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Ecological preference by *Anopheles gambiae* complex (Diptera: Culicidae) in small natural microcosms in Maiduguri, Borno State, Arid Zone of North-Eastern Nigeria

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A study on ecological preference of breeding sites of *Anopheles gambiae* compared to other mosquito species were carried out in small natural microcosms. A total of sixteen small ponds, four each from North, South, East and West of Maiduguri Metropolitan were surveyed for the breeding and non-breeding sites for mosquitoes. In each pond mosquito larvae samples were collected by dip method after identifying species by their angular positions and later confirmed by Polymerase Chain Reaction (PCR). Water samples from which collection of *A. gambiae* and non-*Anopheles gambiae* larvae were also collected and analyzed for physico-chemical properties following the standard laboratory procedures. The results revealed that, preference of breeding site of *A. gambiae* is dependent on the physico-chemical nature of water habitat. Of a total of 30 parameters analyzed, pairwise comparison using SPSS software revealed that 11 of the physico-chemical parameters significantly varied ($P < 0.05$) between *A. gambiae* and non-*A. gambiae* breeding sites. These parameters include Turbidity, pH, Conductivity, Temperature, Suspended solid, Sodium, Chloride, Sulphate, Calcium, Magnesium, Total hardness and Magnesium hardness. The proportion of *A. gambiae* in larval habitats were significantly ($P < 0.05$) and positively correlated to these parameters. However, of the eleven parameters, pH ($r = 0.429$, $P = 0.001$), temperature ($r = 0.269$, $P = 0.050$), calcium ($r = 0.256$, $P = 0.048$) and turbidity ($r = 0.515$, $P = 0.000$), were found to be the most influential parameters that determine habitat selection for breeding.

Key words: Arid zone, ecological preference, physico-chemical, *Anopheles gambiae*, distribution.

INTRODUCTION

Previously it was thought that the control of malaria would be easy, based on the assumption that the relationship between the parasites, the vector and the human host was clearly understood, that the effective therapeutic and chemotherapeutic agents were available and that

insecticides held a great promise for vector control (Ranson et al., 2009; Ranson and Lissenden, 2016). However, despite the tremendous progress made in the acquisition of the knowledge of biology of the malarial parasites, the human host and the development of anti-

malarial drugs, the disease has proven far harder to control (WHO, 2017). Malaria still remains an insidious and ever present scourge that constitutes obstacle to human development (Dobson, 1999; WHO, 2017). At every turn when it was believed that the disease could be eradicated through vector control, the *Anopheles* mosquito vectors eased their way out of extinction. A prominent factor responsible for this inability to control this disease has been attributed to lack of adequate knowledge of the vector ecology and species composition (CDC, 2010). The role of *Anophele gambiae* in malaria transmission have been reported to depends largely on the presence of favorable environment for egg laying and larval development (Manuela et al., 2014) that translate to adult populations in a geographically defined area (Rejmánková et al., 2005, Gimnig et al., 2005, Mwangangi et al., 2007). Traditionally, malaria control has been directed to the adult stages and studies of larval ecology have been neglected (Gimnig et al. 2005). This has been the main reason for the dearth of information on factors affecting larval productivity and distribution. *A. gambiae* complex laid eggs in a wide variety of selected aquatic environments (Himeidan et al., 2013) such as small pools that are partially or completely exposed to the sun, while others prefer to breed in shaded stagnant pools, or even in slow moving water (Lanzaro et al., 1998, Budiansky, 2002). However, the underlying ecological determinant of the distribution is not yet quite understood. For instance under laboratory conditions, *A. gambiae* carries out normal development when the pH varies as much as from 4.0 to 7.8, as long as there is sufficient phytoplankton and zooplankton for it to consume and maximum larval habitat temperature does not exceed 37°C (Mereta et al., 2013). However, these conditions rarely occur in nature, especially in the intense heat of equatorial Africa, hence the need to understand the ecological characteristics of their natural breeding sites (Paaijmans et al., 2009).

The finding that *A. gambiae* larvae in their natural habitats tend to aggregate in a particular aquatic microcosm suggests that there could be some variation between physico-chemical properties of the breeding and the non-breeding habitats (Mereta et al., 2013). Understanding this phenomenon would no doubt contribute tremendously towards effective control of malaria transmission from source preferably targeting different parts of the mosquito life cycle (Lardeux et al., 2008; Killeen, 2014). Source reduction (larval control) has been reported to be one of the best methods of choice for mosquitoes control (Killeen et al., 2002; Tusting et al., 2013; Bhatto et al., 2015), especially when mosquitoes species targeted are concentrated in small number of discrete habitats (Kitron and Spielman, 1989). Therefore

for effective larval control to be achieved, larval habitat physical and chemical properties need to be considered as one of the priorities in the mosquitos' abatement program hence the focus of this study. The aim of this study was to determine whether there is variation between ecological factors of habitats between *A. gambiae* larvae and non- *A. gambiae* larvae at breeding sites in arid zone of north eastern Nigeria by determining which of the ecological factors that influence the distribution and abundance of *A. gambiae* larvae at breeding sites.

MATERIAL AND METHODS

Study area

The study was carried out in Maiduguri the capital of Borno State, North-Eastern Nigeria. Maiduguri is located within latitude 13°N and 14°N, longitude 12°N and 13°N. The area has a tropical climate with mean temperature of 34.8°C. The hottest part of the year are the months of March and April with the temperature ranging between 30-40°C. During the period between November to February, the weather is usually very cold and dry with a temperature as low as 18°C, being the coldest months. During the hot season, the ambient temperature is usually high between 40-45°C. The relative humidity is around 45% in August and October and gradually lowers to about 5% in April and May. The mean annual rainfall in Borno is about 650 mm/annum for 3-4 month which starts in June and ends in September, followed by a long period of dry season of about 8-9 months.

Identification of breeding sites and collection of water samples for physicochemical analysis

Survey was carried out to locate mosquito breeding and non-breeding sites forth nightly during rainy season from July to October (Gadzama et al., 2011). Water samples taken for physico-chemical analysis taken forth nightly for six months from where mosquito larvae were found and where they were not found. The water samples collected in each site was fixed immediately using alkaline iodide-azide to maintain it biochemical oxygen demand.

Physico-chemical analysis of water samples

The physical factors were measured right on the field using their respective measuring instruments. The chemical analyses of water were done following standard laboratory procedures as described by Fishman and Friedman (1989) and Sunil and Shyam (2017). The parameters measured include: Temperature, pH, conductivity, turbidity, suspended solid, total dissolved solids, sodium concentration, potassium, sulphate (SO₄⁻), phosphates (PO₄), calcium, bicarbonate, carbonate, calcium hardness, total hardness, total alkalinity, magnesium, Chloride, fluoride, silica (SiO₂), total iron concentration, magnesium hardness, ammonium, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, nitrite and nitrate.

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Table 1. Mean values of significantly different ecological parameters between breeding and non-breeding habitats of *A. gambiae* complex in Maiduguri.

Parameter	Mean \pm S.E		P value
	Without larvae (Non-breeding site)	With larvae (Breeding site)	
Turbidity (NUT)	249.8 \pm 62.7	449.8 \pm 15.2	0.000
Suspended solid (SS) (mg/l)	308.1 \pm 48.2	608.1 \pm 88.3	0.030
pH	6.61 \pm 0.24	7.91 \pm 0.26	0.003
Conductivity (u/cm)	2182. \pm 22.2	192.0 \pm 19.1	0.005
Sodium (mg/l)	130.6 \pm 51.3	240.1 \pm 3.20	0.024
Sulphate (mg/l)	45.6 \pm 2.02	15.6 \pm 6.81	0.010
Temperature	22.10 \pm 0.02	29.30 \pm 0.08	0.002
Calcium (mg/l)	68.3 \pm 11.2	124.3 \pm 18.3	0.016
Magnesium (mg/l)	24.5 \pm 8.6	47.5 \pm 8.60	0.010
Chloride	75.94 \pm 31.3	175.94 \pm 21.3	0.002
Magnesium hardness (mg/l)	183.1 \pm 28.1	83.1 \pm 19.88	0.003

The P. value observed was obtained from pair wise comparison of measured ecological factors between where *A. gambiae* larvae were found and where they not at the time of sampling ($P \leq 0.05$).

Table 2 Top discriminatory factors influencing habitat selection for breeding by *A. gambiae* complex in arid zone.

Steps	Parameter	Exact statistics	Wilks' Lambda	P. value
1 ^a	pH	14.752	0.779	0.000
2 ^b	Temperature	14.558	0.637	0.000
3 ^c	Calcium	14.888	0.528	0.001
4 ^d	Turbidity	15.001	0.931	0.002

Predictors: a. pH was first selected as the most influential factor in the model, followed by b. temperature, c. Calcium and d. Turbidity in that order ($P \leq 0.05$).

Data analysis

SPSS software (version 20) was used to carry out the statistical analysis. Pair wise comparison was used to compare mean value between physico-chemical factors of water samples where *A. gambiae* were found breeding as evidenced by the presence of *A. gambiae* larvae and where they were not found breeding as evidenced by absence of larvae of *A. gambiae* but presence of other mosquito species at the time of study. To select in hierarchical order of discriminatory ecological factors influencing habitat selection for breeding by *A. gambiae*, a stepwise discriminate function analysis was performed on dataset set that were significantly different for the model to select in order of strength the factors that influenced habitat selection for breeding. Multiple regression analysis was adopted to determine dependent factors within the factors.

RESULTS

Mean comparison of values of physico-chemical parameters between habitats with *Anopheles gambiae* and those without

The comparison of the mean values of physico-chemical

factors between *A. gambiae* breeding site and non-breeding sites revealed that 11 out of 30 analyzed parameters were significantly different ($P \leq 0.05$). The values of the significantly different factors are presented in Table 1 while Table 2 shows the topmost influential factors from the eleven parameters that differed significantly. To determine which factors were dependent factors among the eleven significantly measured parameters, the results revealed that pH, temperature, calcium and turbidity (Table 2) were found to the most influential factors that discriminates habitat selection for breeding by *A. gambiae*.

Determination of dependent factors using all the measure parameters

When all the measured parameters were analyzed to select discriminatory factors that influence the presence or absence of *A. gambiae* in the studied microcosms, the model revealed that turbidity, pH, calcium and dissolved oxygen (Table 3) are the significant factors that

Table 3. Multiple regression analysis using proportion of *A.gambiae* as dependent variable and all the measured parameters as the independent variables.

Model	R square	R. adjusted	S. E.	Correlation	P. value
1 ^a	0.265	0.251	37.4293	0.515	0.00
2 ^b	0.367	0.342	35.0817	0.606	0.01
3 ^c	0.786	0.430	12.231	0.325	0.04

Predictors: a. turbidity, b. pH, calcium and c. dissolved oxygen, S.E. = standard error.

Table 4. Multiple regression analysis using turbidity as dependent variable and all the measured parameter as the independent variables.

Model	Mean	Standard error	Correlation	P value
1 ^a	0.521	245.2238	0.728	0.000
2 ^b	0.590	227.0838	0.778	0.000
3 ^c	0.629	215.8864	0.806	0.000
4 ^d	0.708	191.6289	0.854	0.000
5 ^e	0.735	182.5416	0.872	0.000
6 ^f	0.761	173.4506	0.888	0.000

Predictors: a. = SS was first selected in the model, followed by b. = Sulphate c. TDS d. Mg hardness, e. Ammonia and f. BOD in that order (P ≤ 0.05).

Table 5. Multiple regression analysis using pH as dependent variable and all the measured parameters as the independents.

Model	Correlation	Adjusted R ²	Standard error	P. value
1 ^a	0.401	0.145	0.5878	0.003
2 ^b	0.549	0.273	0.5417	0.000
3 ^c	0.624	0.353	0.5111	0.000
4 ^d	0.685	0.426	0.4814	0.000

Predictors: a. DO was first selected in the model, followed by b. TDS, c. silica and d. Calcium in that order (P ≤ 0.05).

Table 6. Multiple regression analysis using calcium as dependent variable and all the measured parameters as the independents variables.

Model	Correlation	R square	Adjusted R	Standard	F. value	P value
1 ^a	0.568	0.322	0.309	91.5114	24.717	0.000
2 ^b	0.650	0.423	0.400	85.2630	18.696	0.000

Predictors: a. Total dissolved solutes and b. Turbidity.

determine whether or not *A. gambiae* larvae would be found at a particular time.

factor on the other factors and the results are presented in Tables 4 to 6.

Interrelationship between physico-chemical factors

To determine the association between the selected influential factors and all the measured parameters, each of the influential factors were analyzed as dependent

DISCUSSION

Water is an important component of ecosystem and its quality in the breeding sites of *A. gambiae* is an important determinant of whether or not the female Anopheles

mosquito will lay their eggs and the resulting immature stages will successfully complete their development to adult stage (Piyaratne et al., 2005; Manuela et al., 2014). In this study the habitat characteristics of *A. gambiae* were found to be remarkably different from those of other mosquito species. Of the total 30 water parameters analyzed, the breeding habitat for *A. gambiae* were significantly different for 11 parameters (Table 1) compared to other species ($P < 0.05$). However, of the 11 parameters temperature, pH, turbidity and calcium were found to be the best discriminatory parameters predicting the suitability of breeding habitat for *A. gambiae* (Table 2) in the model. pH was first selected followed by temperature, calcium and turbidity in that order. These four ecological factors together accounted for 62% of the total variation observed among the predictors (Table 3). All the three models that were applied selected temperature, pH calcium and turbidity in that order. However, when multiple regression analysis was performed using all the 30 analyzed parameters, only temperature, turbidity and dissolved oxygen were selected as best predictors associated with proportion of *A. gambiae* (Table 4). The two parameters however, accounted for 36.7% of the total variation.

This finding seem to some extent disagree with the report of Mwangangi et al. (2007) who reported that only temperature was found to be significantly associated with *A. gambiae* s.l. habitat along Kenyan Coast, East Africa. The observed disagreement could be as a result of variation in the ecology of the study regions. Kenya is located in the coastal region with its peculiar characteristics of deep valleys and high elevation, while Maiduguri is located in the arid Sahelian region of West Africa. Water temperature was not expected to vary significantly because all habitats were exposed to direct sunshine and the topographic relief of Maiduguri is flat and all areas will have similar temperature.

Although might not be as obvious as nutrition and larval density, ambient temperature can dramatically affect mosquito production. In the laboratory, most mosquito larvae are reared around 22-27°C which is within the similar range to the mean environmental temperature of 22.10°C found in this study from which the larvae were isolated. Too high or low temperatures can be lethal to almost all shallow aquatic organisms more especially mosquito larvae. For instance, in *Anopheles albitarsis* and *Anopheles aquasalis*, colder temperatures have been found to cause delayed embryo eclosion (Ayetkin et al., 2009). Additionally, there was also observed reduction in the hatch rate of *A. albitarsis* when reared at below 21°C. Similarly, it has also been reported that *Anopheles albopictus* larvae reared at 26°C pupate faster than those reared at below 22°C; however, fewer larvae completed ecdysis at the higher temperature (Alto and Juliano, 2001). This trend has also been reported in *Culex tarsalis* (Reisen et al., 1984) and *Anopheles sergentii* (Beier et al., 1987). In addition to reduced

ecdysis rates, adults from temperature stressed environments have been found to have reduced longevity (Beier et al., 1987). Similarly, it was also reported that adults derived from heat stressed larval regimens were found to have reduced life spans by several days as was found in *A. gambiae* (Afrane et al., 2006), *Anopheles superpictus* (Ayetkin et al., 2009) and *Culex tarsalis* (Reisen et al., 1984). In *Aedes dorsalis*, high temperature regimen had a reduced number of ovarian follicles (Parker, 1982) while *A. gambiae* derived from the same environment had increased fecundity when compared to adults from a lower temperature region (Afrane et al., 2006). Finally, it was reported that as temperatures increased above the optimum rearing temperature in *Anopheles merus*, lead to reduction the larval head and adult wing size (Lesueur and Sharp, 1991; Ayetkin et al., 2009). The finding of pH as one of the influential factor for breeding in this study was not a surprise because many studies have shown that the effect of pH is of unquestionable importance and that its significance lies in the fact that, under natural conditions, it dictates the favourability of association between chemical and biological factors in breeding places upon which the successful of unsuccessful development of larvae depend (MacGregor, 2009). The larvae of certain species tend to actually restrict themselves to water exhibiting a pH index within a definite short range, and that the pH indexes is consequently often reliable as to whether the chemical and biological group associations will favour or preclude the successful development of such larvae (Malcom, 2009). The finding of Calcium as one of the important factor is not unusual because as reported by White, (1985), Calcium-rich water favours the growth of macrophytic algae, *Chara*, whose presence positively correlated with abundance of *A. gambiae* larvae.

The selection of these parameters could be attributed to the correlation to other factor measured which also directly or indirectly influence habitat selection. For example, The bivariate correlation procedure computed using Pearson's correlation coefficient revealed that the proportion of *An. gambiae* in larval habitats were significantly and positively correlated to Turbidity ($r = 0.515$, $P = 0.000$), pH ($r = 0.429$, $P = 0.001$), Conductivity ($r = 0.380$, $P = 0.005$), Suspended solids ($r = 0.384$, $P = 0.004$), Dissolved solid ($r = 0.443$, $P = 0.001$), Sodium ($r = 0.310$, $P = 0.023$), Calcium ($r = 0.256$, $P = 0.048$), Magnesium ($r = 0.272$, $P = 0.046$), Chloride ($r = 0.363$, $P = 0.007$), Sulphate ($r = 0.299$, $P = 0.028$) and Temperature ($r = 0.269$, $P = 0.050$).

To determine which of the non-selected parameters were either counting to or were associated with turbidity, pH and calcium, multiple regression analysis were performed using these as dependent variables. The results obtained are shown in Table 4 to 6. The results revealed that suspended solid, sulphate, total dissolved solid, magnesium hardness, ammonium and biological oxygen demand were the best variables, together

accounting for approximately 79% of the variation existing in turbidity. Furthermore, all were significantly correlated to turbidity ($p < 0.05$ in all case). However, dissolved oxygen, total dissolved solids, silica and calcium were the best variables associated with pH, together accounting for 47% of the variation existing in pH whereas total hardness and suspended solids were the only variables associated with calcium and accounting for 42% of the observed variation. The pH of water is dependent on the concentration of anions and cations derived from salts, fertilizer compound and other synthetic compounds all together accounted for the pH (Bos, 1991). Therefore, it may directly or indirectly detect the life of any aquatic organisms. The *anions* and *cations* may indirectly affect mosquito breeding by favouring certain aquatic organisms or vegetation on which mosquito larvae feed or affect potential biological control agents of *A. gambiae*.

Conclusion

Finding from this study suggest that *A. gambiae* breeding sites were strongly under the influence of ecological factors of the breeding sites at a particular time. Though eleven parameters were found to be significant, however, the top discriminatory factors influencing the distribution and abundance of *A. gambiae* larvae in small microcosms were found to be pH, temperature, calcium, turbidity and dissolved oxygen.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

- Afrane YA, Zhou G, Lawson BW, Githeko AK, Yan G (2006). Effects of microclimatic changes caused by deforestation on the survivorship and reproductive fitness of *Anopheles gambiae* in western Kenya highlands. *American Journal of Tropical Medicine and Hygiene* 74:772-778.
- Alto BW, Juliano SA (2001). Temperature effects on the dynamics of *Aedes albopictus* (Diptera: Culicidae) populations in the laboratory. *Journal of Medical Entomology* 38:548-556.
- Ayetkin S, Ayetkin AM, Alten B (2009). Effect of different larval rearing temperatures on the productivity (Ro) and morphology of the malaria vector *Anopheles superpictus* Grassi (Diptera: Culicidae) using geometric morphometrics. *Journal of Vector Ecology* 34:32-42.
- Beier MS, Beier JC, Merdan AA, Sawaf BM, Kadder MA (1987). Laboratory rearing techniques and adult life table parameters for *Anopheles sergentii* from Egypt. *Journal of American Mosquito Control Association* 3:266-270.
- Bhatt S, Weiss DJ, Cameron E. (2015). The effect of malaria control on *Plasmodium falciparum* in Africa between 2000 and 2015. *Nature* 526(7572):207-211.
- Bos R (1991). Water Quality, Disease and Human Health. Paper presented at the Water Quality Conference, Bratislava.
- Budiansky S (2002). The mosquito genome: *Anopheles gambiae*. *Creatures of our own making. Science* 298:80-86.
- CDC (2010). *Anopheles* mosquitoes. *Malaria* (04 September 2014).
- Dobson MJ (1999). The Malariology Centenary. *Parasitologia* 41:21-32.
- Fishman MJ, Friedman LC (1989). Methods for determination of inorganic substances in water and fluvial sediments. U.S. Geological survey techniques of Water-Resources Investigations, book 5, chap A1, 545.
- Gadzama UN, Toyosi RI, Madakan SP, Ali AF (2011). Effect of livestock, human hosts and aquatic habitat distribution on the abundance of *Anopheles gambiae* complex in Borno State, Arid Zone of Nigeria. *International Journal of World Rural Observations* 3(4):71-77.
- Gimnig JE, Oombe M, Kamau L, Hawley WA (2005). Characteristics of larval Anopheline (Diptera: Culicidae) habitat in Western Kenya. *Journal of Medical Entomology* 38:82-88.
- Himeidan YE, Temu EA, El Rayah EA, Munga S, Kweka EJ (2013). Chemical cues for malaria vectors oviposition site selection: challenges and opportunities. *Journal of Insects* 685-82.
- Killeen GF (2014). Characterizing, controlling and eliminating residual malaria transmission. *Malaria Journal* 13(1):330.
- Killeen GF, Fillinger U, Kiche I (2002). Eradication of *Anopheles gambiae* from Brazil: lessons for malaria control in Africa? *Lancet Infectious Diseases* 2(10):618-62711.
- Kitron U, Spielman A (1989). Suppression of transmission of malaria through source reduction: Anti-anopheline measures applied in Israel, the United States, and Italy. *Reviews of Infectious Disease* 11:391-406.
- Lanzaro GC, Toure YT, Carnahans J, Zheng L, Dolo G, Troare S, Petrarca V, Vernick KD, Taylor C E (1998). Complexity in the genetic structure of *Anopheles gambiae* population in West Africa as revealed by microsatellite DNA analysis. *Proceeding of the National Academy of Sciences USA* 95:14260-14265.
- Lardeux FJ, Tejerina RH, Quispe V, Chavez TK (2008). A physiological time analysis of the duration of the gonotrophic cycle of *Anopheles pseudopunctipennis* and its implications for malaria transmission in Bolivia. *Malaria Journal* 7:141.
- Lesueur D, Sharp BL (1991). Temperature-dependent variation in *Anopheles merus* larval head capsule width and adult wing length: implications for Anopheline taxonomy. *Medical and Veterinary Entomology* 5:55-62.
- Manuela H-V, Jenny L, Steven WL, Ulrike F (2014). Habitat discrimination by gravid *Anopheles gambiae* sensu lato – a push-pull system. *Malaria Journal* 13:133.
- Mwangangi JM, Mbogo CM, Muturi EJ, Nzovu JG, Kabiru EW, Githure JI, Novak RJ, Beier JC (2007). Influence of biological and physicochemical characteristics of larval habitats on the body size of *Anopheles gambiae* mosquitoes (Diptera: Culicidae) along the Kenyan coast. *Journal of Vector Borne Diseases* 44:122-127.
- Mereta ST, Yewhalaw D, Boets P, Ahmed A, Duchateau L, Speybroeck N (2013). Physico-chemical and biological characterization of anopheline mosquito larval habitats (Diptera: Culicidae): implications for malaria control. *Parasite and Vectors* 6:320.
- Paaijmans KP, Read AF, Thomas MB (2009). Understanding the link between malaria risk and climate. *Publication of National Academy of Science, USA* 106:13844-13849.
- Parker BM (1982). Temperature and salinity as factors influencing the size and reproductive potentials of *Aedes dorsalis* (Diptera: Culicidae). *Annual Entomological Society America* 75:99-102.
- Mattah ADP, Godfred F, Leonard KA, Memuna MM, Dziedzorm KS, Worlasi DK, Langbong B, Michael DW ((2017). Diversity in breeding sites and distribution of *Anopheles* mosquitoes in selected urban areas of southern Ghana. *Parasites and Vector* 10:25.
- Piyaratne MK, Amerasinghe MP, Amerasinghe PH, Konradsen F (2005). Physico chemical characteristics of *Anopheles culifacies* and *Anopheles varuna* breeding water in a dry zone stream in Sri Lanka. *Journal of Vector Borne Diseases* 42:61- 67.
- Ranson H, Abdallah H, Badolo A, Guelbeogo WM, Keraf-Hinzoumbe C, Yangalbe-Kalnone E, Sagnon N, Simard F, Coetzee M (2009). Insecticide resistance in *Anopheles gambiae*: data from the first year of a multi-country study highlight the extent of the problem. *Malaria Journal* 8(1):299.
- Ranson H, Lissenden N (2016). Insecticide Resistance in African *Anopheles* Mosquitoes: A Worsening Situation that Needs Urgent Action to Maintain Malaria Control. *Trends Parasitology*, Elsevier Ltd.

- 32(3):187-196.
- Rejmánková E, Higashi R, Grieco J, Achee N, Roberts D (2005). Volatile substances from larval habitats mediate species-specific oviposition in *Anopheles* mosquitoes. *Journal of Medical Entomology* 42:95-103.
- Reisen WK, Milby MM, Bock ME (1984). The effects of immature stress on selected events in the life history of *Culex tarsalis*. *Mosquito News* 44:385-395.
- MacGregor ME (2009). The significance of pH in development of mosquito larvae. *Parasitology* 2(1-2):132-157.
- Sunil RV, Shyam NL (2017). Determination of Physico-Chemical Parameters and Water Quality Index (WQI) for drinking water available in Kathmandu Valley, Nepal: A review *International Journal of Fisheries and Aquatic Studies* 5(4):188-190.
- Tusting LS, Thwing J, Sinclair D (2013). Mosquito larval source management for controlling malaria. *Cochrane Database Systematic Reviews* (8):CD008923.
- White GB (1985). *Anopheles bwambae* species n., a malaria vector in the Semliki valley, Uganda, and its relationship with other sibling species of the *Anopheles gambiae* complex (Diptera: Culicidae). *Systematic Entomology* 10:501-522.
- World Health Organization (WHO) (2017). *World Malaria Report, 2017*, Geneva.

Full Length Research Paper

Influence of land use and land cover changes on ecosystem services in the Bilate Alaba Sub-watershed, Southern Ethiopia

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Human well-being was obsessed with the natural scheme that provides various functions vital to support management at various levels. Land use/ land cover (LULC) dynamics over 45 years within four intervals (1972, 1986, 2008, and 2017) to evaluate its influence on ecosystem services. Geographic information system (GIS) and global value of coefficients' database together with LULC dynamics were used to determine ecosystem service values (ESV). The results showed that cultivated land and settlement land expanded by 67.38 and 532% respectively whereas forest land, shrub land and grassland declined by 66.35 and 18.36% respectively over the analysis period. A decline of total ESVs from US\$ 35.23 million in 1972, to 33.61, 27.91 and 25.87 million in 1986, 2008 and 2017, respectively. Approximately US dollar of 9.37 million ESVs were lost owed to LULC changes from 1972 to 2017 in the sub-watershed. In terms of ES functions, erosion control, nutrient cycling, climate regulation and raw material provisions were the key bringers to loss of ESV. Global ESV data sets together with LULC change information helps to make a possible judgment about past environmental changes and reliable results achieved to make sound decisions. The decline of ESV was an indication of environmental degradation in the sub-watershed and needs future appropriate intervention policies in land conservation.

Key words: Land use/Land cover, Bilate Alaba subwatershed, ESV, geographic information system (GIS), remote sensing, landsat image.

INTRODUCTION

Ecosystem services (ES) defined as situations through which natural ecosystem support and sustain human life, maintain a healthy environment and support production of

goods such as fuels or fibers (Daily et al., 1997), offer services varied both quality and quantity (MEA, 2005). Goods and services derived from Ecosystem functions

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benefit man both directly and indirectly in the territorial environment (Costanza et al., 1997). Ecosystem services categorized in different ways based on functional groupings, production, and information services (MEA, 2005; De Groot et al., 2002; Lobo, 2001). Agricultural activities including cultivation in various watersheds had modified the existing landscapes; the conversion of the natural ecosystem to agriculture would have a strong impact on the watershed capacity to produce important ecosystem functions (Power, 2010). Land use changes focusing on cultivation and settlements were the major human activities that influence the ES (Kindu et al., 2016; Tolessa et al., 2017a).

The changes in ecosystem services were varied on the spatial and temporal distribution of land use/land cover (Bryan, 2013; Hu et al., 2008). Ecosystem service is defined as the ecology provisions any kinds which make the sustainable life of human being in the biosphere (Li et al., 2017). In terms of functionalities, ES is categorized into four major components; provisioning, regulating, cultural, and supporting services (MEA, 2005). An ecosystem service is correlated to changes in LULC in certain areas in the global world (Yirsaw et al., 2017).

LULC dynamics has direct effects on ecosystem services (Hu et al., 2008; Polasky et al., 2011). LULC change influenced the variation of ES components (an increase of some services on the contrary decreasing others) that would affect human beings needs, indicating ecological disturbances (Polasky et al., 2011). Land use altered some ecosystem services, affected social and government practices (Garcia-Llorente et al., 2015).

Land use changes (cultivation and settlements) were dominant in rural landscapes influencing ecosystem services in most parts of Ethiopia. LULC and ecosystem services valuation information would facilitate to identify the mainly exposed to alter in ecosystem services at the watershed scale. Most studies conducted to monitor LULC change in Ethiopia given little attention to address the influence on ecosystem services (Tolessa et al., 2018). Inside current science, an ecosystem service global database is commonly used for assessment of ESs together with the investigation of LULC changes intended for various biomes (Costanza et al., 2014).

In Ethiopia rural landscapes, LULC changes were a very common occurrence in which agriculture and settlements had been affecting ecosystem services. Furthermore, most studies in the country focused on LULC detection and its causes Ethiopia (Tsegaye et al., 2010; Meshesha et al., 2014). The influence of LULC changes on rural ecosystem services which are important in watershed scales are not recognized (Kindu et al., 2016). The objective of this study is to evaluate the influence of LULC changes occurred over the past four decades (1972-2017) on ecosystem service values in the Bilate Alaba sub-watershed of the Southern Ethiopian and to investigate changes of individual ecosystem service function.

MATERIALS AND METHODS

Description of the Study area

Bilate Alaba sub-watershed located in Alaba woreda, Southern Ethiopia about 310 km south of Addis Ababa and about 85 km southwest of the Southern regional state capital of Hawassa. The sub-watershed has lied UTM coordinates of 387500 to 413750 m north latitude and 797000 to 824500 m east longitude (Figure 1). The sub-watershed comprises 45 rural kebeles and one town of Alaba wereda (kulito town).

The elevation ranges from 1613 to 2201 m above sea level, but the majority of the sub-watershed is found at about 1880 m above sea level, the sub-watershed coverage estimated is about 403 km², it is proper for crop production and animal husbandry because of its major portion is flat with regard to its landscape.

The major soils of the subwatershed are Andosol, Chromic Luvisols, Phaeozem and Nitisol (FAO, 1998). The soils in the study area are potentially fertile if properly managed through various soil management practices and smallholders can get reasonable yield without application of inorganic fertilizers. The nature of the soil in the study area have been detached by both water and wind resulted from the development of huge gullies in the northern and eastern parts; in some north-eastern part it was totally removed and degraded by the effects of cattle and human interference of the natural ecosystem (IPMS, 2005).

Agro-ecologically, the sub-watershed is characterized as Subtropical zone (IPMS, 2005) having the mean precipitation of 1093 mm per year and the average annual temperature value of 21°C. It has received bimodal rainfall where the main rainfalls (kiremt) are from July to October whereas small rains (belg) are between March and April. Rainfalls in both seasons were erratic unevenly distributed resulted in crop failures in most parts of the sub-watershed. Maize, sorghum, wheat, pepper and haricot beans are the common rain-fed crops grown in the area.

All these crops are managed using traditional agricultural techniques and equipment. Moreover, a few types of vegetables and livestock feed like rodus grass and cowpea are grown with the help of small irrigation scheme (IPMS, 2005). The population of livestock exceeded the available feed sources in the sub-watershed has affected animal production in existing crop-livestock farming systems.

DATA SOURCES AND MATERIALS

Time series data for LULC changes created from Landsat images of four periods (1972, 1986, 2008 and 2017) acquired from the United State Geological Survey (USGS) source (Table 1). Topographic maps were used for verification of 1972 Landsat image since Google earth was not functioning on this time series. ERDAS Imagine 14.0 was used for image process techniques, and ArcGIS 10.1 software was implemented for the production land use land cover maps. Dry season images were selected in order to get clear images, not having clouds to facilitate the image classification without difficulty, along years the same cropping season.

Classification and processing of images

Evaluation of LULC changes was carried out using supervised classification specifically maximum likelihood approach of the Landsat images (Jensen, 2007). Images of a similar season were used to reduce the misclassification. For this study, five LULC types were recognized (Table 2). Field visits, as well as discussion with key informants, were conducted to encompass a clear judgment of the major classes of LULC.

In addition to image classification, a field visit was conceded to

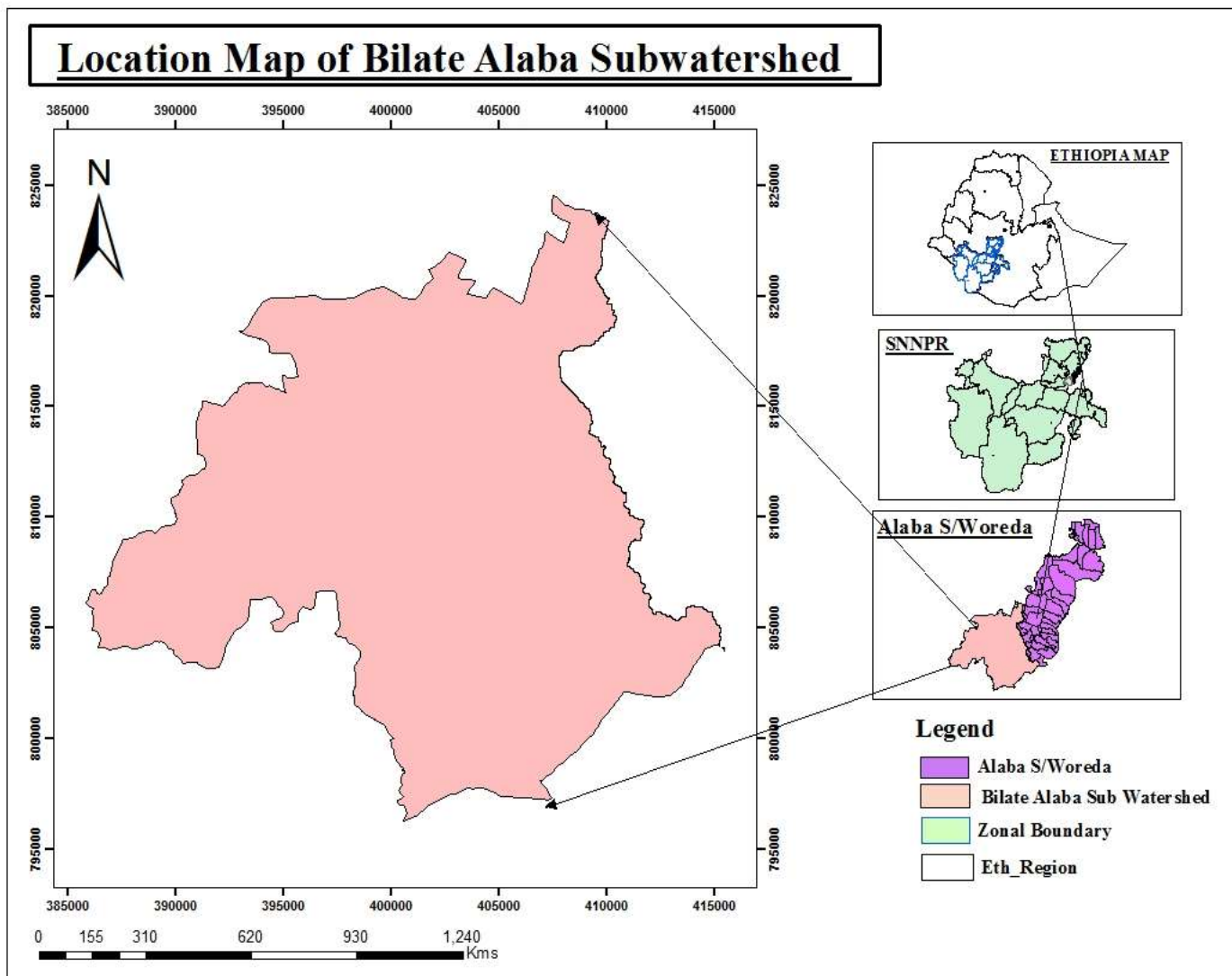


Figure 1. Bilate Alaba sub-watershed map.

Table 1. Landsat image description.

Image	Path	Row	Pixel Size (m)	Observation Date	Source
Landsat MSS	181	55	30*30	1972	USGS*
Landsat TM	169	55	30*30	1986	USGS
Landsat TM	169	55	30*30	2008	USGS
Landsat TM	169	55	30*30	2017	USGS

*United States Geological Survey.

collect data for Ground Control Points (GCPs). Classified LULC using image classifications were cross-checked with ground truth data with the support of the global positioning system (GPS) which is generated during field trips. To monitor a correctness of the categorization method, 660 GCPs were collected using GPS from

the field and Google Earth. Overall LULC classification was based on the general framework presented in Figure 2 (Alemu et al., 2015).

The overall producer's accuracy of LULC map of the sub-watershed was 92.9%, overall user's accuracy was 93.3% and

Table 2. Land Use and Land Cover description of the study area.

LULC	Classes
Forest land	Land covered mainly eucalyptus trees, indigenous tree and not found near river courses
Shrub & grassland	Land covered mixed up both small shrubs and traditional grasses.
Bare land	Areas covered with huge gullies, degraded with exposed rocks and badlands.
Cultivated land	Areas covered by annual crops including cereals and leguminous
Settlement	Areas covered by structures, which included towns and rural villages

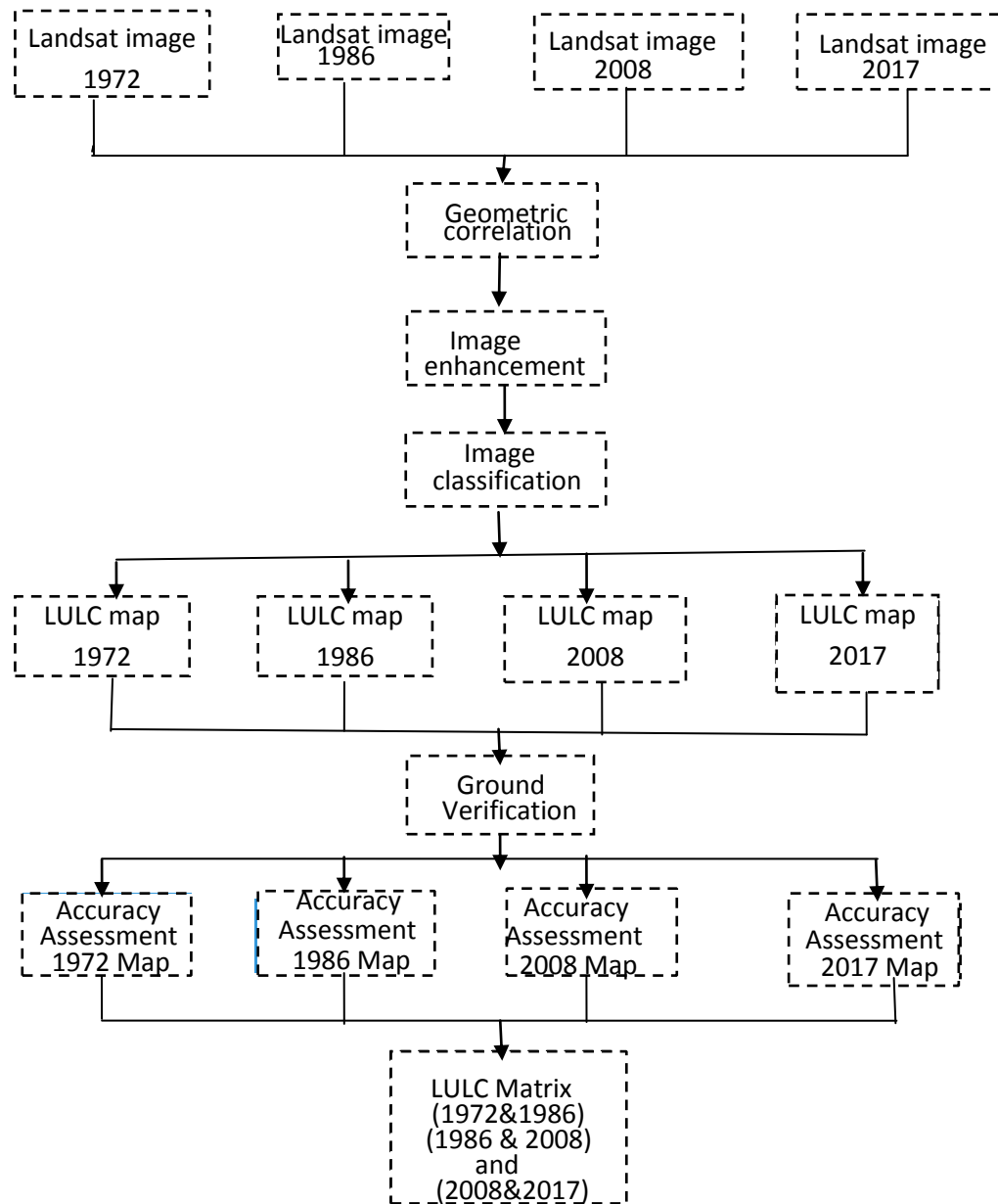


Figure 2. Schematic representation of LULC change analysis.

overall kappa statistics was 91.1%, met the requirement outlined by (Anderson et al., 1976). Hence, the data considered for auxiliary evaluation of values of ecosystem services for five LULC classes.

ArcGIS was used to analyze LULC data and ecosystem services valuation (ESV) for different biomes was computed by following the methods of (De Groot et al., 2012; Li et al., 2007; Hu et al., 2008).

The global databases were used for five LULC classes to estimate the values of ecosystem services (Costanza et al., 1997). The identified major LULC was not matched with existing biomes (Costanza et al., 1997), a replacement for each LULC classes was used for forest, shrub and grassland, settlements and cultivated lands (Table 3).

Although the value coefficient proposed by Costanza et al. (1997) was criticized because of uncertainties (Nelson et al., 2009). The identified major LULC was not perfectly matched with the existing biomes, proxy for each LULC category were used for cultivated, shrub, settlements, forest and bare lands (Table 3). Standard methods deployed by Li et al. (2007) and Hu et al. (2008) was used to estimate the total ESV in the sub-watershed for 1972, 1986, 2008 and 2017, mathematically expressed in Equation 1:

$$ESV = \sum AK \times VCK \quad (1)$$

Where ESV is the estimated Ecosystem service value, A_k is the area (ha) and VC_k the value coefficient (US \$ ha⁻¹ yr⁻¹) for LULC class k.

To estimate the impacts of LULC changes ecosystem services, it was attempted to make manipulation of individual ecosystem services (TEEB, 2010; Costanza et al., 1997). Individual ecosystem services values were calculated using Equation 2 developed so far Hu et al. (2008)

$$ESV_f = \sum A_k \times VC_{fk} \quad (2)$$

Where ESV_f is the estimated ecosystem service value of function f, A_k is the area (ha) and VC_{fk} the value coefficient of function f (US \$ha⁻¹yr⁻¹) for LULC category k is taken from (Costanza et al., 1997). With the consideration of uncertainty (Costanza et al., 1997), sensitivity analyses were conducted due to the fact that biomes used as a proxy for LULC classes were not exactly contests. The coefficient of sensitivity (CS) was determined the robustness of calculated ESV, which was calculated based on Equation 3 outlined by Li et al., (2007 and Hu et al. (2008). The value of the cultivated land, shrub and grassland and forest land coefficients were adjusted by 50% in sensitivity analysis.

$$CS = \frac{(ESV_j - ESV_i) / ESV_i}{(VC_{jk} - VC_{ik}) / VC_{ik}} \quad (3)$$

Where CS is Coefficient of Sensitivity, ESV_i and ESV_j are initial and adjusted total estimated ecosystem service values respectively, and VC_{ik} and VC_{jk} = initial and adjusted value coefficients (US \$ ha⁻¹ yr⁻¹) for LULC type 'k'.

RESULTS AND DISCUSSION

LULC dynamics analysis

Generally, there were five LULC classes identified; cultivated land, forest land shrub and grassland, bare land and settlement (Figures 3 and 4). The largest coverage of sub-watershed was the shrub and grassland in all years (Figures 3, 4, 5 and 6); while in terms of the categories of shrub and grass land and cultivated land encompassed the biggest of the sub-watershed. Cultivated land increased from 23.1% (9402.48 ha) in

1972 to 33.79% (13745.20 ha) in 1986, to 38.82% (15648 ha) in 2008 to 39.14% (15728 ha) in 2017. The settlement was also overspread followed the similar trend as cultivated land, and its area became highest in 2017 compared with the land cover in 1972 (Table 4 and Figure 3).

On the contrary, the forest land reduced from 9.28% in 1972 to 9.48% in 1986 to 4.16% in 2008, auxiliary to 3.15% into 2017. Similarly shrub and grassland declines from 55.39% in 1972 to 50.51% in 1986 to 47.70% in 2008, further to 45.19% in 2017. Nevertheless, settlement and bare land showed incoherent styles of changes (Table 4, Figures 4, 5 and 6). Similar result obtained by (Zelege and Hurni, 2001; Tolessa et al., 2017b; Meshesha et al., 2016; Gashaw et al., 2017; Alemu et al., 2015) forest land was shrinking, while settlement and agricultural land increased significantly whereas Bewket (2002), Fentahun and Gashaw (2014) found the opposite, in terms of magnitude for changes. Zelege and Hurni (2001) reported an increase in cultivated lands by 38% in 38 years (1957-1995). Similarly, Belay (2002) reported an increase in croplands only by 5.5% within the interval of 1957-2000; an increase in of forest land at the expense of cropland documented elsewhere in Ethiopia (Amare et al., 2011; Asmamaw et al. 2011).

Land use policy in Ethiopia has been changed remarkably since 1972 because there was a change of regime from feudal to the Derg regime (Reid et al., 2000). During Hail Selassie regime, he encouraged commercialization and mechanization of agriculture. Firms were easily accessed tractors and fertilizers on loan basis (Kibret et al., 2016). However, the state was owned land in the Military regime and it was communal property (land reform) with the promotion of cooperatives in the villagization programme across the country resulted in depletion of natural resources and cultivation of land became increased, forests were cleared, lands highly degraded. When Ethiopian People Revolutionary Democratic Front (EPRDF) took power after the downfall of military regime was kept the same land policy which encouraged smallholders to put extra forest area to cultivation to produce high value-crops for possible markets and agro-processing plants (Dejene et al., 2013) favored mixed economy. Rural land utilization proclamation was effective in SNNPR since 2007 focused on citizens had got land certificates and given the use right based on the federal level government land use policy; there were no significant changes in land management's by farmers after the effect of the proclamation (SNNPR, 2007) farmers had strong fear lead to conflicts due to land registration (Zerga, 2016).

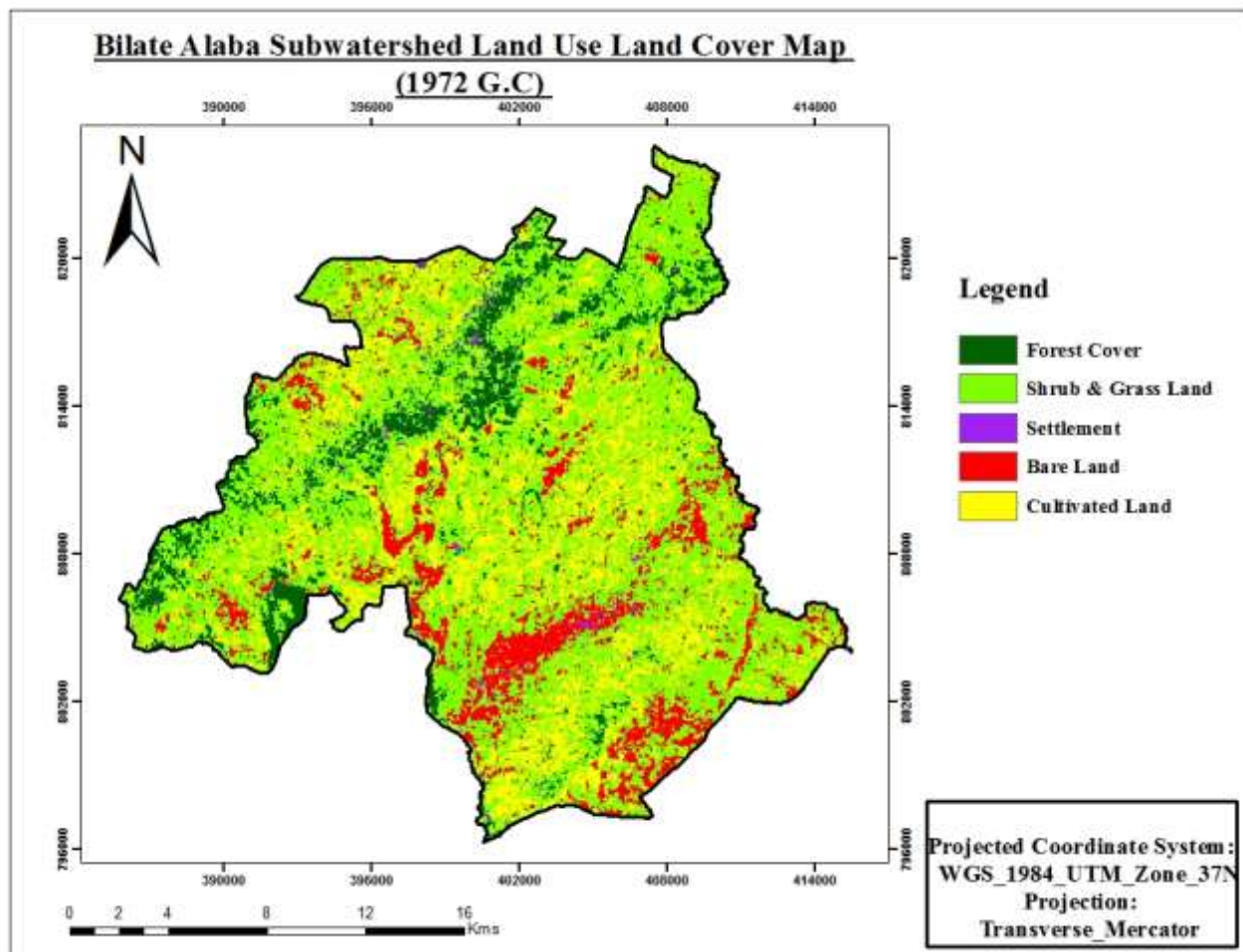
Ecosystem services values of land uses

ESV of shrub and grassland land use was decreased,

Table 3. Land use classes, proxy and equivalent VC.

Land use and land class	Proxy	Value of Coefficient(US \$ ha ⁻¹ yr ⁻¹)
Cultivated Land	Crop land	92
Shrub land	Forests	1201
Forest land	Tropical forests	2007
Settlement	Urban	0
Bare	Urban	0

Source: Costanza et al. (1997).

**Figure 3.** Bilate Alaba Subwatershed LULC map of 1972.

while cultivated land increased (Table 5). Considering ecosystem service value changes across the different intervals, 1972-1986, 1986-2008, 2008-2017 and 1972-2017, shrub and grassland ecosystem services decreased while cultivated land use ecosystem service increased.

It was observed there was a rising trend in forest land use ESV from 1972 to 1986, then a decline for 1986-

2017; general trend showed a decreasing tendency. Considering ESV values across land use classes, Shrub and grassland use system had the highest value in all study years (1972-2017). Ecosystem services value was reduced from US\$ 35.23 million in 1972 to US\$ 25.87 million in 2017, with the net loss of US dollar of 9.37 million (Tables 5 and 6) which was 26.6% in the sub-watershed.

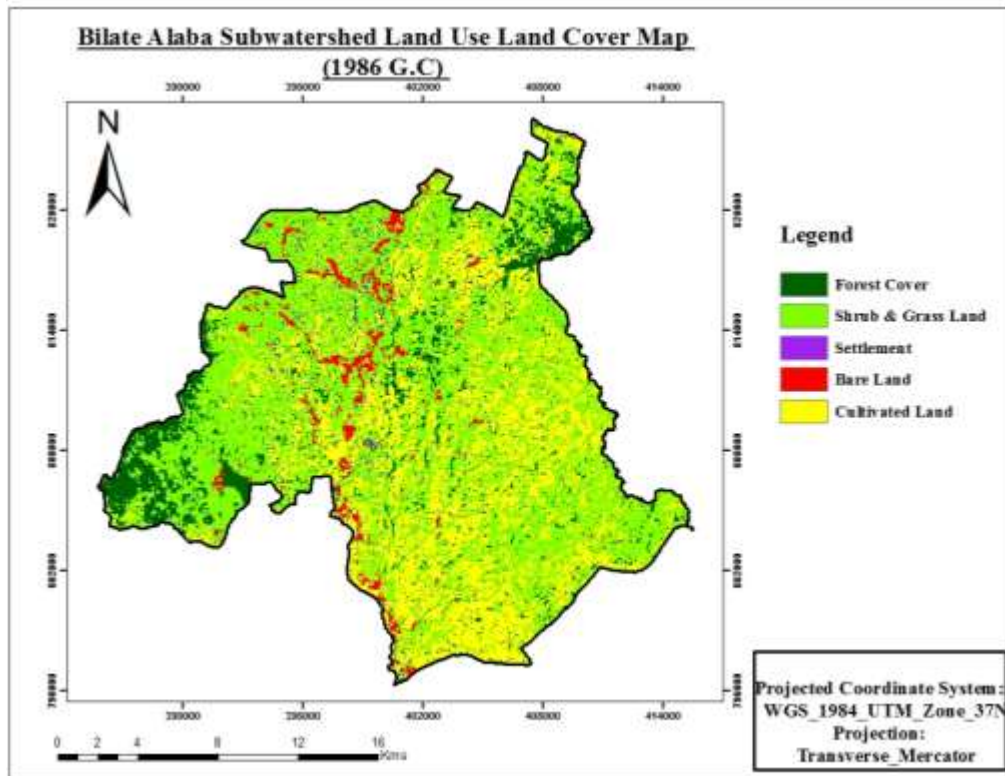


Figure 4. Bilate Alaba Subwatershed LULC map of 1986.

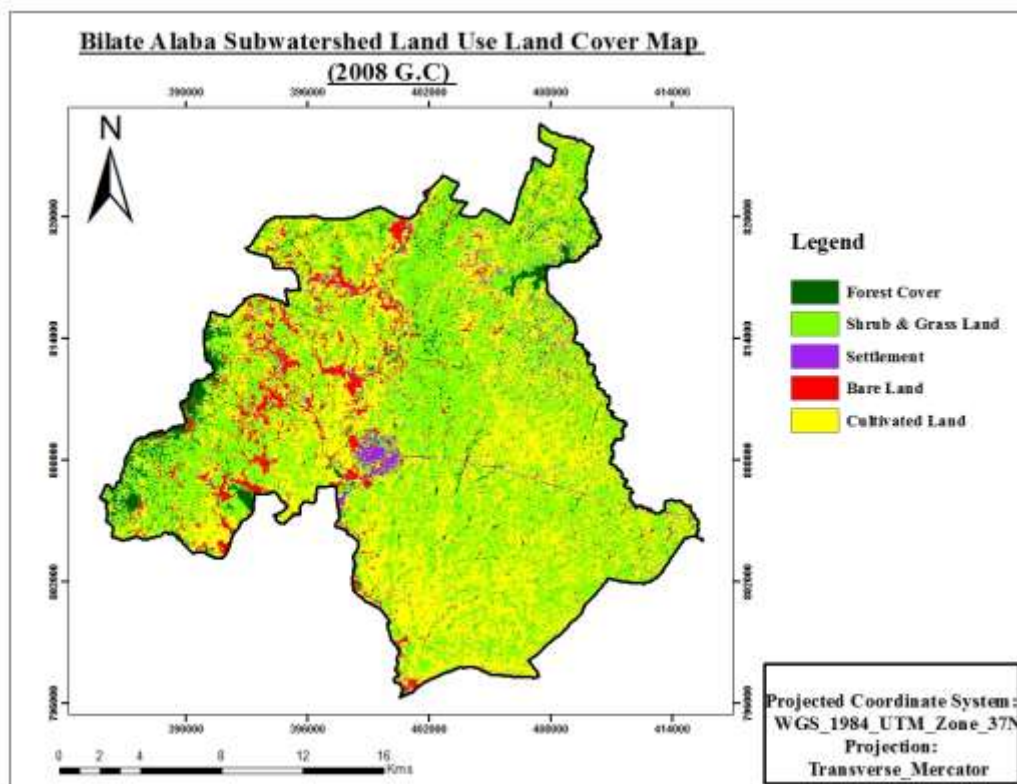


Figure 5. Bilate Alaba Subwatershed LULC map of 2008.

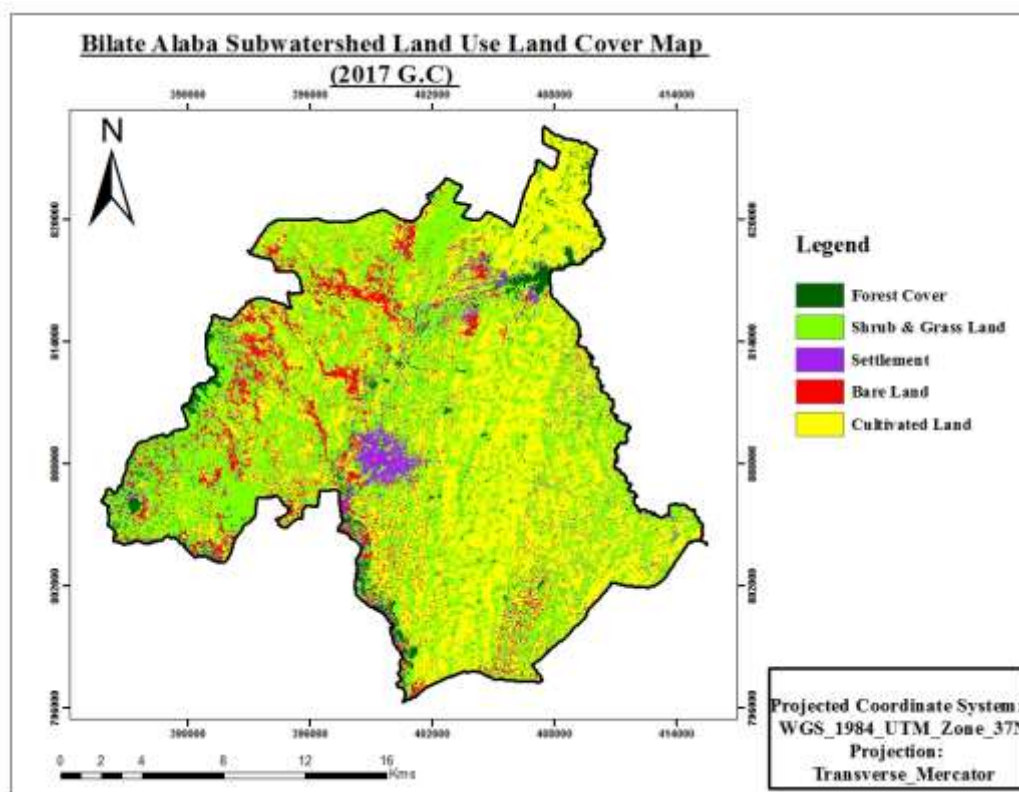


Figure 6. Bilate Alaba subwatershed LULC map of 2017.

Table 4. Areas of LULC of Bilate Alaba subwatershed between 1972 and 2017.

LULC	1972		1986		2008		2017	
	Area (ha)	(%)	Area (ha)	(%)	Area (ha)	(%)	Area (ha)	(%)
Cultivated land	9402.48	23.35	13335.20	33.12	15648	38.83	15738.3	39.06
Settlement	318.0	0.79	1318	3.27	1262.34	3.13	2011.1	4.99
Shrub & Grassland	22303.5	55.39	20340	50.51	19221.6	47.70	18208.3	45.19
Forest Cover	3777.48	9.38	3961.44	9.84	1686.4	4.18	1270.93	3.15
Bare Land	4467.97	11.10	1314.36	3.26	2478.15	6.15	3068	7.61

Regarding to individual ecosystem service functions, nutrient cycling (US\$ 3.789 million), climate regulation (1.136 million), and raw material (US\$ 1.355 million), and erosion control (US\$ 1.126 million) were reduced, whereas biological control (US\$ 0.05 million) and pollination (US\$ 0.035 million) were gained in ESV (Table 7). The average ESV of the land use in sub-watershed was lower than other results such as in Dendi District (Tolessa et al., 2018), Gedeo–Abaya, Southern Eastern escarpment (Temesgen et al., 2018) and Munessa-Shashemene landscape (Kindu et al., 2016) whereas higher than in Chillimo forest (Tolessa et al., 2017b) and Andassa watershed upper Nile basin (Gashaw et al., 2018).

The coefficients of sensitivity (CS) of these investigations were smaller than one in all land uses. The value of the ESV coefficients of selected land uses 50% adjustment results shown in (Table 8), CS varied from a small of 0.02-0.06 for cultivated land to a larger of 0.73-0.84 used for shrub and grassland. CS for shrub and grassland was the highest since relatively larger coverage in addition to 2nd highest service value. The results of all analyses indicated that the ESVs calculated for the sub-watershed was fairly inelastic in relation to changes ESV coefficients, which also suggests the estimation of the ES value is reliable since all the CS values are less than one.

LULC changes were influenced ecosystems services,

Table 5. ESV for each LULC class during the study period from 1972 to 2017 in Bilate Alaba Subwatershed.

LULC class	ESV (US\$ million)				ESV (US\$ million) change			
	1972	1986	2008	2017	1972-1986	1986-2008	2008-2017	1972-2017
Cultivated land	0.87	1.23	1.44	1.45	0.36(41.8)	0.21(17.3)	0.01(0.6)	0.58(67.4)
Shrub and grassland	26.78	24.43	23.09	21.87	-2.36(-8.8)	-1.34(-5.5)	-1.22(-5.3)	-4.92(-18.4)
Forest	7.58	7.95	3.38	2.55	0.37(4.9)	-4.57(-57.4)	-0.83(-24.6)	-5.03(-66.4)
settlement	0	0	0	0	0	0	0	0
Bare land	0	0	0	0	0	0	0	0
Sum	35.23	33.61	27.91	25.87	-1.63(-4.6)	-5.70(-17.0)	-2.04(-7.3)	-9.37(-26.6)

Table 6. ESV for each LULC category and changes of 1972 and 2017 in Bilate Alaba Subwatershed, Southern Ethiopia.

LULC class	ESV (US\$ million)			Change
	1972	2017	ESV	Contributed of change in ESV (ccf)
Cultivated land	0.87	1.45	0.58	1.65
Shrub and grassland	26.79	21.87	-4.92	-13.96
Forest	7.58	2.55	-5.03	-14.28
settlement	0	0	0	0
Bare land	0	0	0	0
Sum	35.23	25.87	-9.37	-26.60

Table 7. Estimated individual ecosystem functions (ESVf in US \$ million per year).

Ecosystem service	ESVf1972	ESVf2017	Change	Contributed of change in ESV (ccf)
Gas regulation	0.156	0.127	-0.029	-0.081
Climate regulation	3.987	2.851	-1.136	-3.225
Disturbance regulation	0.063	0.043	-0.021	-0.059
Water regulation	0.134	0.099	-0.036	-0.101
Water supply	0.097	0.065	-0.032	-0.092
Erosion control	3.713	2.587	-1.126	-3.195
Soil formation	0.283	0.213	-0.070	-0.199
Nutrient cycling	11.534	7.745	-3.789	-10.753
Waste treatment	4.209	3.279	-0.931	-2.641
Biological control	0.783	0.833	0.050	0.141
Food production	3.082	2.893	-0.189	-0.535
Raw material	4.268	2.913	-1.355	-3.844
Genetic resource	0.512	0.343	-0.168	-0.478
Recreation	1.940	1.381	-0.559	-1.587
Cultural	0.052	0.039	-0.013	-0.037
Pollination	0.422	0.457	0.035	0.101
Sum	35.237	25.868	-9.369	-26.585

Table 8. Coefficient of sensitivity (CS) and valuation coefficients (VC) in the Bilate Alaba Subwatershed, Southern Ethiopia.

Variable	1972		1986		2008		2017	
	Percent	CS	Percent	CS	Percent	CS	Percent	CS
Cultivated land VC \pm 50%	1.23	0.02	1.83	0.04	2.58	0.05	2.80	0.06
Shrub and grassland VC \pm 50%	38.01	0.76	36.34	0.73	41.37	0.83	42.27	0.84
Forest land VC \pm 50%	10.76	0.22	11.83	0.24	6.05	0.12	4.93	0.10

the ecosystem service value of the sub-watershed was reduced over the analysis years due to the decline of important components of the sub-watershed especially forest, shrub and grassland, which is similar to the findings of Eshetu and Högberg (2000), Li et al. (2007) and Yirsaw et al. (2017). With regard to individual ecosystem functions, the raw material, nutrient cycling, and cultural services were reduced in the sub-watershed, which agreed with the results of Tolessa et al. (2017a), Hu et al. (2008) and Kindu et al. (2016). The robustness test carried out in sensitivity analysis confirmed that ESV calculated was reliable, agreed with the findings of Li et al. (2007), Hu et al. (2008) and Tolessa et al. (2017b). However, the global database may underestimate the current potential land use practices by smallholders (Costanza et al., 1997).

Even though there were significant improvements of ecosystem services in developed nations, there was a huge loss of certain ecosystem services in developing countries, for example, in Ethiopia, due to land use changes derived from natural to agricultural (Haines-Young et al., 2012). Monitoring and quantification of each watershed functions in rural areas could help to understand the benefits and minimize associated losses to the natural ecosystem (Nelson et al., 2009). To diminish the cost of ground data collection which is expensive, estimation of ESV using LULC change and established global database is an alternative way, moreover, getting real data about land use in rural areas is challenging.

CONCLUSION AND RECOMMENDATIONS

There is a substantial influence of LULC data on ecosystem services at the local and global level to indicate how many services lost through human cultivation in both space and time. The ecosystem services reduced due to deforestation and overgrazing might have an effect on the livelihoods of local communities and hence the need for improving land for sustainable production is vital. Regards the major LULC change observed in the last 45 years (1972-2017), cultivated land and settlement land expanded by 67.38 and 532% respectively whereas forest land, shrub land and grassland declined by 66.35 and 18.36% respectively over the analysis period.

ESV decreased by 26.6%, among the ecosystem functions identified biological control (0.05%) was the highest positive value as compared to other, while other remaining services had negative value indicated decreasing trend; nutrient cycling, provision of raw materials, climate regulation and erosion control were major contributors for the loss of ESV indicated that the study area needs proper soil fertility management together with soil conservation measures. The CS values selected land use types (cultivated, forest and shrub and grassland) were less than one implied the estimation is

robust. CS for shrub and grassland use has the highest among all land uses. It was estimated about US\$ 9.37 million loss of service in 45 years has revealed of ecological degradation. The agricultural development under current pattern should take into financial related losses occurred at ordinary settings whether lost or transformed; crop production systems should have appropriate land use plan incorporating to protect forest, shrub and grassland having bigger ESV.

Many tropical countries land use policies encourage the alteration of woods to crop production outcome of the loss of important ESs (Lira et al., 2012), moreover, the current investment policy put most natural forest/shrub areas converted to agro-processing industries affecting the natural setup of ecology and this also practiced in the sub-watershed. The need for appropriate intervention of rural land policies and active participation of smallholders for the long-term management of land assets (forest, shrub and grassland) is crucial to prevent the degradation of the ecological resources.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

- Alemu B, Efreem G, Zewdu E, Habtemariam K (2015). Land Use and Land Cover changes and associated driving forces in North Western lowlands of Ethiopia. *International research journal of agricultural science and soil science* 5(1):28-44.
- Amare B, Hurni H, Gete Z (2011). Responses of rural households to the impacts of population and land-use changes along the Eastern Escarpment of Wello, Ethiopia. *Journal geography research* 65:42-53.
- Anderson JR, Hardy EE, Roach JT, Witmer RE (1976). A land use and land cover classification system for use with remote sensor data, *Geological Survey Professional Paper* 964:1-27.
- Asmamaw L, Mohamed A, Lulseged T (2011). Land use/cover dynamics and their effects in the Gerado catchment, northeastern Ethiopia. *International Journal Environment Study* 68:883-900.
- Bewket W (2002). Land cover dynamics since the 1950s in Chemoga Watershed, Blue Nile Basin, Ethiopia. *Mountain research and development* 22:263-269.
- Belay T (2002). Land-Cover/Land-Use Changes in the Derekolli Catchment of the South Welo Zone of Amhara Region, Ethiopia. *Eastern Africa Social Science Research Review* 18(1):1-20.
- Bryan BA (2013). Incentives, land use, and ecosystem services: synthesizing complex linkages. *Environmental science and policy* 27:124-134.
- Costanza R, de Groot R, Sutton P, Van der Ploeg S, Anderson SJ, Kubiszewski I, Farber S, Turner RK (2014). Changes in the global value of ecosystem services. *Global environmental change* 26:152-158.
- Costanza R, d'Arge R, De Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, Belt MV (1997). The value of the world's ecosystem services and natural capital. *Nature* 387:253-260.
- Daily G, Alexander S, Ehrlich P, Goulder L, Lubchenco J, Matson P, Mooney H (1997). Ecosystem services: benefits supplied to human societies by natural ecosystems. *Ecology society of America* 2:2-16.
- De Groot R, Brander L, Van Der Ploeg S, Costanza R, Bernard F, Braat L, Christie M, Crossman N, Ghermandi A, Hein L (2012). Global estimates of the value of ecosystems and their services in monetary

- units. *Ecosystem services* 1(1): 50-61.
- De Groot RS, Wilson MA, Boumans RM (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological economics* 41(3):393-408.
- Dejene T, Lemenih M, Bongers F (2013). Manage or convert *Boswellia* woodlands? Can frankincense production payoff? *Journal of arid environments* 89:77-83.
- Eshetu Z, Högberg P (2000). Reconstruction of forest site history in Ethiopian highlands based on ^{13}C natural abundance of soils. *Journal of the Human Environment* 29(2):83-89.
- FAO (1998). The Soil and Terrain Database for northeastern Africa: Crop Production System Zones of the IGAD subregion (scale 1: 1 M). Land and Water Digital Media Series (2).
- Fentahun T, Gashaw T (2014). Evaluation of land use/land cover changes in Bantnek watershed, Ethiopia. *Civil and Environment research* 6(2).
- Gashaw T, Tulu T, Argaw M, Worqlul AW (2017). Evaluation and prediction of land use/land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia. *Environment System Research* 6:17.
- Gashaw T, Tulu T, Argaw M, Worqlul AW, Tolessa T, Kindu M (2018). Estimating the impacts of land use/land cover changes on Ecosystem Service Values: The case of the Andassa watershed in the Upper Blue Nile basin of Ethiopia, *Ecosystem Services*, Elsevier 31:219-228.
- García-Llorente M, Iniesta-Arandia I, Willaarts BA, Harrison PA, Berry P, del Mar Bayo M, Castro AJ, Montes C, Martín-López B (2015). Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds. *Ecology and Society* 20(3):39.
- Haines-Young R, Potschin M, Kienast F (2012). Indicators of ecosystem service potential at European scales: mapping marginal changes and trade-offs. *Ecological Indicators* 21:39-53.
- Hu H, Liu W, Cao M (2008). Impact of land use and land cover changes on ecosystem services in Menglun, Xishuangbanna, Southwest China. *Environmental monitoring and assessment* 146:147-156.
- IPMS (2005). Alaba pilot learning woreda diagnosis and program design. <https://cgspace.cgiar.org/bitstream/handle/10568/16748/Alaba.pdf?sequence=1>
- Jensen J (2007). *Remote sensing of the environment: an earth resource perspective*: Pearson Prentice Hall. Upper Saddle River, NJ.
- Kibret KS, Carsten M, Georg C (2016). Assessment of land use and land cover change in South Central Ethiopia during four decades based on integrated analysis of multi-temporal images and geospatial vector data. *Remote Sensing Applications Society and Environment* 3:1-19.
- Kindu M, Schneider T, Teketay D, Knoke T (2016). Changes of ecosystem service values in response to land use/land cover dynamics in Munessa–Shashemene landscape of the Ethiopian highlands. *Science of the Total Environment* 547:137-147.
- Li Q, Zhang X, Liu Q, Liu Y, Ding Y, Zhang Q (2017). Impact of land use intensity on ecosystem services: An example from the agro-pastoral ecotone of central inner mongolia. *Sustainability* 9(1030):1-11.
- Lira PK, Tambosi LR, Ewers RM, Metzger JP (2012). Land-use and land-cover change in Atlantic forest landscapes. *Forest Ecology and Management* 278:80-89.
- Li R-Q, Dong M, Cui J-Y, Zhang L-L, Cui Q-G, He W-M (2007). Quantification of the impact of land-use changes on ecosystem services: a case study in Pingbian County, China. *Environmental monitoring and assessment* 128:503-510.
- Lobo G (2001). *Ecosystem functions classification*. Ecological Economics and Environmental Management Centre (ECOMAN).
- Millennium Ecosystem Assessment (MEA) (2005). *Ecosystems and Human Well-being: Synthesis*. Millennium Ecosystem Assessment, Island Press, Washington, DC.
- Meshesha TW, Tripathi SK, Khare D (2016). Analyses of land use and land cover change dynamics using GIS and remote sensing during 1984 and 2015 in the Beressa watershed northern central highland of Ethiopia. *Model Earth System Environment* 2(4):168.
- Meshesha DT, Tsunekawa A, Tsubo M, Ali SA, Haregeweyn N (2014). Land-use change and its socio-environmental impact in Eastern Ethiopia's highland. *Regional environmental change* 14(2):757-768.
- Nelson E, Mendoza G, Regetz J, Polasky S, Tallis H, Cameron D, Chan KM, Daily GC, Goldstein J, Kareiva PM (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment* 7(1):4-11.
- Polasky S, Nelson E, Pennington D, Johnson KA (2011). The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the state of Minnesota. *Environmental and Resource Economics* 48(2):219-242.
- Power AG (2010). Ecosystem services and agriculture: tradeoffs and synergies. *Philosophical Transactions of the Royal Society of London, Biological Sciences* 365:2959-2971.
- Reid RS, Kruska RL, Muthui N, Taye A, Wotton S, Wilson CJ, Mulatu W (2000). Land-use and land-cover dynamics in response to changes in climatic, biological and socio-political forces: the case of southwestern Ethiopia. *Landscape Ecology* 15(4):339-355.
- SNNPR (2007). SNNPR Rural Land Administration and Utilization Proclamation. 110/2007. <https://ethiolex.com/content/proc-no-110-2007-%E2%80%93-rural-land-administration-and-utilization-proclamation-southern-nations>
- The Economics of Ecosystems and Biodiversity (TEEB) (2010). *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundation*. Earthscan, Cambridge, Washinton.
- Temesgen H, Wu W, Shi X, Yirsaw E, Bekele B, Kindu M (2018). Variation in Ecosystem Service Values in an Agroforestry Dominated Landscape in Ethiopia: Implications for Land Use and Conservation Policy. *Sustainability* 10:1126.
- Tolessa T, Gessese H, Tolera M, Kidane M (2018). Changes in Ecosystem Service Values in Response to Changes in Landscape Composition in the Central Highlands of Ethiopia. *Environmental Processes* 5:483-501
- Tolessa T, Senbeta F, Abebe T (2017a). Land use/land cover analysis and ecosystem services valuation in the central highlands of Ethiopia. *Forests, Trees and Livelihoods* 26(2):111-123.
- Tolessa T, Senbeta F, Kidane M (2017b). The impact of land use/land cover change on ecosystem services in the central highlands of Ethiopia. *Ecosystem services* 23:47-54.
- Tsegaye D, Moe SR, Vedeld P, Aynekulu E (2010). Land-use/cover dynamics in Northern Afar rangelands, Ethiopia. *Agriculture, ecosystems & environment* 139:174-180.
- Yirsaw E, Wu W, Shi X, Temesgen H, Bekele B (2017). Land use/land cover change modeling and the prediction of subsequent changes in ecosystem service values in a coastal area of China, the Su-Xi-Chang Region. *Sustainability* 9(1204):1-17.
- Zelege G, Hurni H (2001). Implications of land use and land cover dynamics for mountain resource degradation in the northwestern Ethiopian highlands. *Mountain research and development* 21(2):184-191.
- Zerga B (2016). *Land Resource, Uses, and Ownership in Ethiopia: Past, Present and Future*. International Journal of Scientific Research and Engineering 2:17-24.

Full Length Research Paper

Floristic and structural traits of tree vegetation in three sites with different level of disturbance in dense humid forest of Cameroon

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This study characterizes the floristic and structural traits of trees in three sites of rainforest of Cameroon. The sites were exposed to different intensities of disturbances: Mangombe, highly and frequently disturbed; Bidou, moderately disturbed and Campo, undisturbed. Data collection were carried in a dispositive comprising 65 plots of 20 m × 20 m randomly installed in each site for inventory, identification and measurement of diameter of trees greather than 10 cm at 1.30 m height. In total, 4717 plants belonging to 130 species and 43 families were recorded in all the sites. Basal area showed a declining trend with the increase in disturbance intensity while tree density, species richness and families increase with disturbances: Campo (87 m²/ha, 569 trees/ha, 75 species and 29 families); Bidou (54, 538, 88 and 32); Mangombe (49, 708, 91 and 38). The vegetation indices showed a high diversity in all the sites. The Shannon index (5.40 to 5.52) and generic diversity (1.10 to 1.16) had greater value. According to the sample, the floristic composition of Mangombe considerably differs from those of Bidou and Campo. The undisturbed site (Campo) contained young tree population showing a vigorous regeneration while in the highly disturbed site (Mangombe), tree density was scarce, with few big size trees having high cultural importance and low economic value. Low shrub density was recorded in Mangombe and Bidou due to frequent human disturbances. Canopy gaps favor direct sunlight which enhanced the abundance of Shrub in all the sites. More protection is needed for the restoration in the long term of forest cover in Mangombe, which can be done naturally due to high density of small trees composed of species generally found in the upper strata.

Key words: Cameroon, dense humid forest, disturbance, species richness, structure of population.

INTRODUCTION

Forest ecosystem offers various ecosystemic services for humanity. Its plays an important role for the survival of

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rural communities. These anthropogenic disturbances in tropical forests are old and date from the beginning of their occupation by men (Chazdon, 2003). Therefore the dense humid forest of Cameroon presents heterogeneity in the spatial distribution of patches of disturbed and undisturbed forest. The studied sites were formerly inhabited and cultivated during a century, then gradually abandoned with old and even contemporary reoccupation; making disturbance old in this ecosystem (Letouzey, 1968). A selective cutting of wood and harvesting of non-timber forest product were made in the sites at different period, intensity and frequency. Mangombe was highly and frequently disturbed; Bidou, moderately disturbed and Campo, undisturbed. Various studies attest that anthropogenic activities constitute one of the major threats to the conservation of tropical forest. Soft logging exploitation does not exist, but reduces the diversity and richness of forest in wood species with high economic value. Logging exploitation also involves damage on the surrounding forest. These disturbances can affect the floristic and structural threat of ecosystems (Thapa et al., 2010; Naing et al., 2011). Other authors think that disturbances related to moderate human pressure cannot necessarily affect the species richness of forest because it create new environmental condition which sometimes increase the flora diversity (Budke et al., 2010). The comparison of the vegetation analysis would help in understanding the effects of disturbance on the composition and dynamics of forest community and also help in managing the Mangombe and Bidou secondary forests more exposed to anthropogenic disturbance.

MATERIALS AND METHODS

Description of study area

This study was conducted in the southwestern dense humid forest of Cameroon, in the middle of the Biafran Rain Forest. The area is an important site of the Guineo Congolian regional centre of endemism. The sites especially Campo is composed of many forest types with species of high conservation priorities (114 endemic species of which 29 are only found in the area and rich fauna). Despite his importance, the area is under human pressure which leads to the degradation of coastal forest and depletion of lowland forest. The main conservation effort was the creation of community council forest in Mangombe and a national park in Campo (Tchouto, 2004).

Sampling and data collection methods

A set of 65 plots of 20 m × 20 m were randomly installed in each site, a total cover of 2.6 ha; for inventory, and measure of tree (using a meter) with diameter greater than 10 cm at 1.30 m height. The use of plots has many advantages; it helps to highlight the different phenomena of forest dynamics, to intensify the study of the milieu and study the composition and structure of a forest ecosystem (Picard, 2007).

Data analysis

Floristic analysis

Specific Richness (SR): The specie richness is the total number of species observed. The Area - Species curve and Hurlbert curve (Abundance - Species) show evolution of the species richness in relation with the sampled area and help to describe the forest. This approach was used by several authors to estimate extinction rate of species in rain forests (Reid, 1992; Jha et al., 2005).

Diversity of families and genera: The diversity of families is the expression in percentage of appearance of each of the inventoried families.

$$E / G \quad (1)$$

where E represents the number of species and G the number of genera which helps to appreciate the floral diversity. A low value (close to 1) of this equation indicates a strong diversity of the flora, but does not inform about the species distribution between the various genera and families. Analysis of families' spectrum is important, because rich ecosystems are characterized by few large genera and families rich in species.

Important Value Index (IVI): Important Value Index (IVI) helps to determine the place occupied by each tree species within the community according to Curtis's and Macintosh (1950) formula.

$$IVI = \left(\sum_{i=1}^n \frac{N_i}{N} + \sum_{i=1}^n \frac{G_i}{G} \right) \times 100 \quad (2)$$

In this Equation 2, N_i/N is the relative frequency of the individuals of specie "i"; N_i is the population of specie and N is the total number of the counted individuals. The report G_i/G is the relative dominance of the individuals of a specie "i"; G_i is the basal area of the individuals of the specie "i" and G is the total basal area.

Shannon diversity Index (H'): The Shannon (1949) diversity index in Legendre and Legendre (1984) is an indicator of the specie richness ponderated by the number of individuals per species. It compares the floral richness of different forest sites, in particular when the number of individuals censured in the different sites presents a large gap (Magurran, 2004).

$$H' = - \sum_{i=1}^n \frac{N_i}{N} \log_2 \frac{N_i}{N} \quad (3)$$

The Shannon-Wiener index varies from 0 to $\log_2 S$. The value 4.5 corresponds to a rich community, composed by an important number of species with almost equal frequency per species (Senterre, 2005).

Structural parameter

Mean Diameter (D_m): The mean diameter of trees (Equation 4) is:

$$D_m = \sum_{i=1}^n \frac{D_i}{N} \quad (4)$$

Basal area (B): The basal area gives a good visualization of a

Table 1. Abundance and diversity index of tree species censured in Mangombe, Bidou and Campo forest sites

Parameter	Mangombe	Bidou	Campo	All the sites
Number trees	1840	1398	1479	4717
Density (trees/ha)	708	538	569	605
Number of species	91	88	75	130
Number of genus	77	81	68	110
Number of families	38	32	29	43
Generic diversity (E/G)	1.16	1.10	1.10	1.19
Shannon index (H')	5.52	5.41	5.40	6.12
Mean diameter (cm)	23.45 ± 18.28 ^c	28.21 ± 22.02 ^a	33.91 ± 28.27 ^b	28.14 ± 23.31
Basal area (m ² /ha)	49.13 ^c	54.08 ^a	87.06 ^b	63.42
Level of disturbance	High	Mean	Low	

forest ecosystem and highlights the species and the families which occupy most place. It is a descriptor directly connected to the diameter usually used to study the structure of forest and was calculated using the following formula.

$$B = \frac{\pi}{4} \sum_{i=1}^n D_i^2 = \frac{1}{4\pi} \sum_{i=1}^n C_i^2 \tag{5}$$

where B: Basal area (m²/ha), d: diameter (m), C: circumference (m), N: number of trees.

Data were compiled and analyzed with Excel, while R was used to test the significance of differences between parameters of the three forest site, and also for cluster analysis.

RESULTS

Floristic richness, basal area and important value index (IVI) of taxas

A total of 4717 trees were counted in the 195 plots which cover 7.8 ha. The average density of trees is estimated to 605 individuals/ha. This density presents a highly significant difference between the three sites ($F_{2, 192} = 20.95, P < 0.001$). The density was high in Mangombe (708 individuals/ha), average in Campo (569) and low in Bidou (538). The inventoried trees can be grouped into 43 families, 110 genera and 130 species. Shannon index is high in all the sites. The specific diversity decreases with the level of disturbance. The floristic diversity value is high in Mangombe the most disturbed site (38 families, 77 genera and 91 species), comparing to Bidou (32, 81 and 88) and Campo (29, 68 and 75). The basal area is significantly low at Mangombe (49.13 m²/ha) with regard to Bidou (54.08 m²/ha) and Campo (87.06 m²/ha) ($F_{2, 4714} = 93.21, P < 0.001$) (Table 1).

The Areas - Species curve and the Abundance - Species Richness curve of Mangombe and Bidou are very close. They belong to the same reliable intervals and both present a regular growth more important than that of

Campo, characterized by the recruitment of a high number of species when the number of trees and the inventoried area increase. The site of Campo is the least disturbed and less diversified comparing to others, with reliable intervals which do not recover those of Mangombe (Figure 1). In terms of their IVI, the five most important families and species are respectively estimated at 57 and 31% in Mangombe, Bidou (54 and 34%) and Campo (61 and 30%) (Table 2).

Floristic composition

Abundant species are generally more frequent and more distributed. This group is composed in Mangombe by: *Tabernaemontana crassa* Benth (8%), *Strombosia scheffleri* Engl. (8%), *Oncoba glauca* (p. Beauv) Planch (6%) and *Lophira alata* Banks ex C.F. Gaertn (5%). In Bidou, this group includes *Dialium guineense* Willd (8%), *Diospyros crassiflora* H. Perrier (8%), *Uapaca guineensis* Müll Arg. (6%) and *Keayodendron bridelioides* (Gilg and Mildbr. Ex Hutch. and Dalziel) Leandri (6%), whereas in the site of Campo, we have *K. bridelioides* (11%), *Anthonotha macrophylla* P. Beauv. (6%), *D. crassiflora* (6%) and *Polyalthia suaveolens* (Engl. and Diels) Verdc (5%).

Table 3 presents the specific composition of genera; it shows that Kola is the most diversified with 5 species. The forests of Mangombe and Bidou are more varied in genus. The number of genus represented by single specie is estimated at 67 genera at Mangombe, 74 at Bidou and 61 in Campo. In all the sites, more than 88% of the genera were composed of single specie. The numbers of genera composed of several species decreases considerably while the number of species per genus increases.

In Mangombe, the more diversified genus are *Dacryodes* and *Strombosia* (with three species each), and *Kola* (with 4 species). In Bidou they are: *Afzelia*, *Anthonotha*, *Kola*, *Hallea*, *Markhamia*,

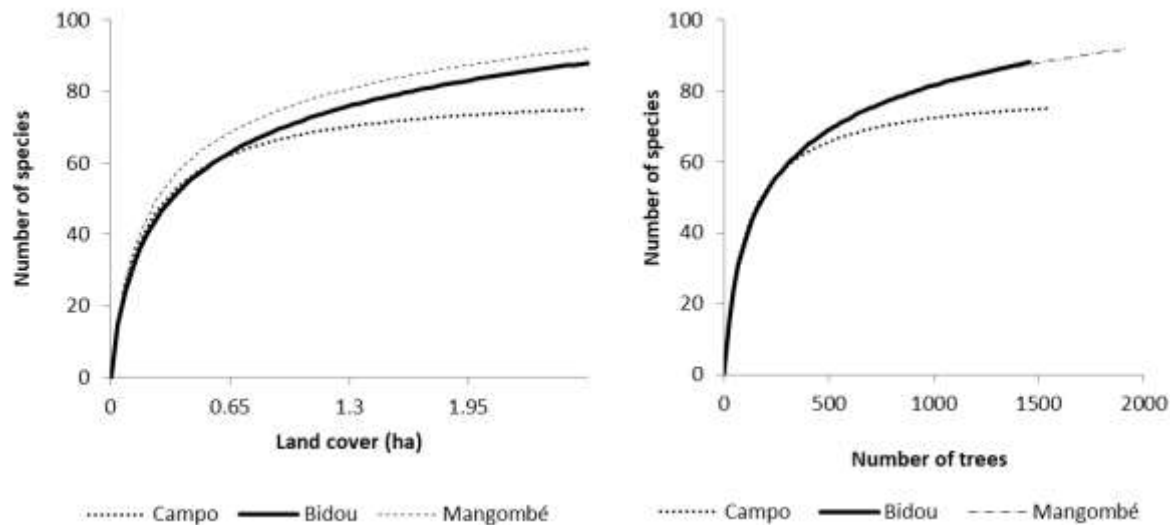


Figure 1. Area-species curve (left) and Abundance-species curve of Hurlbert (right) of censured species in Mangombe, Bidou and Campo forest station.

Table 2. Biological parameters of the 5 most important families and species in Mangombe, Bidou and Campo forest station.

Site	Families	G (m ² /ha)	N (ind/ha)	IVI (%)	Species	G (m ² /ha)	N (ind/ha)	IVI (%)
Mangombe	Olacaceae	13.32	125	22	<i>Strombosia scheffleri</i>	5.82	54	10
	Fabaceae	6.13	93	13	<i>Coula edulis</i>	5.30	19	7
	Annonaceae	3.63	74	9	<i>Tabernaemontana crassa</i>	1.53	55	5
	Apocynaceae	2.64	72	8	<i>Oncoba glauca</i>	2.11	41	5
	Euphorbiaceae	1.84	45	5	<i>Lophira alata</i>	1.55	34	4
Bidou	Fabaceae	15.60	102	24	<i>Dialium guineense</i>	7.01	43	11
	Humiriaceae	8.12	18	9	<i>Sacoglottis gabonensis</i>	8.12	18	9
	Euphorbiaceae	2.47	72	9	<i>Diospyros crassiflora</i>	1.32	42	5
	Annonaceae	2.55	47	7	<i>Anthonotha macrophylla</i>	2.75	21	5
	Ebenaceae	1.32	42	5	<i>Uapaca guineensis</i>	1.20	32	4
Campo	Fabaceae	26.30	112	25	<i>Keayodendron bridelioides</i>	3.18	60	7
	Annonaceae	7.17	73	11	<i>Lovoa trichilioïdes</i>	6.93	24	6
	Meliaceae	9.67	49	10	<i>Anthonotha macrophylla</i>	4.41	37	6
	Euphorbiaceae	4.48	77	9	<i>Sacoglottis gabonensis</i>	7.89	11	6
	Humiriaceae	7.89	11	6	<i>Erythrophleum suaveolens</i>	8.03	4	5

IVI: Important value index, N: density; B: basal area.

Table 3. Synthesis of number of species per gender in Mangombe, Bidou and Campo forest station.

Number of species	Number of genera in the different forest station		
	Mangombe	Bidou	Campo
1	67	74	61
2	7	7	7
3	2	/	/
4	1	/	/
Total	77	81	68

Tabernaemontana, *Xylopia* and *Zanthoxylum* (with 2 species each) and at Campo the diversified genera are *Azelia*, *Anthonotha*, *Kola*, *Entandrophragma*, *Tabernaemontana*, *Xylopia* and *Zanthoxylum* (2 species).

In Mangombe, the five abundant families are: Olacaceae (18%), Fabaceae (13% dominated by the Caesalpinioideae 10%), Annonaceae (11%), Apocynaceae (10%), and Euphorbiaceae (6%), while in Bidou the group is composed of Fabaceae (19% dominated by the Caesalpinioideae 16%), Euphorbiaceae (13%), Annonaceae (9%), Ebenaceae (8%) and Meliaceae (7%), whereas in Campo we have Fabaceae (20% dominated by the Caesalpinioideae 16%), Euphorbiaceae (14%), Annonaceae (13%), Meliaceae (9%) and Ebenaceae (6%).

The diversified families are among the more abundant. Fabaceae is the more diversified floral group in all the sites and are dominated by the sub family of Caesalpinioideae. Other richness families are Euphorbiaceae, Apocynaceae and Annonaceae.

Comparison of the floristic composition of Mangombe, Bidou and Campo

Comparison of Bidou and Campo: The sites of Bidou and Campo have 63 common species. These common species represent 91% (1275 trees) of the counted trees in Bidou and 94% (1397 trees) of the effective of Campo. With regard to the sampling, this information suggests that there is very little difference between the floral compositions of these two sites. Bidou, still have impact of logging exploitation. The timber species like *L. trichilioides* are little represented with regard to the site of Campo. *P. suaveolens* used as firewood is less frequent at Bidou than Campo. The population of *P. nitida* presents gaps between Bidou and Campo, due to exploitation. *P. nitida* is a medicinal plant, with the bark and the roots used to cure malaria, stomach pains and pneumonia. *K. bridelioides* is a mesophanerophyte generally abundant in semi deciduous forests, and can be found scattered in dense humid forests. *D. guineense* is more abundant in Bidou; it is a riparian species found in the undergrown of dense humid forest, and the seeds of this species are consumed by local communities. In the site of Campo, we found emergent trees with bigger diameters.

Comparison of Mangombe with Bidou-Campo: The vegetation of Mangombe (91 species, 1840 individuals) is very different from those of Bidou (88, 1398) and Campo (75, 1479), in particular as regards the density, structure of population and floral composition. The Mangombe vegetation has 30 species (574 individuals) different from those of Bidou and Campo, and 44 common species (814 individuals) representing 44% of the species present in Mangombe. The common species are dominated by

those familiar to less disturbed forest; they are mostly commercial wood such as: *Azelia pachyloba* (Doussié), *Canarium schweinfurthii* (Ailé), *Coula edulis*, *Didelotia africana*, *D. crassiflora*, *Duboscia macrocarpa*, *Irvingia gabonensis*, *Khaya ivorensis*, *Pachyasma tessmanii*, *Pseudospondias longifolia*, *Saccoglottis gabonensis*, *Triplochiton scleroxylon*, and *U. guineensis*. The species of secondary forests in this group are: *Cleistopholis patens*, *Dacryodes macrophylla*, *L. alata*, *Markhamia tomentosa*, *Musanga cecropioides*, *Pycnanthus angolensis*, *Spathodea campanulata*, *Zanthoxylum gillettii*, *Zanthoxylum heitzii*, and *Xylopia aethiopica*.

Structural analysis of tree population in the different sites

Figure 2 represents the ACP based on the projection of the structural parameters for all the 4717 trees listed and distributed in class (Cl) of individuals with amplitude of 10 cm diameter. Cl₁ represents the class of the individuals 10 cm ≤ dbh ≤ 20 cm; Cl₂: 20 cm < dbh ≤ 30 cm; Cl₃: 30 cm < dbh ≤ 40 cm etc. These analyses show on axis 1 an opposition between diversified diameter classes, composed of abundant tree with small diameters, on one hand, and on the other hand classes of individuals with low density and big trees. This confirms the presence of forest patches at different growing stage.

In Mangombe, the vegetation is characterized by height trees with small diameters; this can be due to disturbance and canopy gap which favor the growth in height among trees which are in competition for light in the undergrowth. In all the sites, the first class of individuals Cl₁ is distinguished from others by the presence of various small sizes trees, while the upper classes are composed of few big trees.

In Mangombe, the classes of big diameters (Cl₁₁) distinguish themselves from others by their very low density (5 individuals and 3 species) and the presence of emergent species like *Sacoglottis gabonensis* (dbh = 135.35 cm), *C. edulis* (dbh = 318.18 cm). There is a big difference in the abundance of trees between the small size diameter classes Cl₁ (1025 trees), Cl₂ (429 trees) and Cl₃ (202 trees).

In Bidou, the class of big trees Cl₁₃ counts only 6 individuals composed of 6 species, such as *Staudtia kamerunensis* (156.13 cm), *D. africana* (162.69 cm) and *Baillonella toxisperma* (238.73 cm), which dominate the landscape by their sizes. The difference in terms of trees abundance and species richness explains the gap between Cl₁ (702 ind), Cl₂ (276 individuals) and Cl₃ (143 individuals).

In Campo, the class of the superior diameters is composed of 3 species (3 individuals); they are emergent species like *S. gabonensis* (207.16 cm), *Erythrophleum suaveolens* (382.23 cm).

The structures of trees population of Bidou and Campo

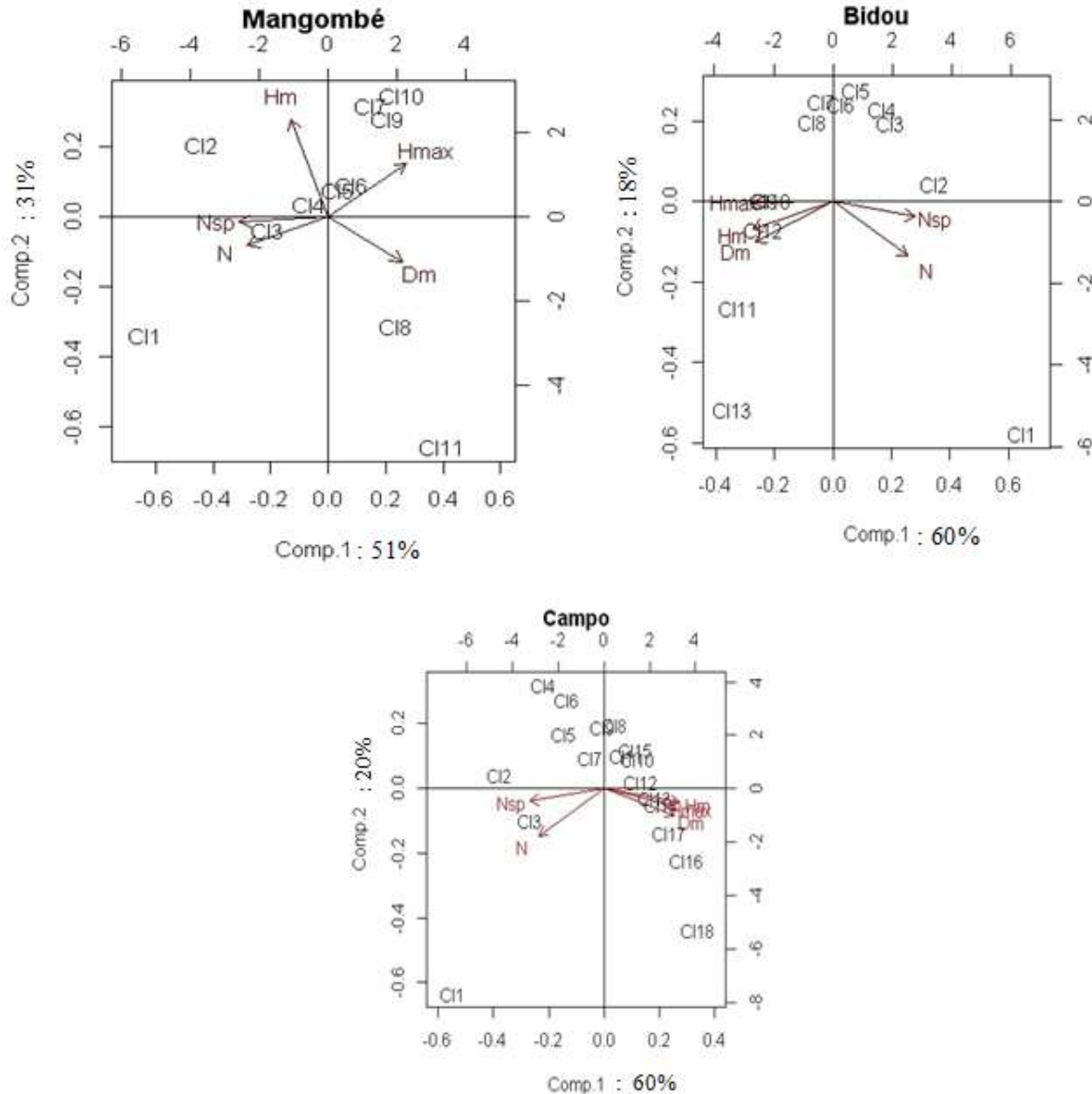


Figure 2. ACP presenting the correlation between two axis and structural parameters of trees in Mangombe, Bidou and Campo forest station. (Hm: mean height of trees, Hmax: maximum height, N: density, Dm: mean diameter, Number of trees per diameter class: Cl₁, Cl₂.....Cl_n).

are similar to an opposition between groups of plots composed of small trees, dense and diversified which doubtless find themselves in disturbed area; while on the other side there is a group of plots composed of big trees. Also, a group of intermediate plots was observed; and in Mangombe, the appearance of new altitudinal strata was observed.

Individualization of group of trees

Figure 3 is the HAC obtained from the presence/absence of tree species censused in 195 plots. It shows five

groups of trees. The composition of groups indicates that: Group 1 is a mixture at equal proportion of plots of Bidou and Campo; the Group 2 represents the site of Bidou, the Group 3 can be linked to the site of Campo and the Groups 4 and 5 belong to Mangombe.

According to their floral and structural composition, the groups can be classified in various types of forests.

Frequently disturbed patches of forest

Group 2 is vegetation in a dynamic state. The most abundant families are Fabaceae (20%), followed by

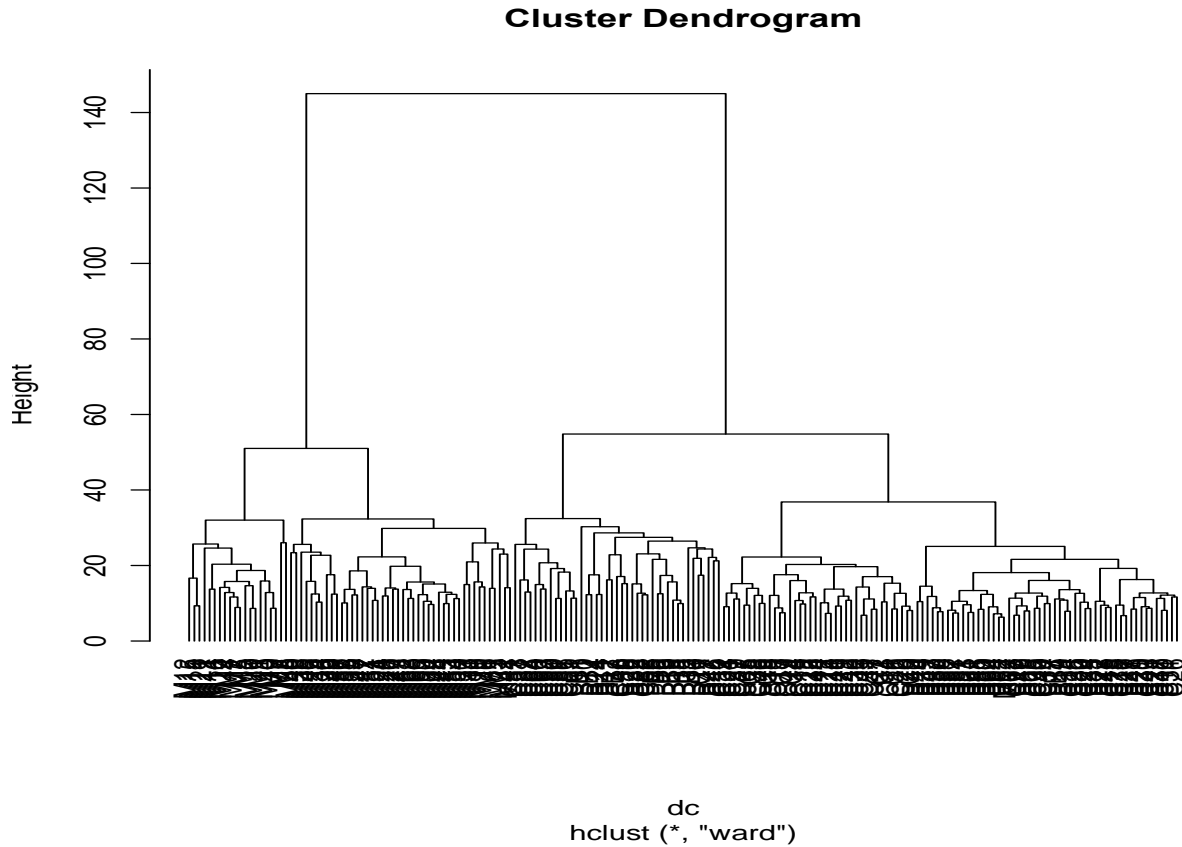


Figure 3. Representation of group of plots by the Hierarchical Ascendant Classification (HAC) 195 plots x 130 species.

Euphorbiaceae (17%), Meliaceae (8%) and Annonaceae (8%), whereas the abundant species are in decreasing order: *K. bridelioides* (9%), *D. crassiflora* (8%) and *D. guineense* (7%).

Group 4 counts various shade-intolerant species like *A. macrophylla*, *T. pachysiphon*, *P. suaveolens*, *D. macrophylla* and earlier growing species such as *C. patens*. These species mark signs of past and present disturbances. The abundant families are: Olacaceae (24%), Fabaceae (15%), Annonaceae (9%), Ebenaceae (9%) and the abundant species are: *S. scheffleri* (10%), *Diospyros kamerunensis* (9%), and *O. glauca* (6%).

Moderately disturbed patches of forest

The plant grouping 5 is the densest. The abundant families are: Olacaceae (15%), Apocynaceae (12%), and Annonaceae (11%). While the abundant species comprise: *T. crassa* (11%), *L. alata* (7%), *S. scheffleri* (6%), and *O. glauca* (6%). The higher number of pioneers and shade-intolerant species is an indicator of disturbed forest.

Table 4 presents the average biological parameters of

the groups; we can note that Groups 4 and 5 are diversified, with a strong density and an ascendancy of shrubby stratum (23 cm ≤ dbh ≤ 24 cm), these characteristics shows vigorous forest regeneration. Group 2 is composed of trees with average diameter (29 cm) whereas Group 3 and 1 have big trees.

Undisturbed patches of forest

In Group 1, the abundant ligneous families are: Fabaceae (18%), Annonaceae (10%), Euphorbiaceae (10%) and the frequent species are: *D. guineense* (6%), *D. crassiflora* (5%), and *U. guineensis* (5%).

Group 3 possesses the most important families, Fabaceae (20%), Annonaceae (15%), Euphorbiaceae (14%); whereas the frequent species are: *K. bridelioides* (13%), *D. crassiflora* (8%), and *A. macrophylla* (7%).

In these plant groupings, the abundance of Meliaceae in the understory indicates the importance of shade-intolerant species which are gradually replaced by tolerant species; this marks signs of past disturbances and the presence of Ebenaceae reminds one of an advanced maturity of the forest.

Table 4. Biological parameters of the vegetation groups issued from the 195 plots censused in Mangombe, Bidouand Campo forest stations.

Group	Number of trees	Number of species	Density (ind/ha)	B (m ² /ha)	Dm (cm)	Hm (m)
GR1	945	94	591	70	31	18
GR2	1004	72	502	55	29	17
GR3	942	61	628	97	33	18
GR4	580	60	580	55	24	16
GR5	1246	76	692	39	23	18

B: Basal area; Dm: mean diameter; Hm: mean height.

DISCUSSION

Floristic traits

The studied sites are rich and diversified as indicated by their species diversity (75 - 91), Shannon's index (5.40 - 5.52), low value of the generic coefficient ($1.10 \leq E/G \leq 1.16$) and the ascendancy of families and mono specific genera. This wealth characterizes rainforests recognized by their favorable environment necessary for their evolution (Stebbins, 1974), for the preservation of biodiversity (Leigh, 2008) and marked by the presence of a high number of genera represented by low number of species.

The number of species is high in Mangombe, a situation that results from logging exploitation and other human pressures which increased canopy gaps and favored pioneers and shade-intolerant species, which are added to the species existing in the forest before exploitation. Gaps in the canopy engendered by the death of trees modify the ecological conditions of the forest and constitute the driver of sylvigenesis. Other processes such as the substitution of emergent trees dead from foot and by the dominated trees also contribute to the mechanisms of renewal of the forest.

Generally, when environmental conditions are favorable, the natural regeneration which settles down after deforestations, can contain, a few years later, the seedling of all the forest species of the environment with however an important frequency and vitality of pioneers species able to mask the presence of other species (Chazdon, 2008). According to Sahu et al. (2008) and Chazdon et al. (2009), natural disturbances (tree blow downs) or anthropogenous pressures can contribute to biodiversity in the canopy gaps, or constitute a threat (Hanster Steege, 2010; Loreau, 2010). In disturbed area, certain species can easily settle down favoring a fast increase of the biodiversity; however, some of these species cannot sustainably stay in these environments. Therefore, the maturity of the forest can lead to the reduction of specific richness (Chave et al., 2003). Disturbances are not always negative to an ecosystem as it depends on their frequency and intensity. It can contribute to the diversity richness, renewal of the

ecosystem and release of nutrients.

The higher value of observed Shannon diversity index corresponds to the conditions where environment is favorable to installation of several species represented by few numbers of individuals. This tendency to a high specific diversity associated with a low density of species is a remarkable phenomenon in rain forest.

Specific richness and diversity

The Area - Species curve for all the sites shows a regular growth. It presents a classic structure of the recruitment of species when the number of trees increases. These curves are not stabilized; it indicates that additional inventories may increase the number of species. The comparison of the Area - Species curves shows a good correlation between the curve of Mangombe and Bidou where the number of species increase more quickly with the sample area comparing to the site of Campo. These tendencies find themselves in the Abundance - Species curve. The sites of Mangombe and Bidou seem richer and diversified than that of Campo, resulting from the importance and frequency of disturbances.

Important value index (IVI) and floral composition of the sites

This index shows a general representation of the composition of the vegetation in term of dominant species. Few numbers of species has an important contribution in IVI. Several wooden species are listed among the ten important species by their IVI in Bidou and Campo, viz; *U. guineensis*, *Lovoa trichilioïdes*, *E. suaveolens*, *K. ivorensis*, *D. africana*, *Eribroma oblonga*. At Mangombe, non wood species belong to those with important IVI such as *C. edulis* Baill., *S. scheffleri* Engl., *O. glauca* (P. Beauv.) Planch, *T. crassa* and *L. alata* Banks ex C.F. Gaertn which is a secondary forest wooden species.

At Mangombe, one can assume that wood exploitation which is selective because it takes only few big trees on a

reduced number of species, affects the specific composition of the forest and the process of reconstitution of the natural environment by increasing or strengthening the abundance of certain less appreciated species.

Family richness

Fabaceae, particularly the sub families of Caesalpinioideae and Mimosoideae is well represented in the whole forest sites. One of the fundamental characters of the African dense forests is their higher richness in Fabaceae who is closer to those of America and different from those of Asia (White, 1986). Small size trees are abundantly represented by Anacardiaceae, Annonaceae, Apocynaceae, Ebenaceae, Euphorbiaceae, Guttifères, Icacinaceae, Ochnaceae, Olacaceae, Rubiaceae, Tiliaceae, Sapindaceae and Violaceae.

The floristic composition of lower and superior strata in Campo and Bidou differs from that of Mangombe. At Mangombe, we can observe in the undergrowth the presence of some species generally found in superiors strata like *Alstonia congensis* Engl, *Ceiba pentandra* (L.) Gaertn, *C. edulis* Baill., *D. africana* Baill., *L. alata* Banks ex C.F. Gaertn, *Milicia excelsa* (Welw) CC Berg, and *Piptadeniastrum africanum* (Hook f) Brenan.

Structural trait of the vegetation

Trees density

The density of trees in the studied forest is situated in the order of the average density of trees observed in dense humid forest estimated at 400 to 650 individuals with dbh ≥ 10 cm per hectare (Riéra, 2011). We can however note a higher density of trees in Mangombe compared with that of many tropical sites; this is due to the reconstitution of the forest after exploitation and the regrowth who settle down and develop after anthropogenic and natural disturbances. The disturbances have a direct influence on trees density, diversity and their specific composition (Hitimana et al., 2004; Kessler et al., 2005).

Basal area

Trees population in Mangombe is dense and the basal area low (708 trees/ha; 49.13 m²/ha) compared to Bidou (538 trees/ha; 54.08 m²/ha) and Campo (569 trees/ha; 87.06 m²/ha). This situation can be explained by the abundance of big trees particularly in the site of Campo. The low gap between the basal area of Mangombe and that of Bidou can be explained by the effect of the exploitation of trees which is more frequent in Mangombe than Bidou. The basal area in Mangombe is however

biased by the presence of two emergent trees *B. toxisperma* and *C. edulis* which have exceptional diameters (dhp = 373 and 318 cm) and contribute to 15% of the basal area.

In Mangombe, shrubs are abundant like in the floristic groups GR5 and GR4; in Bidou, trees have a little big diameter (GR2); whereas in Campo we have many trees with big diameters (GR3). Basal area in Bidou and Campo are higher than the average value (30 - 50 m²/ha) frequently observed in rain forests (Riéra, 2011). Table 5 presents the distribution of basal area in some African forests. We can note that the basal area in Campo is exceptional and probably due to the type of ecosystem which is a forest rich in Fabaceae (Tchouto, 2004).

Tree and diameter class distribution

The structures of population reveal a strong presence of trees with small diameters and little number of big trees, the characteristic of vegetation with constant regeneration and in equilibrium. This forest structure is close to that of Rollet (1974), which showed that the distribution of trees in the diameter classes follows an exponential model. Mangombe forest presents a deficit of big trees due to anthropogenic cutting.

Conclusion

The studied forest sites are rich and diversified; they distinguish themselves by a mosaic of forest patches with different development stages, structure and floristic composition. The study of flora and the vegetation group highlights the role played by anthropogenic pressures in the spatial distribution of numerous taxa's and plant associations. The similarity in the floral composition of the various forest sites decreases with the gradient of anthropogenic disturbance.

The floristic composition and structure of population in Mangombe Forest differ from those of Bidou and Campo which are similar. In Mangombe, trees density is higher and the basal area is lower compared to that of the other sites; this can be due to a high number of small trees and shrubs, which is a sign of strong forest regeneration. In this forest site, a few numbers of species without a commercial value dominate by their IVI, showing that cutting of trees affected the specific composition and the process of reconstruction of the forest by strengthening the importance of little appreciated species. The presence in this group of typical secondary forests species (*L. alata*, *T. crassa*) mark the sign of the past and present anthropogenic disturbances. This group is composed at Bidou and Campo of various wooden species such as *D. crassiflora*, *L. trichilioides*, *E. suaveolens*.

Mangombe Forest can be compared to a young

Table 5. Trees density and basal area of trees in some tropical forests.

Site	Code	Forest station	Density (trees/ha)	Basal area (m ² /ha)
Cameroon	1	Mangombe	708	49.13
		Bidou	538	54.08
		Campo	569	87.06
		Takamanda	/	33.5 ± 7.6
		Parc National de Campo	/	57.66 - 88.73
Africa	2	Reserve de biosphère du Dja	352 - 460.4	29.0 ± 5.6 à 37.5 ± 3.9
		Ngovayang - région du sud	532 ± 75	28.8 - 42.1
		Lopé - Gabon	741.5 – 931.5	19.5 - 23.5
		Lopé - Gabon	/	20 - 58
Asia	7	Monte Mitra. Guinée Equatorial	548 ± 108	/
		Waka (Gabon)	589 ± 50	/
		Nouabale-Ndoki (Congo)	300 ± 11	/
Europ	10	Parc de Popa. Myanmar (Asie du sudEst)	604 ± 39	17.17 - 37.80
		Chine. Reserve naturelle de Bawangling île de Hainan	755 ± 170	53.93 ± 23.31
	12	Ukraine	270 - 590	/

1-Sunderland et al. (2003); 2-Tchouto (2004); 3-Djuikouo et al. (2010); 4-Gonmadje et al. (2011); 5-Ukizintambara et al. (2007); 6-Palla (2011); 7-Balinga et al. (2005); 8-Balinga (2006); 9-Sunderland and Balinga (2005); 10-Naing et al. (2011); 11-Scotto Di Vettimo (2010); 12-Trotsiuk et al. (2012).

secondary forest in phase of maturation. The restoration of the forest can be done naturally as shown by trees structure characterized by a high frequency of small size trees and deficit of big trees. Mangombe forest can recover its original structure and functions after a long term and in the absence of anthropogenic disturbance. These will also depend on the behavior of all the species and on the interactions between them and their environment.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Budke JC, Jarenkow JA, De Oliveira Filho AT (2010). Intermediary disturbance increases tree diversity in riverine forest of southern Brazil. *Biodiversity and Conservation* 19:2371-2387.

- Chave J, Condit R, Lao S, Caspersen JP, Foster RB, Hubbell SP (2003). Spatial and temporal variation in biomass of a tropical forest: results from a large census plot in Panama. *Journal of Ecology* 91:240-252.
- Chazdon RL (2003). Tropical forest recovery: Legacies of human impact and natural disturbances. *Perspectives in Plant Ecology, Evolution and Systematics* 6:51-71.
- Chazdon RL (2008). Chance and determinism in tropical forest succession. In W Carson and SA Schnitzer (Eds) *Tropical Forest community ecology* Oxford UK. pp. 384-408.
- Chazdon RL, Harvey CA, Komar O, Griffith DM, Ferguson B, Martinez-Ramos GM, Morales H, Nigh R, Soto-Pinto L, Van Breugel M, Philpott SM (2009). Beyond reserves: A research agenda for conserving biodiversity in human-modified tropical landscapes *Biotropica* 41:142-153
- Hanster S (2010). Will Tropical Biodiversity Survive our Approach to Global Change? *Biotropica* 42(5):561-562.
- Hitimana J, Kiyapi JL, Njunge JT (2004). Forest structure characteristics in disturbed and undisturbed sites of Mt Elgon Moist Lower Montane Forest western Kenya *Forest Ecology and Management* 194:269-291.
- Jha CS, Goparaju Laxmi Tripathi A, Gharai B, Raghubanshi AS, Singh JS (2005). Forest fragmentation and its impact on species diversity: an analysis using remote sensing and GIS? *Biodiversity and Conservation* 14:1681-1698
- Kessler M, Kessler PJA, Gradstein SR, Bach K, Schnull M, Pitopang R (2005). Tree diversity in primary forest and different land use systems in Central Sulawesi Indonesia. *Biodiversity and Conservation* 14:547-560.
- Leigh EG (2008). Tropical forest ecology: Sterile or virgin for theoreticians? In W P Carson and S Snitzer (Eds) *Tropical rain forest community ecology* Wiley-Blackwell Oxford UK. pp. 121-142.
- Legendre L, Legendre P (1984). *Ecologie numérique : le traitement multiple des données écologiques* Tome 1 Masson Paris France 260p.
- Letouzey R (1968). *Etude phytogéographique du Cameroun* Encyclopédie Biologique 69 Ed Paul Lechevalier Paris France 511p.
- Loreau M (2010). Linking biodiversity and ecosystems: towards a

- unifying ecological theory. *Philosophical Transactions of the Royal Society B* 365:49-60.
- Magurran A (2004). *Measuring biological diversity* Blackwell Publishing.
- Naing ZH, Nobuya M, Shigejiro Y (2011). Tree species composition and diversity at different levels of disturbance in Popa Mountain park Myanmar *Biotropica* 43(5):597-603.
- Picard N (2007). Dispositifs permanents pour le suivi des forêts en Afrique Centrale: un état des lieux CIRAD.
- Reid WV (1992). How many species will there be? In: Whitmore TC and Sayer JA (eds) *Tropical Deforestation and Species Extinction* Chapman & Hall London pp. 55-74.
- Riéra B (2011). La forêt tropicale: Architecture et Biomasse Conférence Université de Dschang 8 juin 2011.
- Rollet B (1974). L'architecture des forêts denses humides sempervirentes de plaine CTFT/CIRAD-Forêt Nogentsur Marne 298 p.
- Sahu PK, Sagar R, Singh JS (2008). Tropical forest structure and diversity in relation to altitude and disturbance in a Biosphere Reserve in central India. *Applied Vegetation Science* 11:461-470.
- Stebbins GL (1974). *Flowering plants evolution above species level* Cambridge Massachusetts Belknap Press of Harvard University Press 399 p.
- Tchouto MPG (2004) Plant diversity in a Central African rainforest: implications for biodiversity conservation in Cameroon PhD thesis department of plant sciences Wageningen University the Netherlands 206 p.
- Thapa S, Chapman DS (2010). Impacts of resource extraction on forest structure and diversity in Bardia National Park Nepal. *Forest Ecology and Management* 259:641-649.
- Trotsiuk V, Hobi ML, Commarmot B (2012). Age structure and disturbance dynamics of the relic virgin beech forest Uholka (Ukrainian Carpathians) *Forest Ecology and Management* 265:181-190.
- White F (1986). *La végétation de l'Afrique avec cartes de la végétation* Paris France.

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