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Les effets à court terme de la restauration de l'environnement sur la diversité et l'abondance des carabes dans trois écosystèmes de bas-fonds au Burkina Faso

[Short-term effects of environmental restoration on diversity and abundance of Carabids in three lowland ecosystems in Burkina Faso]

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ABSTRACT: Many human activities affect arthropod diversity and may threaten environmental health. Some insects may act as biological indicators based on their presence or absence in an ecosystem.
The present study was conducted from 2006 to 2009 to evaluate changes in the diversity and abundance of ground Carabids following restoration activities conducted in three lowlands ecosystems that had previously experienced high levels of human pressure in Burkina Faso. Three micro-catchments were identified in the regions of Soum, Sanmatenga, and Kompienga, using a hydrographic chart of Burkina Faso.
The diversity and abundance of carabids collected in pitfall traps at the beginning and end of the rainy season were compared using 2006 as a sampling reference year with restoration activities (abandonment of farming, forestation and scarification) occurring in 2007. Post-treatment surveys were conducted in the same seasons of 2008 and 2009.
Forty-nine species of Carabids have been identified based on monitoring of 1800 pitfall traps. The number of species generally increased in 2008 and 2009, from 9 to 41 species in the three micro-catchments. Species richness and insect abundance definitely increased where human pressure decreased and restoration measures were successfully conducted. However, Carabid diversity increased only in Soum micro-catchment; this site seemed to be more affected by restoration.
Carabids are likely to be good indicator species; reports can be prepared relatively quickly.
The results are discussed in relation to the goal of developing ecologically sound tools based on bio-indicator insects that can be used for environmental management.

KEYWORDS: Carabidae, Biological indicator, Environment Management, Human Activities.

RESUME: De nombreuses activités humaines affectent la diversité des arthropodes et peuvent menacer la santé de l'environnement. Certains insectes peuvent agir comme indicateurs biologiques en fonction de leur présence ou absence dans un écosystème.
La présente étude a été menée de 2006 à 2009 pour évaluer les changements dans la diversité et l'abondance des carabes suite à des activités de restauration menées dans trois écosystèmes des plaines qui avaient connu des niveaux élevés de pression humaine au Burkina Faso. Trois micro-bassins ont été identifiés dans les régions du Soum, Sanmatenga et Kompienga, en utilisant une carte hydrographique du Burkina Faso.
La diversité et l'abondance des carabes recueillis dans des pièges à fosse au début et à la fin de la saison des pluies ont été comparées en utilisant 2006 comme année de référence d'échantillonnage avec des activités de restauration (abandon de l'agriculture, reboisement et scarification) effectuées en 2007. Des enquêtes post-traitement ont été menées dans les mêmes saisons en 2008 et 2009.

Quarante-neuf espèces de carabes ont été identifiées sur la base de la surveillance de 1800 pièges à fosse. Le nombre d'espèces a généralement augmenté en 2008 et 2009, de 9 à 41 espèces dans les trois micro-bassins versants. La richesse en espèces et l'abondance des insectes a certainement augmenté où la pression humaine a diminué et les mesures de restauration ont été menées avec succès. Cependant, la diversité des carabes a augmenté seulement dans le micro-bassin versant du Soum; ce site semblait être plus touché par la restauration.

MOTS-CLEFS: Carabidae, indicateur biologique, gestion environnement, activités humaines.

1 INTRODUCTION

The United Nations Conference on Environment and Development, also known as the Rio Earth Summit, highlighted biodiversity conservation; at the summit several authors pointed out the urgency and need to maintain environment quality (Dunn, 2005 [1]). The direct and indirect effects of human activities on ecosystems often cause a loss of biodiversity, specifically through the transformation and fragmentation of natural habitats (Groombridge and Jenkins, 2002 [2]). Burkina Faso, a tropical country, is an illustrative example of this situation in that anthropogenic pressure on biodiversity is a major concern (Augusseau *et al.*, 2003 [3]). The country's exponential human population growth coupled with declining rainfall has led to the migration of young people and farmers to marginal virgin lands. These marginal lands have previously been colonized by humans; however, the lowlands and south Sudanese humid zones are particularly preferred by agricultural migrants. Therefore, anthropogenic landscapes have rapidly replaced natural areas (around 60% of the country in 2000) regardless of their historic ecological balance and level of biodiversity (Augusseau *et al.*, 2000 [4]). An effective management strategy for ecosystem resources requires an efficient and frequent evaluation of the effects of human activities and other interventions on these areas. One method used to measure the anthropogenic effect on the environment is based on the monitoring of bio-indicator insects (Hilty and Merenlenden, 2000 [5]). Beetles of the Order Coleoptera, the largest group of ground-dwelling arthropods, are an important part of total biodiversity (Ohsawa, 2010 [6]) for many regions of the world and represent more than a quarter of the currently known animal species worldwide. Ground beetles (i.e. Carabidae) are well documented as bio-indicators (Rainio and Niemelä, 2003 [7]) because they are sensitive to habitat change (Roughley *et al.*, 2006 [8]) as well as to variations in humidity and temperature (Ilboudo-Tapsoba *et al.*, 2011 [9]). Moreover, Carabids have previously been used to measure changes induced by land exploitation (Cole *et al.*, 2005 [10]).

The present study aims to determine the effects of restoration on the diversity of the Carabidae family in three lowland ecosystems that have previously experienced intense human pressure. The effectiveness of restoration measures should lead to an increase in taxonomic diversity—or at least an increase in abundance—of this insect group that is highly sensitive to changes in their habitats. The results are expected to show whether the Carabidae family can serve as an effective indicator group which can be used for environmental assessment in lowland ecosystems.

2 MATERIAL AND METHODS

2.1 DESCRIPTION OF THE LOWLAND ECOSYSTEMS MONITORED

Three lowland ecosystems were identified in three micro-catchments (MCs) geographically located in the Soum, Sanmatenga, and Kompienga regions of Burkina Faso. The Soum, Sanmatenga and Kompienga MCs are located in the sub-Sahelian, North-Sudanian, and South-Sudanian phytogeographical sectors, respectively, according to the classification provided by a phytogeographic chart (Figure 1) of Burkina Faso (Fontès and Guinko 1993 [11]) describes the physical characteristics and socioeconomic activities of each micro-catchment. According to data from the General Directorate of Meteorology of Burkina Faso on the climate of the three MCs, the Kompienga MC was less hot and wetter than the Sanmatenga and Soum MCs (Table 1).

2.2 DATA COLLECTION

The study area was identified along the northeast transect in Burkina Faso and the main MCs were selected by reviewing a hydrographic chart and phytogeographical areas (Figure 1) of Burkina Faso. Carabid beetles were collected in each lowland ecosystem and at selected sites within each MC. The collections began in 2006, which is used as a reference year, prior to the implementation of some environmental restoration activities (abandonment of farming and reforestation of lowlands) that were conducted in 2007 (Table 2). Then in 2008 and 2009, insects were collected again to determine whether the restoration activities affected the insect populations, especially Carabid abundance and diversity. For insect collection, three transects have been laid out perpendicular to a stream in each MC; on each transect, at least two 20 × 50 m plots were demarcated on both sides of the stream, starting at the stream edge on a 20 m side of a plot. In each plot the ground-dwelling Carabid beetles were sampled using a Barber trap at the beginning (June–July) and end of the rainy season (September–October). The Barber trap is known as the most efficient method to sample ground-dwelling arthropods, and particularly beetles of the Carabidae family (Cook and Holt, 2006 [12]). Each plot contained five traps set at each of the four plot corners with the fifth in the middle of the plot (Figure 2). Traps were filled with 40% alcohol up to the lower third of the trap to capture in the insects that fell inside. The traps were checked 24 hours after being set. Carabid specimens were sorted and packaged in jars containing 70% alcohol and were then transferred to the laboratory where they were identified taxonomically.

2.3 Specimen Identification And Parameters Calculation

All the collected Carabidae were identified to at least the genus level by comparing the collected specimens with reference collections available in the following museums: National Museum of Natural History in Burkina Faso, Museum of the International Institute of Tropical Agriculture (IITA) in Cotonou (Benin), and the Museum of the Institut Français d'Afrique Noire at Cheick Anta Diop University in Dakar (Senegal); several taxonomic keys (Delobel and Tran, 1993 [13]; Delvare and Aberlenc, 1999 [14]) were also used (Table 3).

Data collected gave a first insight into the variation of insect numbers in relation to ecosystem conditions and sampling period. These data were also used to calculate classical ecological indices that allow an analysis of insect diversity. The calculated indices were:

The specific richness (RS) was determined by the total number of species listed in one site for a given period (Magurran, 2004 [15]);

The Shannon diversity index (Dray, 2003 [16]; Magurran, 2004 [15]) estimates population diversity and is determined by the following formula: $H' = - \Sigma ((q_i/Q) \log_2 (q_i/Q))$ where Q_i is the number of species of the i^{th} taxon and Q is the total number of individuals in the population.

The diversity reaches a maximum when all the observed taxa have the same abundance.

H' max = $\log^2 S$ where S is the total number of taxa in the population.

2.4 Data Analysis

All data were initially transformed using the formula $\log_{10}(x–1)$ and analyzed with SPSS16.0 software. After verifying that the transformed data did not assume a Gaussian distribution using a Shapiro-Wilk test, the non-parametric Friedman analysis of variance was used to compare calculated parameters between independent groups. All differences were considered significant at $P < 0.05$.

3 Results

3.1 Overall Results

In the present study, a total number of 1800 traps were set in the three monitored MCs; 32 genera and 49 species of Carabidae were collected. The genus with the most species (10) was *Chlaenius*; this was also the most frequently encountered genus. Meanwhile, the genus *Lonchochinus* had many individuals but only one species. Species richness varied depending on the MC considered. The Soum MC exhibited the richest Carabid fauna with 43 species compared with 40 and 28 species for Kompienga and Sanmatenga MCs, respectively (table 3). Several species only appeared after the completion of restoration activities, and taxa present varied by the MC considered. The most abundant species was *Chlaenius* (*Chlaenites*) *columbinus.* The total number of collected insects significantly differed among the three MC studied ($\chi^2 = 10.39$; $P<0.005$).

3.2 Effects Of Environmental Restoration On The Carabid Populations

3.2.1 Species Richness

Restoration activities allowed species richness to increase significantly from 29 to 41 in the Soum MC (Table 4; $\chi^2 = 13.03$; $P = 0.01$). The species richness increased from 20 to 23 and from 32 to 39 in Sanmatenga and Kompienga MC, respectively, but the observed variations were not significant ($P > 0.05$).

3.2.2 RELATIVE ABUNDANCE

The number of individuals collected per trap increased from 2006 to 2009 in all of the three MCs (Figure 3). Restoration activities significantly increased the abundance of Carabidae in the Soum (χ^2 =20.4; $P < 0.0001$); Sanmatenga (χ^2 = 11.8; $P < 0.001$) and Kompienga (χ^2 = 18.7; $P < 0.0001$) MCs.

3.2.3 INSECT DIVERSITY

Spatial and temporal variations were noticed in Shannon diversity indices in the three MC monitored (Figure 4). However, the observed diversity was lower than the theoretical diversity calculated for the three MCs, indicating a heterogeneous representation of the species in the Carabid population. Friedman analysis of variance was applied to the matrix of Shannon diversity indices per year and per MC. They showed no significant differences in the diversity of Carabids between the reference year (2006) and the end of the study in 2009 ($P > 0.05$).

4 DISCUSSION

From this study, the Carabidae family appears to be a useful and significant taxonomic group that can be used in the characterization of the condition of lowland ecosystems in Burkina Faso. The overall number of species identified in the three MC monitored (i.e. 49 species) in the present study were comparatively low when considering the total number of known Carabid species throughout the world. However, the present study enabled the expansion of the list of Carabidae known to occur in Burkina Faso from 33 species in 1996 (Sanon, 2010 [17]) to 75 species currently, including, 42 new county-record species for Burkina Faso of the 49 Carabidae species identified. Some variations were noted on other ecological parameters in relation with environmental restoration activities in each MC. Specifically, habitat restoration seems to have allowed a significant increase in species richness and abundance in all three of the MCs whereas insect diversity significantly increased in only the Soum MC. Previous data demonstrated that environmental conditions and habitat structures affect Carabid beetle assemblages (Garcia-Tejero *et al.*, 2013 [18]). However, as far as we know (Ulyshen *et al.*, 2006 [19]; Jahnova *et al.*, 2015 [20]) this is the first time an increase in the species richness and/or abundance of Carabids was noted after environmental restoration in the lowland ecosystems of sub-Saharan Africa. Among the ecological variables assessed during this study, the Shannon diversity index was the least affected considering the fact that this index increased significantly in only one MC (Soum). Therefore, one can assume that Carabid density depends on the quality of the environment and the level of human impact. The restoration has probably created a more favorable environment for the survival and expansion of Carabidae species mainly in Soum and Kompienga. Indeed, more humid conditions, milder temperatures and a favorable microclimate are believed to cause an increase in the diversity of Carabidae (Ilboudo-Tapsoba *et al.*, 2011 [9]).

After two years, the effects of restoration can be observed only for species richness and abundance. Diversity, a more synthetic parameter that considers both species richness and their equitability seems to be more difficult to achieve, specifically where the environment has previously been disturbed by human activities. A longer time (more than two years) after restoration is needed in this type of an environment for the restoration to significantly affect Carabid diversity. Our results can be correlated with the ecological requirements of Carabids and also with the effects/changes induced by restoration activities versus the effects of human activities in each MC.

Several factors influence the diversity of Carabids. Habitat selection and thus the spatial structure of local communities of Carabids are determined by local factors that are not only biotic (species interactions) and abiotic (micro climate conditions) but also include regional factors (pool of species, landscape composition (Michels *et al.*, 2010 [21]). The activities of humans are well known to induce changes to insect habitats. For example, deforestation causes changes in abiotic conditions on the ground (sunshine, light, temperature, soil moisture, air currents) and in the atmosphere (Bornn and Schroeder, 2001 [22]). All of the three MCs considered in this study previously experienced high levels of human pressure through deforestation and farming activities.

The main restoration activities conducted in all of the three MCs included abandonment of farming and reforestation. Clearly, waiting 2 years after reforestation is not long enough for the vegetation to fully recover to the point there is significant variation in Carabid diversity. Therefore, the differences noted among the three MCs monitored could be related to the specific ecology of each MC including soil chemical composition and related soil characteristics (Katherine *et al.*, 2012 [23]), Temperature variation (Katherine *et al.*, 2012 [23]). We hypothesized that the Soum MC meets the requirements needed for Carabid diversification better than the other MCs during or after the restoration period for reasons that remain have yet to be more precisely determined.

Table 1: Location, climate, vegetation, soil and socio-economic activities of the study area

	Soum (MC of Béli)	Sanmatenga (MC of Korsimoro)	Kompienga (MC of Kompienga)
Location	Northern part of Burkina Faso, between the 13°51'10,8'' and 14°40'40,8''paralels of northern latitude and between the 1°16'30'' and 2°03'39,6''meridians of western longitude.	Coordinates: 01°04' of western longitude and 12°49'of northern latitude. Its total surface is 107 949 ha.	Eastern region of Burkina Faso, between the 0°30'and 0°40' eastern longitude and between 11°and 11°20' northern latitude. It covers an area of 93001.3ha.
Climate	Sahelian climate characterized by a rainy season from June to September, with some annual average rainfall below 600 mm. Monthly average temperature ranges between 20 ° C and 35 ° C with relative humidity of 10% to 40 %.	Northern Sudan climatic zone characterized by a rainy season from June to September. Annual average rainfall is 600-800 mm. Monthly average temperature ranges between 25 ° C and 35 ° C with relative humidity of 10% to 60 %.	Average annual rainfall of 900-1000 mm, a rainy season of 4-5 months from May to October. Monthly average temperature ranges between 20 ° C and 30 ° C with relative humidity of 15% to 65 %.
Vegetation	The vegetation described by (Fontès and Guinko 1995), is now highly degraded It is characterized by an herb layer, whose main plant species of the Poaceae family are *Cenchrus biflorus* and *Aristida mutabilis* in the lowlands. The herb layer is associated to a low and clear shrub layer whose dominating species are some *Combretum glutinosum* (Combretaceae), *Guiera senegalensis* (Combretaceae) and *Acacia senegal* (Leguminosae-Mimosaideae).	Shrub savannah dominated by the *Combretun micranthum*, *combretum nigricans*(Combretaceae), an open wooded savannah dominated by *Balanites aegyptiaca* (Mimosaceae), *Lannea microcarpa* (Anacardiaceae), a forest gallery along the water course dominated by some M*itragyna inermis* (Rubiaceae), *Anogeissus leiocarpa* and *Combretum micranthum* (Combretaceae).	The vegetation of the Micro catchment is within the Northern Sudanian phytogeographical sector according to the sectioning of Fontès and Guinko (1995) [24]. It is however much influenced by some recent man-made pressure. The vegetation shows some clear shrub savannah dominated by some *Combretum ghazalense* (Combretaceae), *Balanites aegyptiaca* (Balanitaceae), a wooded savannah dominated by *Terminalia avicennioïdes* (Combretaceae)*, Diospyros mespiliformis* (Ebenaceae)
Soil	*T*he most representative land is the less bleached out ones. They have a great proportion of sand and a low proportion of clay and loam.	The lands are generally poor in organic matter with big proportion of clay and loam and low proportions of sand.	The soils are deeply bleached out Tropical ferruginous varying with some vertisols and Hydromorphic Gley and pseudo Gley soils.
Socio-economic activities	Agriculture and livestock farming.	Agriculture and cut down of trees for sale.	agriculture and livestock farming

Table 2: Restoration activities conducted in each zone of the surveys in 2007

	Soum	Sanmatenga	Kompienga
Abandonment of farming	X	X	X
Reforestation	X	X	X
Soil scarification		X	

Table 3: List and classification of the Carabid species identified in three micro-catchments from 2006 to 2009

	Soum			Sanmatenga			Kompienga		
Scientific Name	2006	2008	2009	2006	2008	2009	2006	2008	2009
**Myriochile dorsata* (Brullé)	x	x	x	x	x	x		x	x
Myriochile melancolica (Fabricius)	x	x	x				x	x	
Cicindela neglecta (Dejean)	x	x	x	x		x	x		
Cicindela plurinotata (Audouin et Brullé)	x	x	x	x	x	x	x	x	x
**Megacephala megacephala* (Olivier)	x	x	x						
**Megacephala quadrisignata* (Dejean)	x	x	x					x	x
Ctenosta senegalense (Dejean)	x	x	x				x		
Lissauchenius caecus (Dejean)	x	x	x					x	x
Lissauchenius sp	x	x	x				x	x	x
Chlaeniostenus denticulatus (Erichson)	x	x	x	x	x	x	x	x	x
Hyparpalus holosericeus (Dejean)	x	x	x					x	x
Systolocranius sp	x	x	x				x	x	x
**Paussus armartus* (Westwood)				x	x	x	x	x	x
**Siagona senagalensis* (Dejean)		x	x	x	x	x	x	x	x
Chlaenius (Chlaenites) morosus (Laferte-Senectere)	x	x	x	x		x	x		x
Chlaenius(Chlaenites) lucidicollis		x	x	x	x	x		x	x
Chlaenius (Chlaenites) senegalensis (Dejean)	x	x	x	x	x	x	x	x	x
Chlaenius (Chlaenites) sp1	x	x	x	x		x	x	x	x
Chlaenius (Chlaenites) sp2	x	x	x	x	x	x	x	x	x
**Chlaenius (Chlaenites) dusaultii* (Dufour)		x	x			x	x	x	x
Chlaenius (Chlaenites) rufomarginatus		x	x	x	x	x	x	x	x
Chlaenius (Chlaenites) columbinus (Dejean)	x	x	x				x		x
Chlaenius (Spilochlaenius) Crutiatus (Dejean)	x	x	x	x	x				
Chlaenius (Spilochlaenius) boisduvali (Dejean)	x	x	x			x		x	x
Dichaetochilus nigricus (Dejean)			x				x		
Xenodochus exaratus (Dejean)	x	x	x	x		x		x	x
Nototachys senegalensis (Alluaud)									
Cyclosomus sp			x						
Anoplogenius velox (Linné)		x						x	x
Styphlomerus spI							x	x	x
Styphlomerus spII			x				x	x	x
Cymindoidae bisignata (Dejean)				x	x	x	x		x
Pachydinodes conformis (Dejean)	x		x		x			x	x
Systocranius senegalensis (Gemminger et Harold)				x	x	x	x	x	x
Galeritola africana (Dejean)		x	x		x		x	x	x
Lonchosternus sp	x	x					x		
**Calosoma senegalensis* (Dejean)		x	x	x	x	x		x	x
Tomochilus carbonatus (Chaudoir)	x	x	x		x	x	x	x	x
Neochryopus savage (Hope)	x	x	x	x	x	x	x		x
Tetragonoderus quadrum (Fabricius)	x	x	x	x		x	x	x	x
Abacetus crenulatus (Dejean)	x	x	x		x	x	x		x
Graphiterus obsoletus (Olivier)		x	x		x			x	x
Brachinus sp1	x	x	x		x		x		x
Brachinus sp2	x	x	x				x		
Aploa nobilis (Dejean)			x						
Drypta ruficollis (Dejean)				x	x	x	x	x	x
Epomis protensus (Chaudoir)			x					x	x
Epomis croesus (Fabricus)	x	x	x				x	x	x
Paracallistoides notula (Fabricus)			x				x	x	x
Overall/MC		**43**			**28**			**40**	

** Species already listed in Burkina Faso before our study*

Table 4: Temporal variation of species richness in three micro-catchments from 2006 to 2009

	Soum			Sanmatenga			Kompienga		
	2006	2008	2009	2006	2008	2009	2006	2008	2009
Specific richness	29	36	41	20	21	23	32	32	37
Friedman Test		13.03			1			1,13	
P		*0.001*			*0.6*			*0.5*	

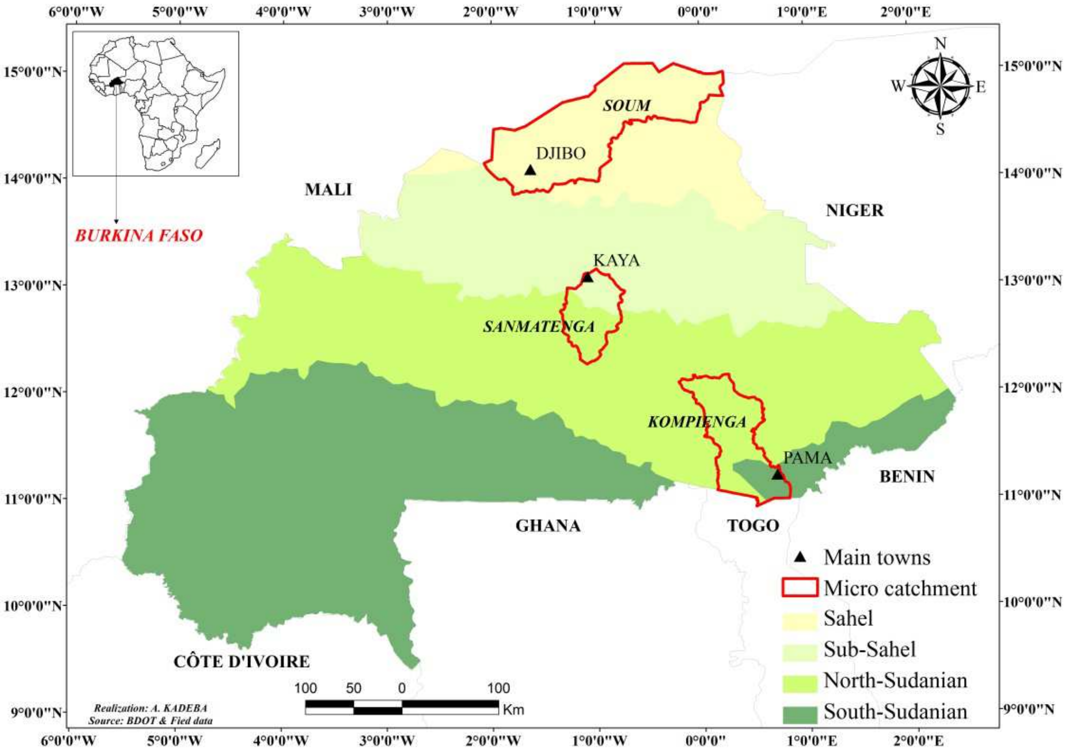

Figure 1: Micro catchment location and phytogeographical areas of Burkina Faso

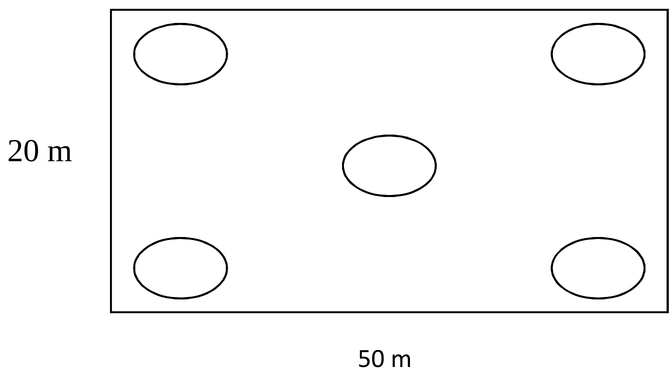

Figure 2: Design of the 20 × 50 m experimental plots containing five pitfall traps

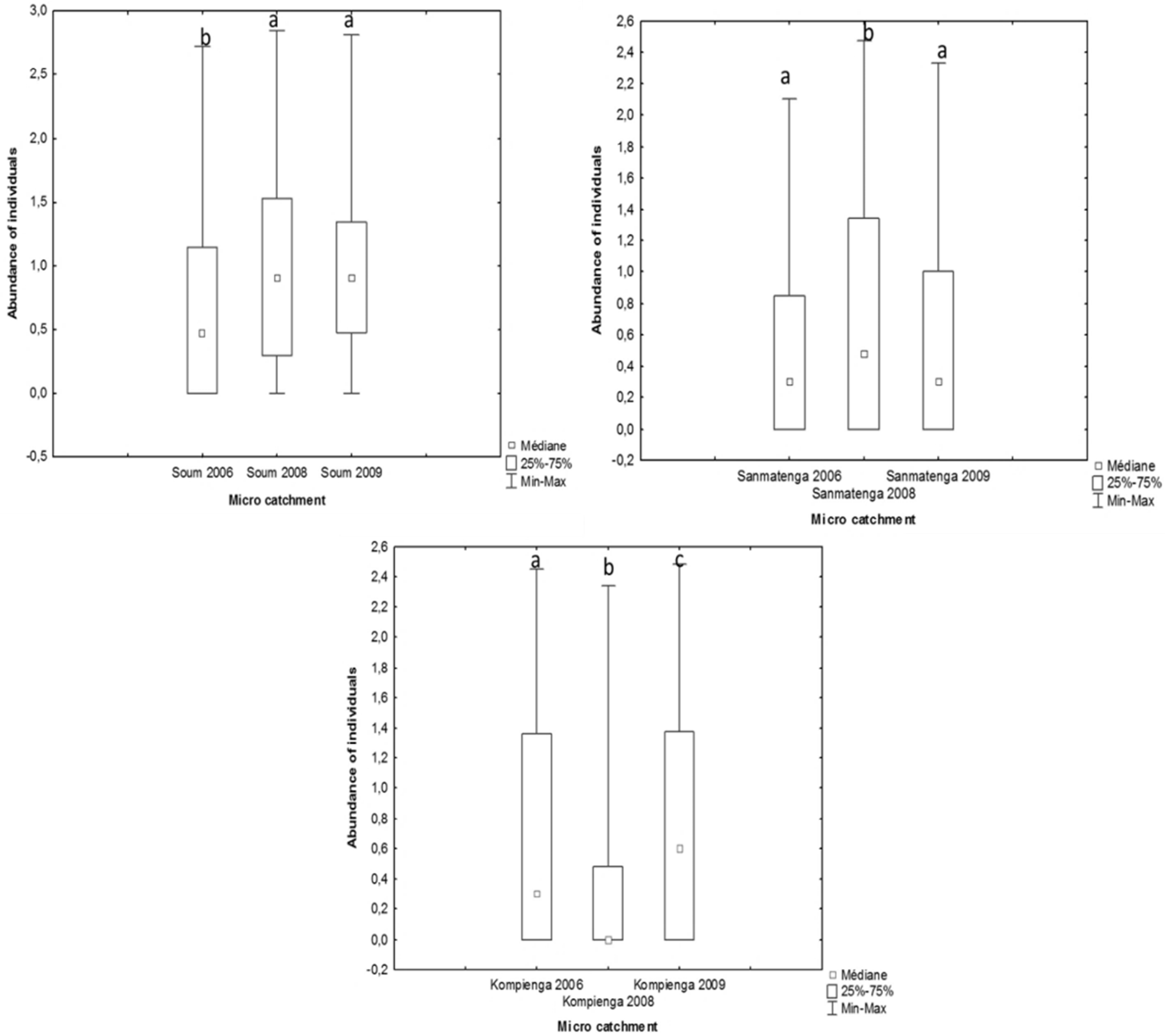

Figure 3: Variation of the Carabidae abundance by micro-catchments from 2006 to 2009

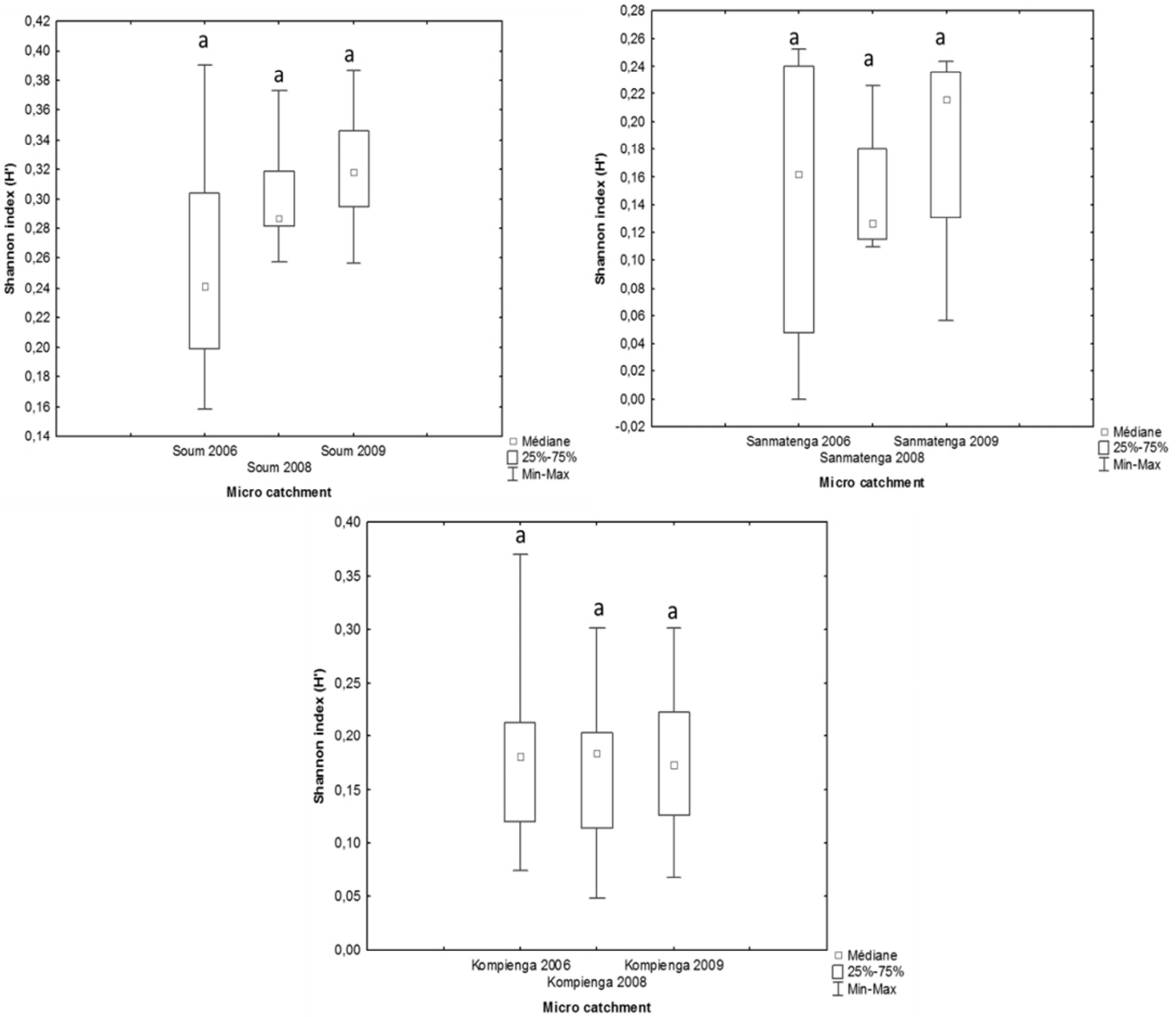

Figure 4: Variation of the Shannon index (H') by micro-catchments from 2006 to 2009

5 CONCLUSION

These results also suggest the dominant species have an important value ecologically and their presence is related to environmental management. Determining the nature of the association of species of Carabidae with particular types and structures of vegetation and also with soil physicochemical parameters will be important steps towards achieving ecologically sound management.

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