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Influence of the Chad-Cameroon pipeline on termite assemblages

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Abstract

The study of Chad-Cameroon pipeline disturbances on termite assemblages was conducted in 9 sites in the savannah and forest ecosystems, five years following the completion of the works. In each site an experimental design was made up of four transect belts, 100 m long by 2 m wide, two in the disturbed zone and two in the undisturbed zone . Soil samples were taken in the fifth, ninth and fifteenth sections of each of the transect belt to measure the impact of the work on soil texture and chemical properties. Furthermore, termites were inventoried in the whole transect belt. The pipeline construction disrupted significantly the soil textural parameters, bulk density, water properties and soil organic matter. In all 36 transects, 99 termite species were collected. The overall species richness decreased in the disturbed zone but the overall density was not changed. However, the abundance of wood feeding termites significantly increased whereas the species richness and abundance of soil feeding termites decreased. The relatively small difference in termite assemblages between disturbed and undisturbed areas is greatly explained by the fact that ecosystems crossed by the pipeline were already noticeably degraded before the pipeline installation.

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Introduction

Disturbances are scattered events that affect a population, an ecosystem or a landscape; they change their structure, their physical environment and their functioning (Pickett *et al.,* 1989). These events may be inherent to the ecosystem dynamics, but agriculture and civil engineering have increased dramatically their frequency and intensity, becoming a threat to biodiversity (Bengtsson, 2002).

Disturbances may have various direct and indirect effects on the soil and hence on soil fauna. Civil engineering clears the vegetation, which exposes it to direct sunshine and hence alters its climatic characteristics. The soil may be compacted locally and its layers mixed elsewhere. Soil fauna is mainly dependent on soil climate and on its type of vegetation (Lavelle & Pashanasi, 1989). So increasing the temperature and decreasing the moisture of top soil results in animal migration to deeper layers and on a longer term selects heat-resistant species (Birang, 2004).

Being a major agent of litter decomposition, termites are a key-group for the functioning of tropical ecosystems and thus have been proposed as indicators (Eggleton *et al.,* 1997). Most studies focus on changes in the diversity of termites along gradients of human disturbance (Eggleton *et al.,* 1996; Dibog *et al,* 1999, Davies & Maryati, 1999; Jones & Eggleton., 2000; Jones *et al.,* 2003), some others insist on the influence of forest fragmentation (DeSouza & Brown, 1994) or on spatial scale and habitat heterogeneity (Deblauwe *et al.,* 2007). In comparison with agricultural practices, the impacts of civil engineering are little documented (Bengtsson & Rundgren, 1988; Lavelle *et al.,* 1997) and more knowledge is needed about effects of repeated and large-scale disturbances on communities and ecosystems (Paine *et al.,* 1998, Romme *et al.,* 1998).

This study focuses on the impacts of a pipeline running across Cameroon through savannahs and forests that have already been more or less disturbed by other types of human activities such as logging, slash and burn cultivation or more intensive agriculture. This study thus assesses the effect of laying down the pipeline on some soil characteristics, species richness and relative abundance of termites.

Materials and methods

Study sites

A pipeline, 1070 km long, crosses Cameroon and carries crude oil from Doba, Chad, to Kribi on the cameroonian coast (Fig. 1). It was laid down from 1999 to 2003 in a trench about 2 m deep and re-covered with soil. This "large infrequent disturbance" (Bengtsson, 2002) has subsequently been maintained twice a year as an open corridor, 20 m wide, and has been invaded by ruderal vegetation. Its impact on the termite communities was assessed in 2008-2009, about five years after the pipeline opening. Nine sites from four ecosystems were sampled along the pipeline in September-October 2008 and in May-July 2009. Their geographic coordinates were taken using a GPS (Magellan Explorist 100) (table 1 and Fig. 1).

Table 1. Locations and characteristics of the study sites.

Annual rainfall and mean temperature in 2006	**Ecosystem**,	**Location**	**Coordinates**	**Disturbance level***
	Savannah			
1530 mm, 23°C	little disturbed savannah	Meidougou 1 Meidougou 2	6°25.65 N, 14°12.13 E, 1042 m alt.	*
	Semi-deciduous forest			
1570 mm, 21°C	old secondary forest (> 30 years)	Tamtchek	5°0.77 N, 13°19.87 E, 670m alt.	3
	Young secondary forest (<20 years)	Mbong Sol	4°39.49E, 12°24.37 E, 643m alt.	4
	Mixed forest			
1900 mm, 25°C	Agroforestry (cocoa plantation)	Ngoya	3°57.14 N, 11°26.78 E, 805 m alt.	5
	old secondary forest (>30 years)	Ongot	3°51,76 N, 11°23,07 E 760 m alt.	3
	Evergreen Atlantic forest			
3030 mm, 23°C	Young secondary forest(<20 years)	Madong	3°27.40 N, 10°74.84 E, 496m alt.	4
	Old secondary forest (>30 years)	Mbikiliki	3°10.48 N, 10°32.73 E, 307m alt.	3
	Old secondary forest (>30 years)	Makouré	3°03.51 N, 10°08.73 E, 68 m alt.	3

* Disturbance level after Eggleton *et al*., 2002), not available for the savannahs.

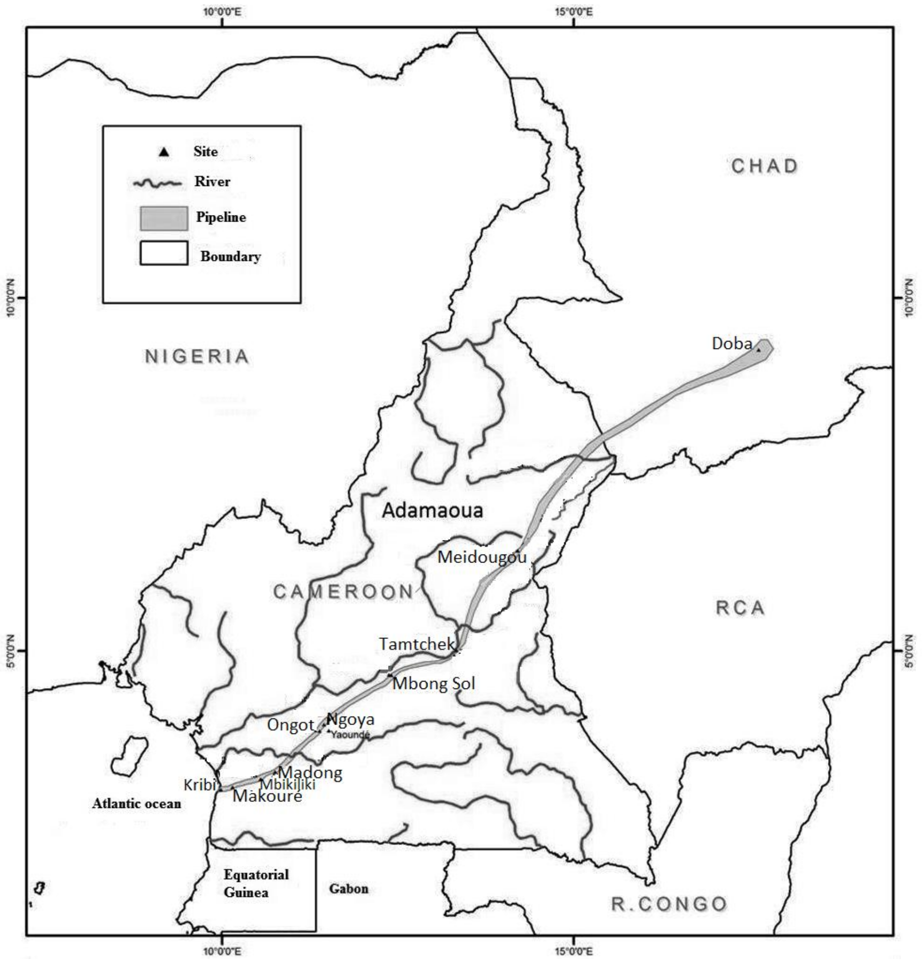

Fig. 1. trajectory of the Chad-Cameroon pipeline (after Dames &Moore, 1999) with the locations of the sampling sites.

The two sites chosen in the savannah ecosystem near Meidougou were scattered with numerous trees and shrubs (*Lophira dota, Daniella Oliveri*, etc). It was yearly burned and grazed extensively by nomadic herds of cattle. Climate is tropical and humid.

Two other sites were respectively sampled in the semi-deciduous (Tamtchek and Mbong Sol) and mixed (Ngoya and Ongot) forest ecosystems. The former ecosystem, near the savannah, was characterized by old secondary forest and patches of savannah and forest galleries; the latter by a mosaic of degraded forest patches, fields and fallows (Letouzey, 1985, Dames & Moore, 1999). In both ecosystems, climate is equatorial.

Additional three sites (Madong, Mbikiliki and Makouré) were sampled in the evergreen Atlantic forest. These sites are highly coloninized by the Cesalpiniaceae; it is the wettest region with an equatorial climate of southern coast type.

Eggleton *et al.,* (2002) defined eight disturbance levels in the Cameroonian humid forests, ranging from 1 (primary forest) to 8 (complete clearance). The sites that were sampled in this study stand between disturbance levels 3 and 5 (table 1) whereas the pipeline corridor itself might be placed near level 6: it is a kind of fallow that had been maintained as such for more than five years but with few disturbance of the soil (and it is intended to remain in this state for about 30 years).

Sampling methods

Soil parameters: Soil samples were taken in the fifth, ninth and fifteenth sections of each of the transect belt to measure the impact of the work on soil texture and chemical properties. After litter removal, 100 cm^3samples were taken from the top soil layer (0-10 cm) with stainless steel rings of known mass. Textural and chemical analyzes were carried out in the laboratory of Soil Science, University of Dschang, Cameroon, while pF analyzes were performed by the laboratory of IITA (International Institute of Tropical Agriculture) in Yaoundé. For each kind of measurement, the three data were averaged providing only one figure per transect belt for further statistical analyses.

Water content and bulk density: the fresh 100 cm^3 soil samples were weighed, oven dried at 105°C and weighed again, allowing calculation of the water content and bulk density.

Texture: organic matter was removed from the soil samples with hydrogen peroxide and aggregates were dispersed with sodium metacitrate. Sand particles (50 – 2000 µm) were sorted out by sieving. Silt (2 – 50 µm) and clay (< 2 µm) were sorted by sedimentation and Robinson pipetting.

pH water: it was measured in water suspended soil by a pH-meter Schötter with a combined glass and reference electrode.

Nitrogen and carbon contents: total nitrogen was measured by the Kjeldahl method and organic carbon by oxidation with potassium dichromate in strongly acidic medium.

Water content at pF= 3 & pF= 4.2: the measurement method is the extraction of the water under pressure in a Richards membrane press (Eijkelkamp). Moisture measurements were carried out at values of pF = 3 (1 bar, saturation point) and 4.2 (16 bars, wilting point) on unstructured (2 mm-sieved) samples.

Termites

The sampling of termites was founded on standardised transect belts 100 m long by 2m wide that are claimed to provide representative samples (Jones & Eggleton, 2000, Eggleton *et al.,* 2002). Each transect is made of 20 sections of 5 x 2 m and every section was searched for 30 minutes by two men (equivalent to a collection effort of 1 man*hour). In each section every termite nest, sheeting and runway was opened up to 2 m in height, tree bases and their foothills, pieces of dead wood and accumulations of litter as well as 12 soil samples 12 × 12 × 10 cm were hand-sorted.

At each of the nine sites four transect belts were made, parallel to the pipeline, two at 3 m on either side (disturbed zone) and two at 32 m on either side of the pipeline (control zone).

Termites were sorted and identified at the IRAD laboratory (Institut de Recherche Agricole pour le Développement, Yaoundé, Cameroon) and checked in the laboratory of systematics and animal Ecology of the Université Libre de Bruxelles (Belgium), to species or morphospecies. They were classified into the four feeding groups according to Donovan *et al.,* (2001): group I: wood and litter feeding, lower termites; group II: wood, litter and grass feeding, higher termites; group III: termites feeding on very decayed wood and organic matter-rich soil and group IV: termites feeding on soil humus.

The presence of a species or morphospecies in a section is designated as an occurrence and the number of occurrences per transect is used as a surrogate for the termite abundance, that can thus vary theoretically between 0 and 20 for every species.

Data analysis

Changes in soil parameters and termite assemblages were analysed according to zones (disturbed versus control), to ecosystems and to sites within the ecosystems by means of nested ANOVAs followed with Tukey's tests at a 5% threshold with the software STATISTICA 9.0. Levene's tests were used to compare the variances; when significant, Kruskal-Walis or U Mann-Withney tests were used instead of ANOVA. The occurrences of termite species per transect were used in principal component analysis

(PCA) and in a cluster analysis to illustrate the proximity/distance between ecosystems or zones. The species richness accumulation curves were produced with EstimateS (Colwell, 2005). The soil-termite relationships were analysed with Spearman's rank correlations.

Results and discussion

Soil changes

Bulk density: The bulk density (kg/dm³) was expected to be higher in disturbed zones due to compaction by earth-movers and trampling, and this was significantly the case (table 2): it was higher in every forest site but it was not in the savannah. The highest value (1.58 kg/dm³) near the pipeline at Mbikiliki was not critical for soil organisms (according to Pierce *et al,* 1983) probably because quite a few plant material was incorporated into the soil during levelling. According to Franzluebbers (2002), a negative correlation should be observed between the concentration of organic carbon and bulk density; this was indeed confirmed ($\rho = -0.62$, $p < 0.001$).

Water content at sampling

The water content (%) of soil samples, besides the fact that it can be influenced by recent rainfalls, was expected to be lower in disturbed zones which were exposed to direct sun radiation. This was indeed the case in all sites (table 2).

Texture

Texture was expected to be affected by bringing up deeper layers generally rich in clay to the soil surface (Segalen, 1967). Indeed the clay content was very significantly increased - and that of sand decreased - in the disturbed zones of all forest sites (table 2). However, it was not the case in the savannah sites, where on the other hand the silt content was increased.

pH water

Sclerenchyma rich litter (tree leaves) entails the accumulation of humic acids (Doucet, 1994) and since ruderal vegetation has replaced the forest in the pipeline corridor, an increase of pH was expected in the disturbed forest zone and such a *tendency* was indeed observed. However, because of very significant heterosecasticity a U test was used and failed to find a significant difference between disturbed and control zones (table 2).

Carbon and nitrogen

Litter mineralization in the pipeline corridor of forest sites was expected to be faster than in the control zone for two reasons: it is poorer in sclerenchyma and exposed to direct sunshine (warmer). Therefore carbon should be released faster (as CO_2) than nitrogen (sequestered in microorganisms) in the disturbed zone, that would increase C/N. It can of course also be argued that the disturbed zones were covered with deep soil which is poor in organic matter (Pfeiffer, 2010), but this has probably only little influence five years after the pipeline completion. Indeed on the one hand the carbon content was very significantly lower in the disturbed zones (of all the sites) and on the other hand the nitrogen content did not differ significantly (table 2) with large variations from site to site. As a consequence the C/N did not differ significantly either.

Table 2. Summary of soil parameters according to the zone (control versus disturbed, all the ecosystems being pooled): means ± standard deviations with the results of the nested ANOVA and Levene's tests. N = 18 / zone.

Variable	Control zone	Disturbed zone	Means ANOVA (1)	Variances Levene's test (1)
Bulk density (kg/dm^3)	1.15 ± 0.15	1.37 ± 0.16	***	ns
Water content at sampling (%)	21.2 ± 4.5	19.0 ± 3.0	**	ns
Clay (%)	24.6 ± 13.7	27.9 ± 13.1	**	ns
Silt (%)	17.7 ± 7.8	18.6 ± 7.5	ns	ns
Sand (%)	57.7 ± 16.1	53.5 ± 13.2	***	ns
pH water	5.05 ± 0.59	5.29 ± 0.39	ns(2)	**
Carbon (g/kg)	35.5 ± 9.0	29.3 ± 7.5	***	ns
Nitrogen (g/kg)	1.56 ± 0.50	1.44 ± 0.58	ns	ns
C/N	23.6 ± 5.1	22.3 ± 8.0	ns(2)	**

(1) ns = not significant ($p > 0.05$), * = $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$.

(2) heteroscedasticity could not be reduced by data transformation ; comparison was made with a Kruskal test.

Termite assemblages

Total species richness and occurrences: In all 36 transects, 1686 termite occurrences were recorded and 99 species or morphospecies recognised. An impact on the termite assemblages was expected in the disturbed zones and indeed the overall species richness and diversity were significantly reduced (table 3), suggesting a reduced range of ecological niches. However, the total number of occurrences was not significantly different (table 3), suggesting a similar amount of resources in the disturbed and control zones. The species accumulation curve approaches an asymptote in the disturbed savannah suggesting that the total species richness was almost reached there, but this is not the case in the other sites (Fig. 2).

The limited number of species will be analysed in comparisons with (a) Eggleton *et al., (*2002) (133 species) who sampled the termite communities in a gradient of anthropogenic disturbance in the humid forests of Congo and southern Cameroon in 17 transect belts from primary forest to complete clearance (disturbance levels from 1 to 8) and (b) with Deblauwe *et al., (*2007) (117 species) who sampled the termite communities in southeast Cameroon in five transect belts in disturbance levels running probably from 1 to 4.

Table 3. Termite species richness, abundance and diversity according to the zone (control versus disturbed, all ecosystems being pooled): means ± standard deviations with the results of the nested ANOVA and Levene's tests. N = 18 / zone.

Variable	Control zone	Disturbed zone	Means ANOVA (1)	Variances Levene's test (1)
Overall species richness	17.9 ± 5.1	14.7 ± 4.3	**	ns
Species richness group I	0.28 ± 0.57	0.33 ± 0.59	ns	ns
Species richness group II	4.61 ± 2.22	4.61 ± 1.85	ns	ns
Species richness group III	5.72 ± 2.37	4.78 ± 2.15	p = 0.06	ns
Species richness group IV	7.28 ± 2.88	5.00 ± 2.00	**	ns
Total occurrences	45.4 ± 14.8	48.3 ± 18.6	ns	ns
Occurrences group I	0.44 ± 0.98	0.61 ± 1.46	ns	ns
Occurrences group II	14.3 ± 8.7	20.9 ± 11.0	***	ns
Occurrences group III	13.0 ± 6.6	14.9 ± 8.2	ns	ns
Occurrences group IV	17.7 ± 6.9	11.9 ± 5.3	***	ns
Diversity (Shannon index)	0.99 ± 0.14	0.90 ± 0.17	**	ns

(1) ns: not significant ($p > 0.05$), *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

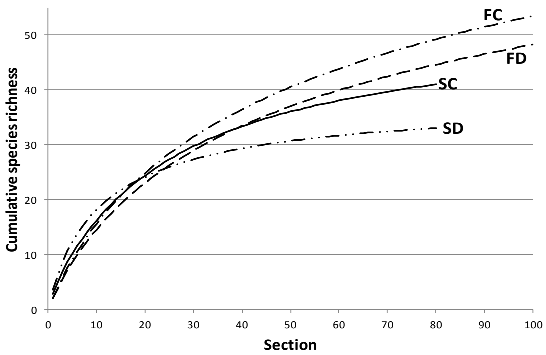

Fig. 2. Species accumulation curves for overall forest control sites (FC) and disturbed sites (FD) and for savannah control sites (SC) and disturbed sites (SD)

Group I species richness and occurrences

The lower termites (feeding on wood and litter) are only represented by three species in 19 occurrences, most of them from the evergreen Atlantic forest without any significant difference between control and disturbed zones (tables 4 and 5). Three and one species of these termites that inhabit pieces of dead wood were recorded by Eggleton *et al., (*2002) and Deblauwe *et al.,* (2007) respectively.

Table 4. Termite assemblages: species richness according to the ecosystem and to the zone (control versus disturbed)

		Group I	Group II	Group III	Group IV	Total
Evergreen forest (N = 12)	Disturbed	2	9	14	19	44
	Control	2	7	13	17	39
	Both zones	**2**	**9**	**17**	**23**	**51**
Mixed forest (N = 8)	Disturbed	0	6	9	9	24
	Control	0	8	15	19	42
	Both zones	**0**	**9**	**15**	**21**	**45**
Semi-deciduous forest (N = 8)	Disturbed	1	7	12	15	35
	Control	1	8	12	19	40
	Both zones	**2**	**8**	**16**	**25**	**51**
Savannah (N = 8)	Disturbed	0	12	9	12	33
	Control	0	17	10	14	41
	Both zones	**0**	**19**	**13**	**15**	**47**
All ecosystems (N = 36)		**3**	**24**	**31**	**41**	**99**

Table 5. Termite assemblages: abundance (number of occurrences) according to the ecosystem and to the zone (control versus disturbed).

		Group I	Group II	Group III	Group IV	Total
Evergreen forest (N = 12)	Disturbed	10	132	51	70	263
	Control	7	65	47	86	205
	Total	**17**	**197**	**98**	**156**	**468**
Mixed forest (N = 8)	Disturbed	0	39	54	27	120
	Control	0	33	70	50	153
	Total	**0**	**72**	**124**	**77**	**273**
Semi-deciduous forest (N = 8)	Disturbed	1	76	69	54	200
	Control	1	56	68	105	230
	Total	**2**	**132**	**137**	**159**	**430**
Savannah (N = 8)	Disturbed	0	129	94	63	286
	Control	0	103	48	78	229
	Total	**0**	**232**	**142**	**141**	**515**
	Grand total	**19**	**633**	**501**	**533**	**1686**

Group II species richness and occurrences

The Termitidae feeding on wood, litter (mainly fungus growers) and grass (in the savannah sites) are represented by 24 species in 633 occurrences (tables 4 and 5). These termites are particularly abundant at Mbikiliki (mainly *Nasutitermes* spp.) feeding on partly rotten wood and in the savannah (mainly Macrotermitinae and *Trinervitermes* spp.) feeding on sound dead wood, fresh litter and grass.

Their species richness does not differ between control and disturbed zones but the numbers of occurrences are very significantly larger in the disturbed zones. This probably results from the burying of felled timber when the pipeline trench was levelled: indeed some residual wood was still found in the soil (more than five years after its burying). Birang (2004) found also that wood feeders were faster resilient in disturbed zones than other termites. Similarly Eggleton *et al.,* (2002) and Deblauwe *et al.,* (2007) recorded 25 and 22 species of the group II respectively.

Group III species richness and occurrences

The Termitidae feeding on very decayed wood and carbon-rich soil are represented by 502 occurrences and 31 species. The number of occurrences does not differ significantly between control and disturbed zones (tables 4 and 5), however, the species richness might be impoverished in the disturbed zone, the difference being marginally significant ($p = 0.06$).

The species richness recorded in group III is markedly lower than those found by Deblauwe *et al.,* (2007) (43 species) and Eggleton *et al.,* (2002) (48 species). This is linked with the relatively low number of species in the *Anoplotermes* group for two reasons: (a) no primary or near primary forest was sampled in this work and (b) some species of this group may have been missed when sorting the samples.

Group IV species richness and occurrences

The Termitidae feeding on soil humus are represented by 44 species in 533 occurrences. The species richness and the number of occurrences are both very significantly lower in the disturbed zones than in the control ones (tables 4 and 5). Termites of group IV being true soil feeders, some correlations with various soil abiotic parameters (clay, C and N content,...) could be expected but only two significant correlations were found between their species richness and (a) bulk density ($\rho = -0.45$, $p < 0.05$) and (b) organic carbon content ($\rho = 0.41$, $p < 0.05$).

The species richness sampled in group IV is lower than those obtained by Eggleton *et al.,* (2002) (57 species) and Deblauwe *et al.,* (2007) (51 species). This is linked with the relatively low numbers of species in both the *Anoplotermes* and *Apicotermes* groups for the same reasons already put forward for the group III.

Termite assemblages

It is striking that the species richness follows the same order of the feeding groups (IV > III > II > I) in all the forests sites of this study, in those sampled by Deblauwe *et al.,* (2007) and in those sampled by Eggleton *et al.* (2002) for disturbance levels lower than 6. On the other hand the species richness follows a different order (II > IV > III > I) in this study and in the savannah of Lamto (Côte d'Ivoire) (Josens, unpublished data), reflecting more available and varied resources above ground and less below ground, the annual bush fires preventing a significant part of the plant production from being incorporated into the soil (Lepage *et al.,* 2006a & b).

It might have been expected (because of its changed climate and vegetation) that the disturbed zone in the semi-deciduous forest, which is located near the savannah, would house a termite assemblage approaching that of the savannah; however, this was not the case and not any one of the typical savannah species (e.g. *Trinervitermes* spp) was sampled there. A cluster analysis based on the termite species occurrences splits the 36 transect belts in four distinguishable clusters: six out of the eight savannah transect belts form a first cluster ('SA group') well apart from the other transects; the two remaining savannah transect belts, relatively poor in Macrotermitinae, cluster with six out of the eight semi deciduous forest transect belts ('DF group'). The four transect belts from Mbikiliki (evergreen Atlantic forest) form a third cluster ('MB group') and finally the fourth cluster is composed of the remaining 18 transect belts ('EF-MF group'). Within each cluster the samples from the disturbed zones tend to aggregate more or less (starred in Fig. 3). The termite assemblages appear thus more influenced by the situational conditions than by the disruption of the pipeline. The shape of the disturbed zone, a narrow strip bordered on a long distance with the semi-natural ecosystems, indeed favours the invasion of the disturbed zone by the nearby assemblages.

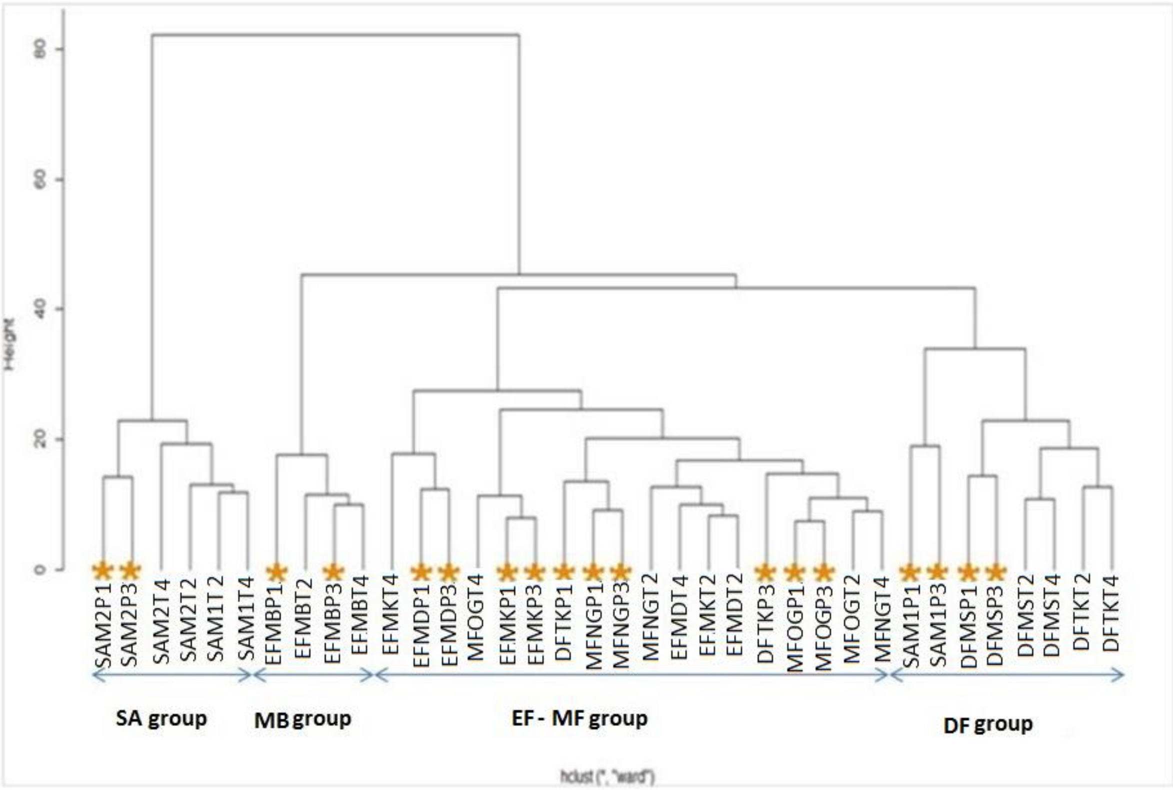

Fig. 3. Classification of transect belts according to the occurrences of all termite species. Each transect name is made of 6 characters. Two first letters: DF: semi-deciduous forest, EF: evergreen Atlantic Forest, MF: mixed forest, SA: savannah. Third and fourth letters: M1 and M2: Meidougou 1 and 2, MB: Mbikiliki, MD: Madong, MK: Makouré, MS: Mbong Sol, NG: Ngoya, OG: Ongot, TK: Tamtchek. Fifth letter: D: disturbed, C: control. Sixth character: transect number. : Transects of the disturbed zone.

A principal component analysis (PCA) was performed on the total species richness (based on the presence/absence of each species in each of the 36 transect belts); when the transect belts are projected onto the factorial plan F1 x F2, on the one hand the forest sites separate totally from the savannah sites along axis 1 and on another hand the forest sites spread out in a gradient along axis 2 (Fig. 4). On the same factorial plan, the disturbed transects do not at all separate from the control transects, the former group being included as a shrunk version within the latter group (Fig. 5A). The same, even striker, result is obtained if only the species of feeding group IV (which appears as the most sensitive to disruptions) are used (Fig. 5B).

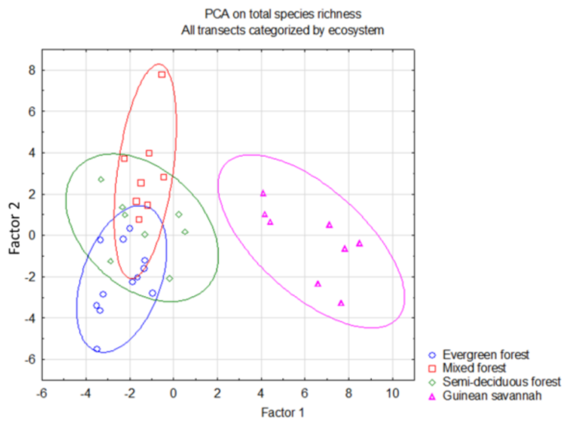

Fig. 4. Projection of the 36 transects belts on the factorial plane F1xF2 grouped according to ecosystems with equiprobable ellipses at 80%.

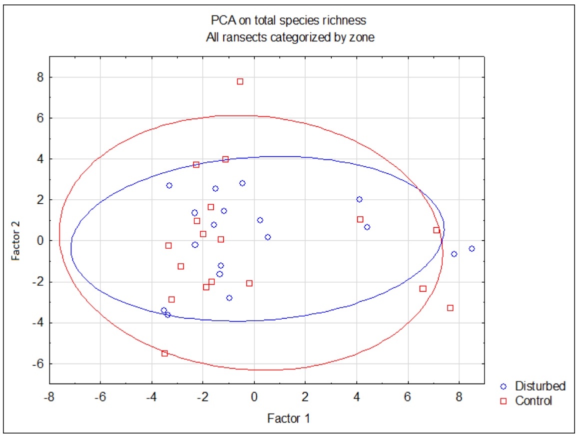

Fig. 5A. Projection of the 36 transect belts on the factorial plane F1xF2 of the total species richness, grouped according to the zones (disturbed vs. control) with equiprobable ellipses at 80%.

Fig. 5B. Projection of the 36 transects on the factorial plane F1xF2 of the feeding group IV species richness, grouped according to the zones (disturbed vs. control) with equiprobable ellipses at 80%.

Conclusion

The Chad-Cameroon pipeline entailed the complete clearing of about 3000 ha in 1999-2003, half in forests and half in savannahs. The disturbed zone, in 2008-2009, looked as a long strip with about 2000 km of boundaries with the crossed semi natural ecosystems. A little more than five years after the pipeline completion the termite communities from the adjacent ecosystems have invaded the disturbed zone. Since those adjacent ecosystems were already degraded (by other human activities) the new termite assemblages showed rather few significant differences with the nearby termite assemblages despite several significant changes in the soil properties. The most dramatic changes in the termite assemblages were (a) a 18 % reduction of the species richness, (b) a 31 % reduction of the number of occurrences of the group IV (humus feeders) and (c) a 17 % increase of occurrences of group II (wood feeders). It will be worth to follow the future changes of the termite assemblages in this unique man-made ecosystem.

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