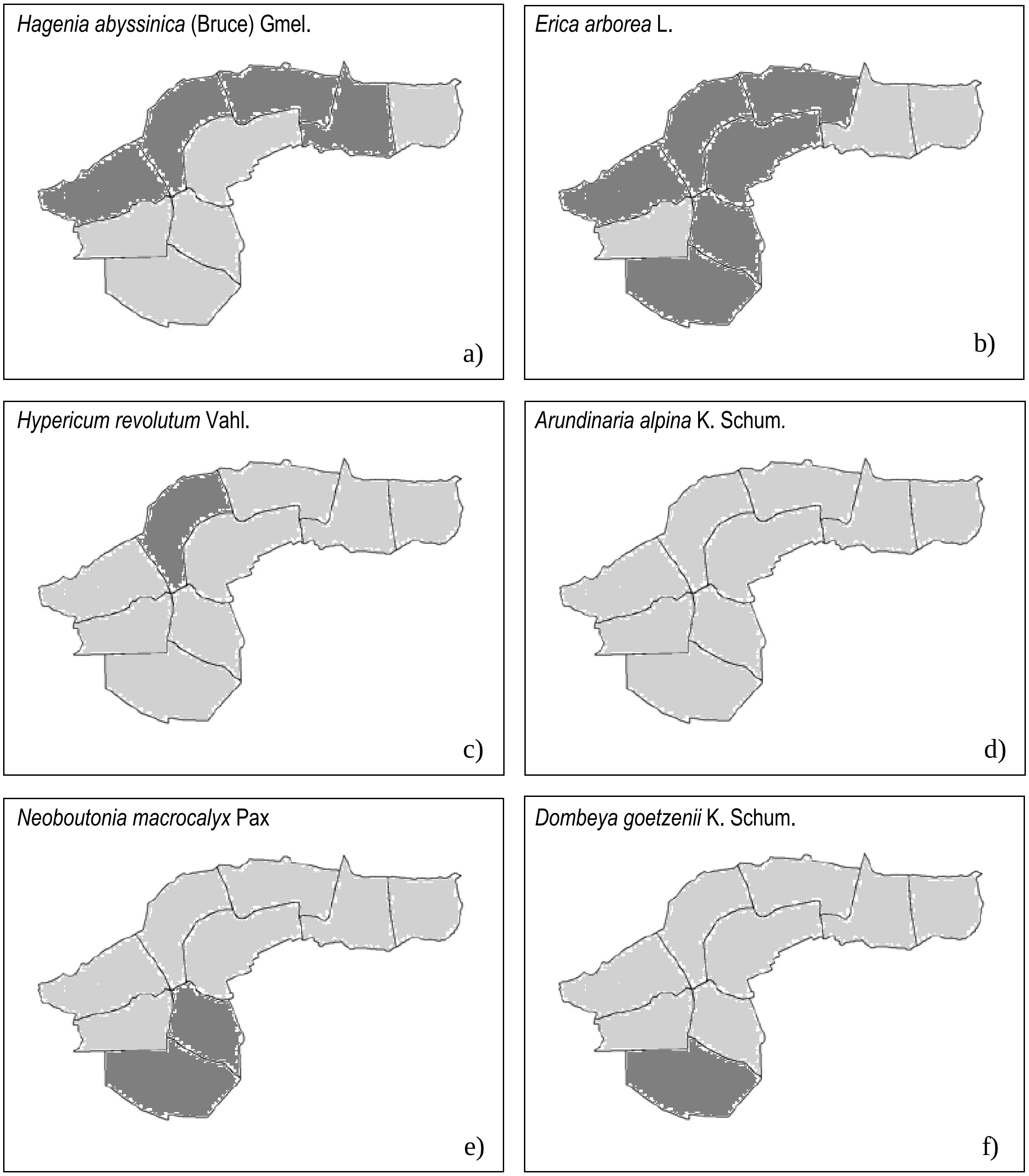

Figure 4. Occurrence of *H. abyssinica* and five other key tree species in virunga parks, including the PNV (for official boundaries of this park, please as shown in Figure 1).

adults than juveniles. For instance, if a tree takes 30 years to mature and lives for 600 years on average, with low mortality rates, a population could be stable with only a little over 30/600 or 5% juveniles. In addition, Norghauer et al. (2011) recognize that wind-mediated seed dispersal of tropical forest trees is poorly understood. Interestingly, they found that tree diameter correlated positively with increased seed shadow extent, with the bulk of seeds falling within *X* m from parent trees and juvenile-to-seed ratios peaking at [X+α] - [X+β] m, where X = 30, α = 5, β = 15, and m = 1 meter). One may infer that variables *X*, *α, and β* would vary from species to another. Note that the trees they studied were relatively isolated from each other. Relevant to the current study, one should wonder what would happen in a population of trees where the average distance between two neighbor trees is equal or less than X m. Obviously, the juvenile-to-seed peaks at [X+α] - [X+β] m would be suppressed and the number of stems within lower DBH classes significantly reduced. To insure more objectivity, further investigation is needed to determine the average age of trees at a given DBH class and juvenile-to-seed ratios in relation to distance between neighbor trees.

Elsewhere in the region, Ayalew (2003) obtained a comparable result, suggesting that *H. abyssinica* in Denkoro forest (Ethiopia) had fallen in the category of those tree species whose majority of individuals was in the highest DBH classes. In neighboring Uganda, *H. abyssinica* is missing on the list of 212 tree species recorded in four important forests [Bwindi Impenetrable National Park (BINP), Kasyoha-Kitomi Forest Reserve (KKFR), Kibale National Park (KNP) and Budongo Forest Reserve (BFR)], implying that it was too rare to be easily encountered during the survey.

Specifically for the virungas, Lejju et al. (2001) came up with a similar result in Mgahinga Gorilla National Park, where *H. abyssinica* was never recorded in undisturbed sites and had so-called highest frequency lower than 0.05% (=0.03%) in exotic woodlots, a result that was still applicable three years later (Lejju, 2004). Karlowski (2006) indirectly corroborated these findings upon examining the soil-seed bank in four afromontane forests in Bwindi Impenetrable National Park, along with two other Uganda’s forests (Mgahinga Gorilla National Park and Echuya Forest Reserve), only to realize that, in the Hagenia-Hypericum zone, the potential for regeneration to an afromontane forest was zero percent.

Hagenia historical occurrence in Rwanda

Although none of herbarium collections of this plant was taken from PNV, the arrested regeneration of *H. abyssinica* in PNV has been noted and reported by researchers for decades. The earliest note is that of Troupin (1980s) when he compiled his book ‘Flore des plantes ligneuses du Rwanda’. Troupin is responsible for four out of the nine collections of *H. abyssinica* at the National Herbarium of Rwanda. Unfortunately, he collected none from PNV or close areas.

The analysis of herbarium records confirmed that the collection of *H. abyssinica* globally followed a usual pattern as compared with five other tree species characteristic of the vegetation in PNV (please refer to Figure 3), such that the idea of a possible link between its absence in PNV records at the National Herbarium of Rwanda and its relatively lower abundance in this park is ruled out. Herbarium records show that Botanist G. Troupin had been in that park in 1974, where he collected specimens *D. goetzenii and A. alpina*. Why did he not collect any of *H. abyssinica*? Perhaps, he remembered to have collected four specimens of this plant in Nyungwe (2), Kibuye (1) and Gisenyi (1) the same year, maybe during the same tour. In any case, that, in his book, he noted the absence of any sign of regeneration of *H. abyssinica* PNV (Troupin, 1982), he attests to the hypothesis that he was well aware of the dynamics of this plant in that part of the country. What about the other four collectors of *H. abyssinica* specimens (Table 3), namely G. Bouxin, M. Radoux, M. Reynders, E. Nzakizwanayo, and F. Ngayabahiga? An examination of the entire plant database revealed that they did not collect any plant specimen of any species from PNV, suggesting that they simply did not work in that park at all.

Hagenia spatial distribution in the virungas

First reported in Troupin (1982), the absence of effective regeneration continued such that, in 1990s, seedlings and saplings of *H. abyssinica* were reported to be very rare in this park, except in few places where scattered cases of vegetative re-sprouting could be observed (Karamuka, 1993).

Steklis et al. (2005) produced an updated map of PNV vegetation. On this map, the area between Karisimbi and Bisoke (conventionally referred to as the "Karisoke" area, a name coined by late Dian Fossey) is shown in a kind of mosaic texture (Figure 5a), reflecting the existence of a more open Hagenia canopy, which aligns with Owiunji et al. (2004) when they indicate that the "Hagenia-Hypericum zone forms open canopies with abundant herbaceous undergrowth". It also is in accord with the findings of Dondeyne et al. (1993), suggesting that *H. abyssinica* had a rarer occurrence (overall frequency: 5 %) as compared with *H. revolutum* (overall frequency: 41%) (Details are provided in Table 5). Interestingly, Dondeyne (1992) suggests that Hagenia canopy in that area was still closed as of early 1990s. Note that the area is represented as a long and relatively wide strip on Marius’ map (Figure 5b); in contrast to the mosaic texture on Steklis et al.’s map (Figure 5a).

In their article on ranging behavior of southern tree hyrax in this park, Milner and Harris (1999) noted the uniform age structure within PNV Hagenia stands and confirmed the absence of regeneration. Owiunji et al. (2004) recognized that this species was IUCN red-listed as vulnerable [note the contradiction with IUCN (2013)], but said nothing about its status in PNV. A re-examination of the data they presented yielded a result that does not conflict with the idea that the problem with this plant is not at the level of presence/absence (Figure 4), but should be addressed from a density- and dynamics-dependent aspect. With knowledge drawn from having regularly visited this park during the second half of 2000s, combined with information from colleagues that continued to work in this park to date, the authors confirm that the species is currently mostly represented by large and old trees surrounded by an ever expanding herbaceous layer (Dondeyne et al. (1993).

Insight on possible conservation implications

The frequency of gorillas out-of-park in PNV has soared

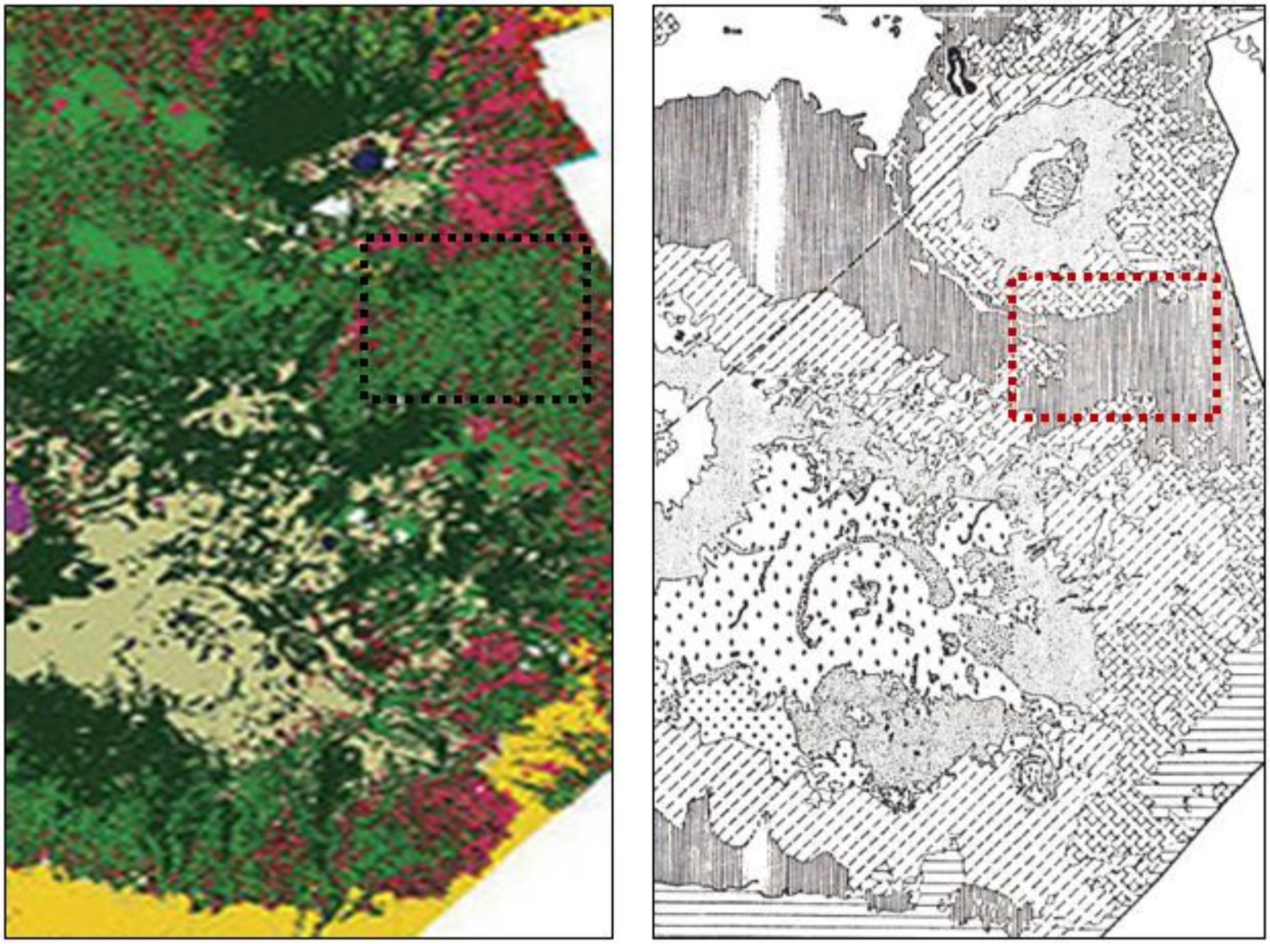

Figure 5. Evolution of Hagenia forest cover in PNV's Karisoke area (area inside black (a) and red (b) dash-edged rectangles): (a) 2000s vegetation map by Steklis et al. (2005) [area inside the black dash-edged rectangle] and (b) 1970s vegetation map by (Dondeyne, 1992) [area inside the red dash-edged rectangle].

Table 5. Presence/absence of *H. abyssinica* and *H. revolutum* in different sites around Bisoke volcano [A Paired sample Wilcoxon Signed Ranks Test yielded a result that suggests significant difference between the two distributions (W = 1, Z = - 2.12; Prob > |W| = 0.0312) (data extracted from Dondeyne et al. 1993).

Site ID number	*H. revolutum*	*H. abyssinica*
1	3	2
2	0	0
3	1	5
4	1	8
5	0	9
6	0	7
7	0	4
8	0	2
9	0	0

since recently. For instance, in 2011, a group of PNV gorillas, for the first time in history, nested on adjacent farmland for two consecutive nights (DFGFI, 2011). Does this unusual foraging behavior have something to do with the long-reported Hagenia forest arrested regeneration [or, as we prefer to call it, the unusual pattern of Hagenia population structure and distribution]? Perhaps, it is too early to establish such a causal relationship. Nevertheless, according McNeilage (2001), corroborated by Kayijamahe (2008), gorillas in PNV [serving as the flag and umbrella species for this park (Cowlishaw and Dunbar, 2000)] spend most of their life time in the nutritious herbaceous habitats near or within the Hagenia-Hypericum zone. Mammal-forest interactions in PNV have also been established as resulting from the 1990s park amputations that caused the animals adapted to the Neoboutonia forest to retreat to the remaining part of the park, thus, exerting more pressure on the vegetation and altering the course of succession within the bamboo and Hagenia forests (Murererehe, 2000; Nsanzurwimo, 2004; Plumptre, 1993). Therefore, there is room to hypothesize that overgrazing and trampling of vegetation under Hagenia tree canopy may have had the effect of widening forest gaps and perpetuating the herb-

Table 6. Protection status of *H. abyssinica.*

Species	International protection			National legal protection	
	ARE	CP	IR	Specific-based	Ecosystem- based
Erica arborea L.	0	0	0	0	1
Hypericum revolutum Vahl.	0	0	0	0	1
Hagenia abyssinica (Bruce) Gmel.	0	0	1	0	1
Dombeya goetzenii K. Schum.	0	0	0	0	1
Arundinaria alpina K. Schum.	0	0	0	0	1
Neoboutonia macrocalyx Pax	0	0	0	0	1

ARE: Albertine Rift Endemic, CP: CITES-protected, IUCN-red listed.

aceous physiognomy through cyclic grassy vegetation renewal, which impedes the return to a closed forest cover (Babaasa et al., 2004; Babaasa, 2009; Chapman et al., 1999; Lange et al., 1997; Paul et al., 2004; Plumptre, 1993). This effect may have been exacerbated by the fact that poaching activities, very common in the areas of Mikeno, south of Karisimbi and eastern part of the virunga massif, caused further confinement of PNV gorilla range to only a small portion of the suitable space (Gray et al., 2005; van Gils and Kayijamahe, 2009). More evidenced, the decline of southern tree hyraxes in PNV has been linked to the ever noticeable rarefaction of large and cavity-forming Hagenia trees, the most preferred trees for hyrax feeding and shelter in PNV (Milner and Harris, 1999; Topp-Jørgensen et al., 2008). Conversely, the decline of tree hyraxes may have had a fallout on Hagenia population structure (Seufert et al., 2009; Shanahan et al., 2001).

The ministerial Order No 007/2008 of 15/08/2008 establishes the list of protected animal and plant species in Rwanda (Primature, 2008). Unfortunately *H. abyssinica* was not included, perhaps because the promoters of this law had shared the view that this species is abundant in Nyungwe National Park (Fischer and Killmann, 2008; Bloesch et al., 2009) [which corroborates the opinion held by scientists at Kew Gardens assigning it the IUCN Red List Index of a "Least Concern" species (Kew Gardens, 2014)] or simply were not advised on its status in PNV and elsewhere (Owiunji et al., 2004). That this species, though already listed in its "Catalogue of Life", has not yet been assessed for the official IUCN Red Listing may suggest that it is too abundant to receive the attention of scientists who would otherwise be prompted to refer it to the IUCN Red List Authorities for consideration (IUCN, 2013). However, such reports should not distract researchers in Rwanda from the aim to investigate the problem Hagenia is faced with in PNV. After all, what suppresses it in PNV, if remained unidentified or not dealt with, may soon follow it also in areas where it is currently abundant.

To illuminate these relationships, there is a need to conduct extensive research on the ecology of regeneration of *H. abyssinica*, which has already begun elsewhere but in Rwanda (Feyissa et al., 2005; Feyissa et al., 2007b). Meanwhile, this tree species should be provisionally listed as endangered in Rwanda, and possibly be included on the checklist of nationally protected species of Rwanda (please see Table 6 for updates on the current status).

Conclusion

This study established that *H. abyssinica* in PNV has an unusual pattern of population structure and distribution, seemingly since many decades ago. The earliest note of PNV Hagenia forest recession dates back to 1980s. Analysis of herbarium records confirmed that the collection of *H. abyssinica* globally followed a usual pattern as compared with five other tree species characteristic of the vegetation in PNV, to such an extent that the idea of a possible link between its absence in PNV records at the National Herbarium of Rwanda and its relatively lower abundance in this park is ruled out. All Hagenia collectors but Troupin G. appeared to have not worked in PNV at all, partly explaining why none of the Hagenia specimens was taken from this park. The reason why Troupin did not collect one in PNV while he collected other species [*Arundinaria alpina* K. Schum. (Specimen No 15444) and *Dombeya goetzenii* K.Schum. (Specimen No 15413)] from this park in 1974 remains an unanswered question. However, there is evidence that he was well aware of the dynamics of this plant in that part of the country. An examination of most recent references to Hagenia forest in PNV showed that the problem with this plant is not at the level of presence/absence, but is mostly a density- and dynamics-related issue. Because extensive research is needed before any course of field-based conservation action should be taken to deal with effects of this problem on other species, its provisional listing as endangered in Rwanda, and possibly its inclusion on the checklist of nationally legally protected species is recommendable.

Conflict of Interests

The author(s) have not declared any conflict of interests.

ACKNOWLEDGMENTS

This paper was compiled as a component of a bigger research project on threatened indigenous plants and invasion risk assessment in Rwanda (TIPIRAR), partly funded by the Rwanda Education Board. The authors thank the Institute of Research in Science and Technology (IRST) to have made the database of herbarium records available. They also acknowledge the contribution of former and current staff at RDB (Parc National des Volcans) and DFGFI-Karisoke Research Center for the information they provided.

REFERENCES

Antonovics J, Hood ME, Thrall PH, Abrams JY, Duthie GM (2003). Herbarium studies on the distribution of anther-smut fungus (Microbotryum violaceum) and Silene species (Caryophyllaceae) in the eastern United States. Am. J. Bot. 90: 1522-1531. http://dx.doi.org/10.3732/ajb.90.10.1522;PMid:21659105.

Ayalew A (2003). A floristic composition and structural analysis of Denkoro forest, South Wello. Master's Thesis, Addis Ababa University.

Babaasa D, Bitariho R, Kasangaki A (2009). Some observations of the impact of Sericostachys scandens on forest regeneration in Bwindi Impenetrable Forest (Uganda). In: Chao N, Rugyerinyange L, and Scholte P (eds.). Conference on the Impact of Sericostachys scandens on the Conservation of Nyungwe National Park. Rwanda Environment Management, Kigali.

Babaasa D, Eilu G, Kasangaki A, Bitariho R, McNeilage A (2004). Gap characteristics and regeneration in Bwindi Impenetrable National Park, Uganda. Afr. J. Ecol. 42: 217-224. http://dx.doi.org/10.1111/j.1365-2028.2004.00519.x

Bloesch U, Troupin G, Derungs N (2009). Les plantes ligneuses du Rwanda: Flore, ecologie et usages. Shaker Verlag, Aachen.

Botanical Garden Meise (2014). The BR herbarium catalogue: Hagenia abyssinica. Available at: www.br.fgov.be (Last accessed on 23.02.2014).

Chapman CA, Chapman LJ, Kaufman L, Zanne, AE (1999). Potential causes of arrested succession in Kibale National Park, Uganda: growth and mortality of seedlings. Afr. J. Ecol. 37: 81-92. http://dx.doi.org/10.1046/j.1365-2028.1999.00159.x

Cowlishaw G, Dunbar R (2000). Primate conservation biology. University of Chicago Press, Chicago. PMid:11075706; PMCid:PMC1690772.

DFGFI (2011). Notes from the field: Titus group sleeps outside of park again [Tuesday, November 8th, 2011]. Available at: www.gorillafund.org (Last accessed on 22.11.2011).

Dondeyne S (1992). A study of the soils and vegetation of the Bisoke volcano (Rwanda). Report prepared for The Digit Fund, Katholieke Univerteit Leuven, Leuven.

Dondeyne S, Deckers JA, Chapelle J (1993). The soils and vegetation of the Bisoke volcano (Rwanda): Habitat of mountain gorillas. Pedol. XLIII, 301−322.

Eilu G, Hafashimana DLN, and Kasenene JM (2004). Tree species distribution in forests of the Albertine Rift, western Uganda. Afr. J. Ecol. 42: 100-110. http://dx.doi.org/10.1111/j.1365-2028.2004.00504.x

Eilu G, Obua J (2005). Tree condition and natural regeneration in disturbed sites of Bwindi Impenetrable Forest National Park, southwestern Uganda. Trop. Ecol. 46: 99-111.

FDRE (1994). Forestry Proclamation (NO. 94/1994). Federal Democratic Republic of Ethiopia, Addis Ababa.

Feyissa T, Nybom H, Bartish IV, Welander M (2007a). Analysis of genetic diversity in the endangered tropical tree species Hagenia abyssinica using ISSR markers. Genet. Resour. Crop. Evol. 54: 947-958. http://dx.doi.org/10.1007/s10722-006-9155-8

Feyissa T, Welander M, Negash L (2005). *In vitro* regeneration of Hagenia abyssinica (Bruce) J.F. Gmel. (Rosaceae) from leaf explants. Plant Cell Rep. 24: 392-400. http://dx.doi.org/10.1007/s00299-005-0949-5; PMid:15827747.

Feyissa T, Zhu LH, Negash L, Welander M (2007b). Regeneration and genetic transformation of Hagenia abyssinica (Bruce) J.F. Gmel. (Rosaceae) with rolB gene. Plant Cell Tissue Organ Cult. 88: 277-288. http://dx.doi.org/10.1007/s11240-006-9200-5

Fischer E, Killmann D (2008). Plants of Nyungwe National Park, Rwanda. Koblenz Geographical Colloquia, First Edition, Koblenz.

Fuentes N, Pauchard A, Sanchez P, Esquivel J, Marticorena A (2013). A new comprehensive database of alien plant species in Chile based on herbarium records. Biol. Invasions 15: 847-858. http://dx.doi.org/10.1007/s10530-012-0334-6

Gray M, McNeilage A, Fawcett K, Robbins M, Ssebide B, Mbula D, Uwingeli P (2005). Virunga volcanoes range mountain gorilla census, 2003.

IUCN (2013). IUCN Red List of Threatened Species. Available at: www.iucnredlist.org (Last accessed on 24.02.2014).

Kayijamahe E (2008). Spatial modelling of mountain gorilla (Gorilla beringei beringei) habitat suitability and human impact. Master's Thesis, International Institute of Geo-Information Science and Earth Observation, Netherlands.

Karamuka F (1993). Variation spatio-temporelles des activités chez un groupe de gorilles de montagne (Gorilla beringei beringei) du parc National des Volcans. BSc Thesis, National university of Rwanda.

Karlowski U (2006). Afromontane old-field vegetation: secondary succession and the return of indigenous species. Afr. J. Ecol. 44: 264-272.http://dx.doi.org/10.1111/j.1365-2028.2006.00647.x

Kew Gardens (2014). Species browser: Hagenia abyssinica (hagenia). Available at: www.kew.org (Last accessed on 20.02.2014).

Kibebew F, Addis G (1996). Utilization and conservation of medicinal plants in Ethiopia. Proceedings of the Workshop on Development Utilization of Herbal Remedies in Ethiopia.

Lange S, Bussmann RW, Beck E (1997). Stand structure and regeneration of the subalpine Hagenia abyssinica forests of Mt. Kenya. Bot. Acta 110: 473-480. http://dx.doi.org/10.1111/j.1438-8677.1997.tb00665.x

Lejju JB (2004). Ecological recovery of an afromontane forest in southwestern Uganda. Afr. J. Ecol. 42: 64-69. http://dx.doi.org/10.1111/j.1365-2028.2004.00463.x

Lejju JB, Oryem-Origa H, Kasenene JM (2001). Regeneration of indigenous trees in Mgahinga Gorilla National Park, Uganda. Afr. J. Ecol. 39: 65-73. http://dx.doi.org/10.1046/j.1365-2028.2001.00273.x; http://dx.doi.org/10.1111/j.1365-2028.2001.00273.x.

McNeilage A (2001). Diet and habitat use of two mountain gorilla groups in contrasting habitats in the Virungas. In: Robbins M, Sicotte P, Stewart KJ (Eds.). Mountain gorillas: three decades of research at Karisoke, Cambridge University Press, Cambridge. http://dx.doi.org/10.1017/CBO9780511661631.011; PMid:11367776

McNeilage A (1995). Carte de la végétation du Parc National des Volcans.

Milner JM, Harris S (1999). Habitat use and ranging behaviour of tree hyrax, Dendrohyrax arboreus, in the Virunga Volcanoes, Rwanda. Afr. J. Ecol. 37: 281-294. http://dx.doi.org/10.1046/j.1365-2028.1999.00184.x; http://dx.doi.org/10.1046/j.1365-2028.1999.00185.x

Murererehe S (2000). Collecte et analyse de données pour l'aménagement durable des forêts -joindre les efforts nationaux et internationaux; Etat des ressources forestières au Rwanda. Technical Report, FAO, Rome.

Norghauer JM, Nock CA, Grogan J (2011). The importance of tree size and fecundity for wind dispersal of Big-Leaf Mahogany. Plos One 6(3): e17488. http://dx.doi.org/10.1371/journal.pone.0017488;PMid:21408184; PMCid:PMC3049789.

Nsazurwimo A (2004). Etude analytique des communautés de Bambous à Sinarundinaria alpina en rapport avec leur milieu écologique (cas du Parc National des Volcans). Mémoire, Butare, Université Nationale du Rwanda.

Owiunji I, Nkuutu D, Kujirakwinja D, Plumptre A, Nsanzurwimo A, Fawcett K, Gray M, McNeilage A (2004). The biodiversity of the virunga volcanoes. WCS, DFGFI, ICCN, ORTPN, UWA, IGCP, Kigali.

Paul JR, Randle AM, Chapman CA, Chapman LJ (2004). Arrested succession in logging gaps: is tree seedling growth and survival limiting? Afr. J. Ecol. 42: 245-251. http://dx.doi.org/10.1111/j.1365-2028.2004.00435.x

Plumptre AJ (1993). The effects of trampling damage by herbivores on the vegetation of the Parc National des Volcans, Rwanda. Afr. J. Ecol. 32: 115-129. http://dx.doi.org/10.1111/j.1365-2028.1994.tb00563.x

Plumptre AJ, Davenport TRB, Behangana M, Kityo R, Eilu G, Ssegawa P, Ewango C, Meirte D, Kahindo C, Herremans M, Peterhanse JK, Pilgrim JD, Wilson M, Languy M, Moyer D (2007). The biodiversity of the Albertine Rift. Biol. Conserv. 134: 178-194.http://dx.doi.org/10.1016/j.biocon.2006.08.021

Primature (2008). Official Gazette of the Republic of Rwanda, JO N°22 OF 15/11/2008 Year 47 n° 22 15 November 2008. Office of the Prime Minister, Kigali.

Sarmiento EE, Butynski TM, Kalina J (1996) Gorillas of Bwindi impenetrable forest and the Virunga volcanoes: Taxonomic implications of morphological and ecological differences. Am. J. Primatol. 40: 1−21. http://dx.doi.org/10.1002/(SICI)1098-2345(1996)40:1<1::AID-AJP1>3.0.CO;2-1

Seburanga JL (2007). Study of forest regeneration in disturbed and undisturbed areas of Mt Muhabura hillsides. BSc. Thesis (draft), National University of Rwanda.

Seufert V, Linden B, Fischer F (2009). Revealing secondary seed removers: Results from camera trapping. Afr. J. Ecol. 48: 914-922. http://dx.doi.org/10.1111/j.1365-2028.2009.01192.x

Shanahan M, So S, Compton S, Corlett R (2001). Fig-eating by vertebrate frugivores: A global Review. Biol. Rev. 76: 529-572. http://dx.doi.org/10.1017/S1464793101005760; PMid:11762492.

Steklis HD, Madry S, Steklis NG, Faust N (2005). GIS Applications for Gorilla Behavior and Habitat Analyses. Available at: www.esri.com (Last accessed on 20.02.2014).

Topp-Jørgensen JE, Marshal AR, Brink H, Pedersen UB (2008). Quantifying the response of tree hyraxes (Dendrohyrax validus) to human disturbance in the Udzungwa Mountains, Tanzania. Trop. Conserv. Sci. 1: 63-74.

Troupin G (1982). Flore des plantes ligneuses du Rwanda: Hagenia abyssinica (Bruce) J. F. Gmelin. IRST, Butare.

Turner IM (2001). The ecology of trees in the tropical rain forest. Cambridge Tropical Biology Series, Cambridge University Press, Cambridge. http://dx.doi.org/10.1017/CBO9780511542206

Vamosi JC, Vamosi SM (2005). Present day risk of extinction may exacerbate the lower species richness of dioecious clades. Divers. Distrib. 11: 25-32. http://dx.doi.org/10.1111/j.1366-9516.2005.00119.x

Van Gils H, Kayijamahe E (2009). Sharing natural resources: mountain gorillas and people in the Parc National des Volcans, Rwanda. Afr. J. Ecol. 48: 621-627.

Verdoodt E, Van Ranst, E (2003). Land Evaluation for agricultural Production in the Tropics: A large-scale land suitability classification for Rwanda. Laboratory of Soil Science, Ghent University.

Watts D (1983). Foraging strategy and sociology of mountain gorilla (Gorilla gorilla beringei) and their relation to food availability. University of Chicago.

Weber W, Vedder AL (1983). Population dynamics of the virunga gorillas: 1959-1978. Biol. Conserv. 26: 341-366. http://dx.doi.org/10.1016/0006-3207(83)90096-4

White L, Edwards A (2000). Conservation en forêt pluviale africaine: Méthodes de recherche. Wildlife Conservation Society, New York.

academicJournals

Vol. 6(5), pp. 183-189, May 2014
DOI: 10.5897/JENE2013.0432
Article Number: 4D1E9AF43795
ISSN 2006-9847

http://www.academicjournals.org/JENE

Journal of Ecology and the Natural Environment

Full Length Research Paper

Diversity of *Vepris heterophylla* (Engl.) Letouzey morphotypes in the Sudano-Sahelian zone of Cameroon

Y. Hamawa[1,2]* and P. M. Mapongmetsem[2]

[1]Department of Agriculture, Breeding and Derived Products, Higher Institute of the Sahel, University of Maroua, P.O. Box 46 Maroua, Cameroon.
[2]Department of Biological Sciences, Faculty of Science, University of Ngaoundéré, P.O. Box 454 Ngaoundéré, Cameroon.

Received 24 December, 2013; Accepted 27 February, 2014

***Vepris heterophylla* (Engl.) Letouzey (Rutaceae) is a useful and threatened plant of Sudano-Sahelian zone of Cameroon. However, its description is not clear. This study aims to evaluate morphological variations among ten populations to delimitating the *V. heterophylla* morphotypes in the zone. Two hundred and fifty (250) individuals belonging to 10 populations were assessed by morphological descriptors including eight quantitative parameters (Leaf length, leaf width, petiole length, petiolule length, acumen length, fruit major axis and fruit minor axis). The data underwent a principal components analysis (PCA). Results show that the leaf length, leaf width, the petiole length, the petiolule length and the acumen length varied from 54.4 to 102.29, 18.61 to 30.0, 16.44 to 31.16, 1.18 to 2.8 and 1.71 to 4.3 mm, respectively. The fruit major axis, the fruit minor axis and the peduncule length ranged respectively from 1.13 to 1.34, 0.95 to 1.15 and 0.31 to 0.44 mm. PCA generated from grower general dissimilarity coefficient among all populations showed three distinct populations. Grouping of populations did not reflect bioclimatic patterns, this allows saying that the distribution of population could be influenced by environmental conditions. The divergence between the 10 populations based on morphological traits presented in this study constitutes a fundamental element in the improvement of the delimitation of the species morphotype.**

Key words: Morphological descriptors, population, *Vepris heterophylla*, Sudano-Sahelian zone, morphotype.

INTRODUCTION

The genus *Vepris* (Comm. ex A. Juss.) (Rutaceae) consists of about 80 species distributed mostly in African continent. Among them about 30 are endemic to Madagascar and one in India. The kinkéliba of Kita is said to reduce high blood pressure and have antipyretic properties. The genus has been reported to be useful for conjunctivitis, as diuretics, as antihelminthic. Moreover, decoctions from leaves of Kinkeliba of Kita have been used as beverage each evening fasting in West Africa countries (Keita and Ouattara, 1995); the leaves have

*Corresponding author. E-mail: hamawayougouda@yahoo.fr.

been traditionally used in crop protection for the reduction of post-harvest losses due to insect pests (Ngamo et al., 2007). The essential oil obtained from leaves of Kinkéliba of Kita contain about 35 compounds mainly alkaloids, triterpenes and flavonoids (Matu, 2011). *Vepris heterophylla* is the most important species. It is a shrub native to Sudano-Sahelian countries and grows wild on rocky mountains. It is a shrub of about 5 m high, low-branched, more or less sarmentous, at rounded crown and dense enough (Arbonnier, 2002). It has a weakly continuous range of distribution in the African continent extending from Mali and Ghana in west towards the Africa centre mountains (Geerling, 1987). In Cameroon, the Sudano-Sahelian mountains represent the easternmost limit of its distribution range (Mziray, 1992; Hawthorne, 1995). This reflects the adaptation of plant to diverse soil and climatic conditions such as drought.

In Cameroon, in spite of the great importance of *V*. *heterophylla*, only little study has been done on its identification. Kinkeliba of Kita is characterized by a wide geographical distribution (Letouzey, 1985). It has a wide variety of synonyms such as *toddaliopsis hetrophylla*, *Tecleopsis heterophylla* and *Teclea heterophylla* (Matu, 2011). However, available reports on its description are insufficient to clarify the situation (Geerling, 1987) leading some authors to make reservations on this species. The existence of this species on the IUCN Red List (Ngamo et al., 2007) as an endangered species reinforces the idea that the revision of its description is necessary. In Cameroon, the distribution and the status of the species population were unknown. Little is known about this species including the morphology description, molecular chemistry, multiplication and ethnobotany. The absence of an accurate taxonomy for *V*. *heterophylla* poses a problem for the botanical classification. The aim of this work is to evaluate the morphological variations among the ten populations of *V*. *heterophylla* using numerical method.

MATERIALS AND METHODS

Study sites

The study was conducted at the Sudano-Sahelian zone of Cameroon that is situated between the 8 and 13° of the Northern Latitude. It extends from Adamawa to the banks of the Lake Chad on about 100,000 km^2, that including more than 1/5 of the surface of Cameroon. It included the following mountains: Kalliao, Bilguim, Ndougour, Kotorba, Mokolo, Tinguilin, Lagdo, Nakalba, Fignolé and Tchollirè which are the different habitats of *V*. *heterophylla* in Cameroon (Geerling, 1987) (Figure 1). The Sudano-Sahelian climate is characterized by two different seasons: the dry season which lasts for 8 months (ranging from October to May) and the short rainy season which lasts for four months (ranging from June to September). The average (± standard deviation (SD)) annual rainfall from 1970 to 2010 was evaluated at 748±120 mm while the mean annual temperature was 28°C. The characteristic of the flora in the region is that of steppes with thorn-bush made up of shrubby savannahs with a very irregular herbaceous floor cover dominated by thorn-bushes, strongly degraded as the result of human actions (Letouzey, 1985). The rainfall of the region has created a network of permanent (Benue, Deo Logone) and seasonal (Mayo Tsanaga) rivers that flows toward the Lake Chad (Mayo Tsanaga, the Logone) and toward the Katsena (Deo, Benue).

Measurements

Morphometric studies were carried out on 250 individuals belonging to 10 mountains presented in Figure 1 (25 individuals/mountain). The different parameters were obtained on parts which are not parasitized. In all, eight descriptors were employed for each population and data collected were statistically analyzed and recorded. Measurements were taken for eight selected quantitative major descriptors which are: leaf length, leaf width, petiole length, petiolule length, acumen length, fruit major axis, fruit minor axis and peduncule length.

As *V. heterophylla* leaf being a compound leaf, the leaf width and the acumen length were obtained from the average of the width of the leaflets and the average of the acumen length of the leaflets. All these parameters were measured using calipers. The mean, standard deviation and coefficient of variation were calculated for all eight descriptors. Principal component analysis was also carried out on the eight selected quantitative measurements. The objective was to determine the descriptor that contributed strongly to the delimitation of taxa.

RESULTS

The eight morphological descriptors of the *V. heterophylla* populations in Sudano-Sahelian zone of Cameroon were examined with numerical methods. The morphological features employed for delimitation of the 10 populations with their means, standard deviations and coefficients of variation are shown in Table 1.

To assess the patterns of variance, principal coordinate analysis was run considering all the studied variables. The first three principal components explained 89% of the total morphological variation in *V*. *heterophylla* populations (Table 2). The traits in the principal components (axis) were identified on the basis of eigenvectors (Table 2 and Figure 2).

The first principal component (axis 1) accounted for 42.01% of inertia explaining the largest portion of the variance (Table 3). It is correlated positively with all parameters. The axis 2 accounted 31.28% of the total inertia and was negatively correlated with leaf length, leaf width and petiole length (Table 3). The population plot in the plan defined by the two-first axes showed the separation of population in three distinct groups coded respectively Gp1, Gp2 and Gp3 independently to their geographical origins (Figure 2). The first group comprises three populations Nakalba, Lagdo and Tinguilin. The second group includes four populations which are Bilguim, Kotorba, Fignolé and Mokolo. Populations of Ndougour, Kalliao and Tchollirè constitue the third group situated at the negative side of axis 1.

Similarity matrix based on correlation of *V. heterophylla* populations presented as Table 4 shows that close

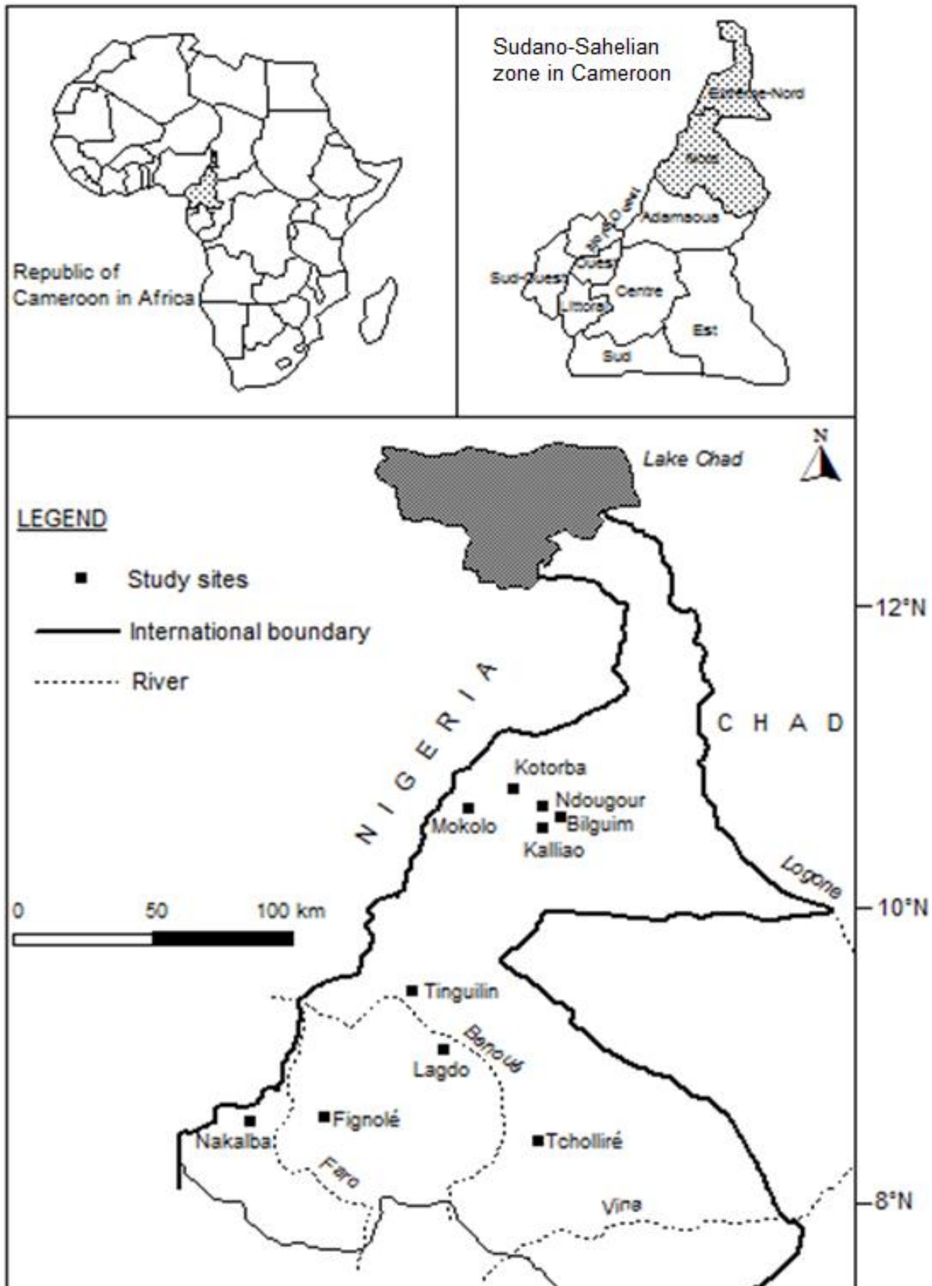

Figure 1. Localization of the study sites.

resemblance of populations could be observed when certain characters are employed. For example, when leaf length was correlated with leaf width, the degree of affinity was 0.965 and 0.117 when correlated with fruit major axis. Similarly when the petiole length was correlated with leaf width, the degree of resemblance was 0.951. It was 0.331 when correlated against peduncule length. Thus, it is shown that there is significant correlation between leaf length and leaf width, leaf length and fruit major axis, petiole length and leaf width, petiole length and peduncule length. The principal coordinates analysis on morphological descriptors determined on 10 populations shown in Table 2 also revealed that some characters carry more weight in the variation than others indicating the importance of certain characters in the delimitation of the population. It gives the figurative

Table 1. The means, standard deviations of morphometric descriptors used. The coefficients of variation are in parenthesis.

Population	Morphometric character (mm)							
	L. length	**L. width**	**P. length**	**Ple length**	**A. length**	**D**	**d**	**Pe. length**
Kalliao	54.4 ± 8.3 (15.3)	19.3 ± 3 (18.1)	17 ± 2.7 (16)	1.18 ± 0.9 (53.5)	2.56 ± 1.1 (42.57)	1.31 ± 0.07 (5,1)	1.12 ± 0.05 (4.9)	0.36 ± 0.01 (1.7)
Bilguim	80.3 ± 11.2 (13.9)	25.7 ± 3 (13.6)	23 ± 4.6 (20.1)	1.44 ± 0.5 (36.1)	1.76 ± 0.5 (27.84)	1.15 ± 0.1 (4.5)	0.95 ± 0.2 (19.8)	0.32 ± 0.03 (10)
Ndougou	52.9 ± 7.4 (14)	18.6 ± 3 (18.8)	16.4 ± 2.7 (16.6)	1.38 ± 0.78(63)	2.44 ± 0.9 (37.29)	1.13 ± 0.1 (6.2)	0.95 ± 0.2 (18.9)	0.31 ± 0.03 (9.84)
Kotorba	79.9 ± 12.8 (15)	25.3 ± 4 (14.6)	21.44 ± 5 (24)	1.92 ± 1.4 (71.1)	1.71 ± 0.6 (33.33)	1.23 ± 0.1 (8.)	1.06 ± 0.2 (20.63)	0.37 ± 0.04 (11.3)
Mokolo	75.9 ± 7.4 (13.3)	24.9 ± 3 (15.7)	21.3 ± 2 (11.4)	1.91 ± 1 (34.9)	1.78 ± 1.1 (40.80)	1.34 ± 0.03 (2.5)	1.15 ± 0.04 (3.86)	0.44 ± 0.2 (46.93)
Tinguilin	90.6 ± 8.2 (8.9)	27.9 ± 2.4 (8.5)	30.6 ± 3.4 (11.8)	1.34 ± 1 (62.7)	2.96 ± 0.7 (23.98)	1.31 ± 0.1 (4.7)	1.12 ± 0.06 (4.96)	0.40 ± 0.1 (14.3)
Lagdo	101.1 ± 8.2 (8.9)	29.9 ± 2 (6.5)	30.8 ± 4 (11.5)	1.34 ± 1 (37.3)	2.96 ± 0.5 (16.38)	1.34 ± 0.03 (2.4)	1.15 ± 0.04 (3.86)	0.40 ± 0.4 (98.7)
Nakalba	102.4 ± 6.2 (6.1)	30 ± 2.4 (7.9)	31.16 ± 3 (9.3)	1.82 ± 1 (39.43)	2.98 ± 0.5 (16.77)	1.17 ± 0.1 (4.1)	0.95 ± 0.9 (98.53)	0.35 ± 0.04 (10.8)
Fignolé	90.6 ± 16.5 (21.9)	24.5 ± 4.2 (16.9)	22.2 ± 5 (24.7)	1.83 ± 1.4 (58.1)	1.74 ± 0.5 (16.77)	1.31 ± 0.1 (5.1)	1.12 ± 0.06 (5.0)	0.36 ± 0.03 (8.6)
Tcholliré	64 ± 105.6 (109.3)	21.8 ± 4 (18.4)	19 ± 4.6 (20.8)	2.8 ± 1 (53.5)	4.3 ± 0.8 (39.8)	1.31 ± 0.1 (4.7)	1.14 ± 0.06 (5.06)	0.37 ± 0.05 (13.1)
F	2.29	5.80	43.01	3.37	3.83	604.205	625.775	615.748
P-Value	0.0038	0.0000	0.0000	0.0000	0.0000	< 0.0001	< 0.0001	< 0.0001

L. length: Leaf length; L. width: Leaf width; P. length: Petiole length; Ple length: Petiolule length; A. length: Acumen length; D: big axis of fruit; d: minor axis of fruit; Pe: length: Peduncle length; F: test F; each value is the mean ± standard deviation

Table 2. Principal coordinates analysis (PCO) on morphological descriptors determined on 10 *Vepris heterophylla* populations.

Parameter	**Axis 1**	**Axis 2**	**Axis 3**
Eigen values	3.361	2.502	1.268
Percentage	42.014	31.280	15.853
Cumulative percentage	42.014	73.293	89.146
Descriptors	Correlations coefficients		
L. length	0.782	-0.575	0.053
L. width	0.800	-0.576	0.093
P. length	0.781	-0.579	0.129
Ple Length	0.090	0.428	0.696
A. length	0.183	0.296	0.794
D	0.679	0.684	-0.199
D	0.603	0.757	-0.184
Pe. Length	0.796	0.439	-0.225

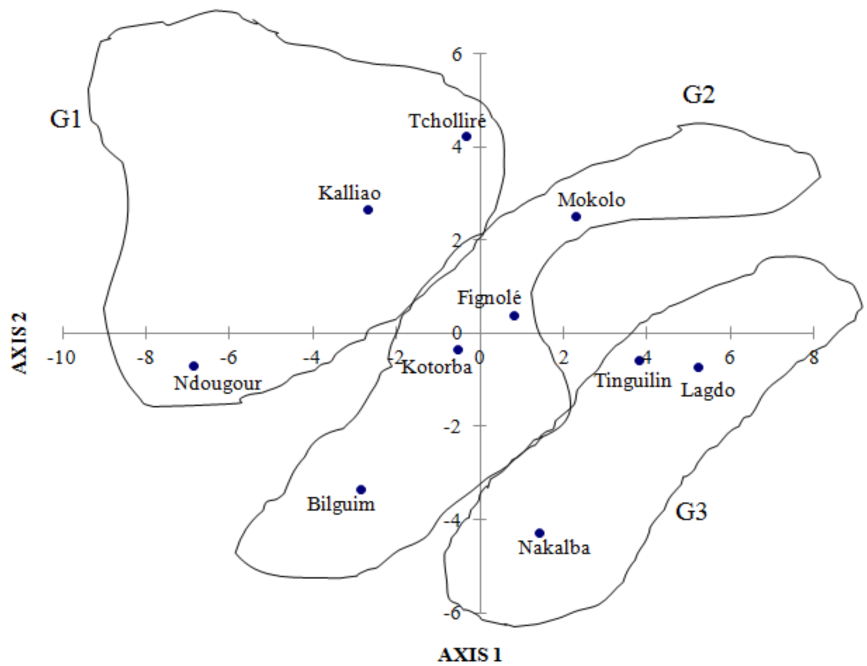

Figure 2: Principal component analysis (PCA) on morphological descriptors data based gower general dissimilarity coefficient determinate on 10 populations of *V. heterophylla* in Sudano-sahelian zone of Cameroon.

Table 3. Similarities matrix based on correlation coefficient of *Vepris heterophylla* populations.

Variable	L. length	L. width	P. length	Ple Length	A. length	D	d	Pe. length
L. length	**1**							
L. width	**0.965**	**1**						
P. length	**0.918**	**0.951**	**1**					
Ple Length	-0.052	-0.057	-0.189	**1**				
A. length	-0.064	0.004	0.163	0.413	**1**			
D	0.139	0.117	0.119	0.166	0.207	**1**		
D	0.040	0.021	0.016	0.216	0.214	**0.987**	**1**	
Pe. length	0.319	0.381	0.331	0.162	0.054	**0.828**	**0.797**	**1**

representation of the weight of the characters employed. Those above +1 eigen values are very much stronger than those below. The higher values of cumulative percentage of these characters explain that it weigh higher than the rest five characters employed in the analysis, with eigen values greater than 1.

DISCUSSION

The methods of numerical taxonomy have been used in classifying many plants as well as interpreting results of taxonomic studies (Sonibare et al., 2004; Soladoye et al., 2008). Morphometric analysis is commonly performed on organisms and is particularly useful in analyzing the fossil record. Morphometrics add a quantitative element to descriptions, allowing more rigorous comparisons. Botanists have usually established differences within species using several morphological traits. These latter are the first step of species identification before the use of molecular markers and other morphological characteristics such as floral traits. In the numerical analysis of 10 populations of *V. heterophylla* utilizing eight quantitative characters, present results confirm that variations in the leaves and fruits characters among the 10 populations are important diagnostic and could be used taxonomically in their delimitation. According to Terzopoulos et al. (2003), some quantitative traits were very important in the evaluation and characterization of broad beans. Equally, Awatef et al. (2013) used the morphological descriptors for delimiting three groups of *Capparis spinosa* in Tunisia. Significant correlation existing between leaf length and leaf width, petiole length and leaf width, fruit major axis and fruit minor axis shows that these characters were important in the overall analyses. Of the eight parameters used in the analyses, leaf length, Leaf width, petiole length, fruit major axis, fruit minor axis and peduncle length have higher value (above 0.5) than the remaining two characters; affirming their usefulness for delimitation purpose. Comparable deduction had been made in earlier studies reported by Stern (2000) and Soladoye et al. (2010) in the morphological features in taxonomic classification of plants. The quantitative characters used in this study showed significant coefficients of variation in the Sudano-Sahelian zone (Table 1) indicating a multitude of morphotypes of *V*. *heterophylla* in the zone. The large number of morphotype was supported by the higher coefficient of variation existing within the population of *V*. *heterophylla*. For these raisons, several authors reported the usefulness of quantitative characters in taxonomic classification of plants (Nwachukwu, 1997; Stern, 2000; Soladoye et al., 2010).

Morphological variation studies are useful to reveal the genetic diversity collections of *V*. *heterophylla*. Then, various studies are necessary to find the "hidden treasure among the collection that could both allow to the scientific community to answer definitively to the species descripttion problems. For this, the morphological variation seems to be the first step in the description and the classification of population of this endangered species based on statistical methods as principal components analyses.

The PCA analyses showed clearly distinction between populations independently of their geographical origins. Some authors explain this situation by the influence of environmental conditions that express variations such as mutations, hybridization, natural selection (Szamosi et al., 2009). However knowledge of the existing variations between various morphological characters is vital for any plant taxonomic practice. Marquiafével et al. (2008) in their study of eight Neotropical species of *indifora* noted that gland types and distribution differed between species and that these gland distribution patterns can be used as diagnostic characters. There are many documents on the influence of the environment on phenotypic variation (Abd El-Ghani and Marei, 2007). However, in this present study, the morphological variations would be useful to distinguish three populations. The diversity of morphotypes of *V*. *heterophylla* in the Sudano-Sahelian zone could be probably also related to an adaptation to environmental conditions. However it is difficult to claim that this adaptation is enough to make distinction between populations. Awatef et al. (2013) had the same difficulties to determine the population of *Capparis spinosa* in Tunisia. In view of this difficulty, it would be interesting to analyze genetic or molecular materials that can give precise differentiation within the population of *V*. *heterophylla*. Qualitative observations showed that there are different forms of leaves confirming the high values of the coefficients of variation within the population of *V*. *heterophylla*.

Conclusion

This study is the first step to the morphological characterization of *V*. *heterophylla* populations in Sudano-Sahelian zone of Cameroon. Numerical taxonomy with its quantitative feature provided greater discrimination along the spectrum of the taxonomic difference and was also more sensitive in the delimitation of the taxa. In addition to demonstrating the relative value of morphometric methods in the taxonomy of the taxa, the study presents greater and more detailed information on the level of relationship within the genus. It is important to note that, morphometric analysis is not enough in delimiting taxa though it has benefited systematic. Others methods which include anatomical, palynological, cytotaxonomic and chemotaxonomic differences should be investigated together with morpholometric in order to confirm or change the existing classification based on morphology in the genus.

Conflict of Interests

The author(s) have not declared any conflict of interests.

REFERENCES

Abd El-Ghani MM, Marei AH (2007). Environment and vegetation of Randonia africana: an endangered desert plant in Egypt. Afr. J. Ecol. 45:469-475. http://dx.doi.org/10.1111/j.1365-2028.2007.00756.x

Arbonnier M (2002). Les arbres, les arbustes et les lianes des zones sèches de l'Afrique de l'ouest. Paris, France, Muséum national d'histoire naturelle, Montpellier, France, CIRAD p. 574.

Awatef R, Hédia H, Sonia H, Mohamed B (2013). The use of morphological descriptors to study variability in wild populations of Capparis spinosa L. (Capparaceae) in Tunisia. Afr. J. Ecol. 51:47-54. http://dx.doi.org/10.1111/aje.12012.

Geerling C (1987). Guide de terrain des ligneux sahéliens et soudano-guinéens. Université agronomique. Wageningen (NL). Netherlands. p.340.

Hawthorne WD (1995). Ecological profiles of Ghanian Forest Trees. Tropical Forestry Papers 29. Oxford Forestry Institute, Department of Plant Sciences; University of Oxford, United Kingdom. p. 345.

Letouzey R (1985). Carte phytogéographique du Cameroun au 1/500.000. 1) [Sahelian and Sudanese domain] Domaine sahélien et soudanien. IRA (Herbier National), [Institute of the International map of vegetation. Toulouse, 1-26] Institut de la Carte Internationale de la Végétation. Toulouse. pp. 1-26.

Marquiafével FS, Ferreira MD, Texiera SP (2008).Novel reports of glands in Neotropical species of Indigofera L. (Leguminosae, Papilionoideae). Flora-Morphol. Distrib. Funct. Ecol. Plants 204:189-197. http://dx.doi.org/10.1016/j.flora.2008.01.012

Matu EN (2011). Vepris heterophylla (Engl.) Letouzey. In: Schmelzer, G.H. & Gurib-Fakim, A. (Editors). Prota 11(2): Medicinal plants/Plantes médicinales 2. [CD-Rom]. PROTA, Wageningen, Netherlands. PMid:21774394

Mziray W (1992). Taxonomic studies in Toddalieae Hook. f. (Rutaceae) in Africa. [Uppsala University]; Stockholm: Almqvist & Wiksell International, distributor, Uppsala. p. 95

Ngamo LSL, Noudjou WF, Ngassoum BM, Mapongmetsem PM, Aminatou Boubakary AB, Malaisse F, Haubourg E, Lognay G, Hance T (2007). Investigations on both chemical composition and insecticidal activities of essential oils of Vepris heterophylla (Rutaceae) from two localities of northern Cameroon towards Tribolium casteneum (Herbst) (Coleoptera: Tenebrionidae). Res. J. Sci. 2(1):56-61.

Nwachukwu CU (1997). Characterization of Maesobotrya barteri var. barteri. M. Sc thesis, Imo state University, Nigeria.

Soladoye MO, Sonibare MA, Rosanwo TO (2008). Phytochemical and morphometric analysis of the genus Acalyfa Linn. (Euphorbiaceae). J. Appl. Sci. 8: 3044-3049.http://dx.doi.org/10.3923/jas.2008.3044.3049

Soladoye MO, Sonibare MA, Chukwama EC (2010). Morphometric study of genus Indigofora Linn. (Leguminosae-Papilionoideae) in South-Western Nigeria. Int. J. Bot. 6(3):343-350.http://dx.doi.org/10.3923/ijb.2010.343.350.

Sonibare MA, Jayeola AA, Egunyomi A (2004). A morphometric analysis of the genus Ficus Linn. (Moraceae). Afr. J. Biotechnol. 3:229-235.

Stern KR (2000). Introduction Plant Biology. 8th Edn. McGraw Hill Co. Inc., USA.

Szamosi C, Solmaz I, Sari N, Barsony C (2009). Morphological characterization of Hungarian and Turkish watermelon (Citrullus lanatus (Thunb.) Matsum.et Nakai) genetic resources. Genet. Resour. Crop Evol. 56, 1091-1105.http://dx.doi.org/10.1007/s10722-009-9432-4.

Terzopoulos PJ, Kaltsikes PJ, Bebeli PJ (2003). Collection, evaluation and classification of Greek population of faba bean (Vicia faba L.). Genet. Res. Crop Evol. 50:373-381. http://dx.doi.org/10.1023/A:1023962618319.


Journal of
Ecology and
The Natural Environment
Related Journals Published by Academic Journals
■ African Journal of Environmental Science and Technology
■ International Journal of Biodiversity and Conservation
■ Journal of Yeast and Fungal Research
■ Journal of Entomology and Nematology
■ African Journal of Biology and Environment
■ Journal of Evolutionary Biology Research
academicJournals