Journal of Animal &Plant Sciences, 2018. Vol.36, Issue 1: 5793-5811
Publication date 29/04/2018, http://www.m.elewa.org/JAPS; ISSN 2071-7024

Investigating urban ant community (Hymenoptera: Formicidae) in port cities and in major towns along the border in Côte d'Ivoire: a rapid assessment to detect potential introduced invasive ant species

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Keywords: Urban ecosystem, biological invasion, Introduction roads, ants, invasive species, Côte d'Ivoire

1 ABSTRACT

Objective: This study aimed at examining ant communities of port and border cities in order to identify introduced and potential invasive ant species and microhabitats likely to contribute to the spread of these ant species. Therefore, the sampling design are linear transects of 200 metres on which ants were collected using tuna baits at 15, 30, 45 and 60 minutes in the two port cities of Abidjan and San Pedro, and seven cities that are Man, Touba, Odienne, Ferkéssedougou, Bouna, Bondoukou and Abengourou located near the borders of Côte d'Ivoire. The results showed 83 ant species including 9 potential introduced or invasive ant species. These invasive ants contributed importantly to the ant assemblage in port cities (23.95±2.7 % of total richness and 37±6.1 % of total abundance) and border cities (20.17±4.7 % / 30.6±7 %). In addition two notorious invaders, *Solenopsis geminata* (Fabricius, 1804) (Tropical fire ant) and *Pheidole megacephala* (Fabricius, 1793) (Big-headed ant) were detected during this study. The results also indicated that potential introduced or invasive ant species were mostly detected in microhabitats where human activities are uninterrupted such port zones, markets, domestic streets and residential. Conclusion: In the end, this study has shown that ant communities in port and border cities harbour invasive potential ant species, particularly microhabitats characterized by high human activities such as port areas, markets, domestic streets and residential areas.

2 INTRODUCTION

Human-induced species introductions surpass by far the consequences of natural range expansion of species (Elton, 1958). This introduction pattern has worsened with transport efficiency. Consequently, the magnitude of alien species movements continues to grow thanks to the globalization of trade (Hulme, 2009). One of the main mechanism which facilitates these introductions of alien species outside their geographical ranges, usually starts with human migrations and trades since the introduction routes of alien species are mostly associated with commercial exchange and human traffics (Hulme, 2007; Molina-Montenegro *et al.,* 2012). The introduction routes are mainly seaports and cross-border corridors, roads, canals and railways worldwide. Among these pathways, seaports and cross-border corridors, which contribute importantly to the industrialization of most developing countries (Yadav, 2012), are often tightly associated with cities. This connectivity facilitates the introduction of alien organisms usually associated to the importation and exportation of commodities such as liquid bulk, food and good shipping containers (Ward *et al.,* 2006). Once geographical barriers have been crossed, these alien species become established in commercial and transport infrastructures (airports, port zones, train stations, bus stations, industrial zones) which house from which they then spread towards urban ecosystem and other cities via vehicles and roads (Von der Lippe and Kowarick, 2008). Otherwise, several species introduced recently, became highly invasive and were causing deleterious impact on biodiversity and enormous economic loss worldwide (Pimentel, 2011). For example, many studies have shown that the introduction of invasive rodents *Rattus rattus* Linnaeus affects severely turtles, seabirds, amphibians and mammals (Jones *et al.,* 2008; Hanna and Cardillo, 2014), and leads to species depletion or extinction in insular ecosystems (Harper and Bunburry, 2015). Likewise, the introduction of the invasive ant *Solenopsis geminata* (Fabricius, 1804) in the Galápagos Archipelago promotes the invasion of other invasive species, disturbs the reproduction of endemic butterflies' species and moreover this ant attacks many vertebrates at their juvenile stage of growth (Wauters *et al.,* 2014). Although indeed very important, studies addressing issues on non-indigenous biota and their future (invasiveness) are still rare for many African countries (Mothapo, 2013), specifically for West African cities located near biodiversity hotspots on coastal areas. This paper aims at identifying the regions that may produce invaders or be particularly prone to invasion and reporting results of ant fauna inventory conducted in port cities and frontier zones from Côte d'Ivoire. This study focused on ant communities because beside their functional important role in tropical ecosystems (Hölldobler and Wilson, 1990), these insects are among notorious invader organisms (Lach *et al.,* 2010; GISD, 2013**).** It is known that many introduced ants are tramp species (McGlynn, 1999) and share common ecological traits such as polygyny, unicoloniality, opportunistic nesting behaviour and omnivory which facilitate their adaptation to human settlements and urban environment (Suarez *et al.,* 2010; Guénard *et al.,* 2014). Moreover, their small size simplifies unintentional transport by humans via tourism and commercial exchange (Holway *et al.,* 2002, Ward *et al.,* 2006). Consequently, amongst more than 600 ant species that have been reported as introduced in exotic ranges, many are among the world's notorious invaders (Miravete *et al.,* 2014). Although invasive ants cause economic damage and are responsible for the loss of diversity of ants other arthropods and even vertebrates in many invaded regions (Holway *et al.,* 2002), studies and general knowledge on the invasiveness status of these ants in West Africa are missing. In Côte d'Ivoire, all existing studies on ants were conducted in natural habitats and agricultural ecosystems so far (e.g. Lévieux, 1971; Diomandé, 1981; Yeo, 2006; Yeo *et al.,* 2011; Koné, 2013). It is only recently that urban ant fauna was surveyed (Yeo *et al.,* 2016). In this context, we hypothesize that major cities located at the border and port cities could act as port of entry for introduced invasive ant species. In this study, there is identification of ant species capable of invading new areas, to assess their abundance in specific microhabitats of urban areas taking into consideration the anthropophilic ant community of border and port cities. Additionally, this study also estimates the contribution of potential invasive ant species to the urban ant species richness and abundance in these surveyed cities.

3 MATERIALS AND METHODOLOGY

Study sites: The study was conducted in two main urban habitats: border and port cities of Côte d'Ivoire. The studied port cities are Abidjan and San-Pedro located in the Southern part of the country. Their nearness to the coastal areas has contributed to the sprawl and industrialization of these cities (Bauchemin, 2002; Halle and Bruzon, 2006**)**. These urban environments are characterized by an intensive urban land development with intensive pavement and open areas rarely covered by lawns. Because Abidjan is a district grouping several municipalities, we selected five municipalities as sampling sites in the capital: Abobo, Adjamé, Attécoubé, Yopougon and Treichville. The border cities are major towns (in size and with basic infrastructures) located near the borders of Côte d'Ivoire and neighbouring countries (Figure 1). The following cities were sampled: Man and Touba in the Western part; Odienne in the North-West, Ouangolodougou in the North; Bouna in the North-East; Abengourou and Bondoukou located in the Eastern part of the country. All these cities differed from the two ports cities by moderate or low urban land development, restricted asphalted roads and pavements which favour again the presence of bushy vacant lots (which are permanently restricted lots of open areas sometimes covered by patches of verdure alternating with lawns, grass and lone trees or bushy vegetation (Appendix, Table S1)). Climate regime of the study sites is hot and humid and ranges between equatorial and tropical with 28°C annual mean temperature and annual precipitation varying between 1000 mm in the North to 2400 mm in the South of the country. Additional information about biodiversity and climate are provided in Konaté and Kampmann (2010).

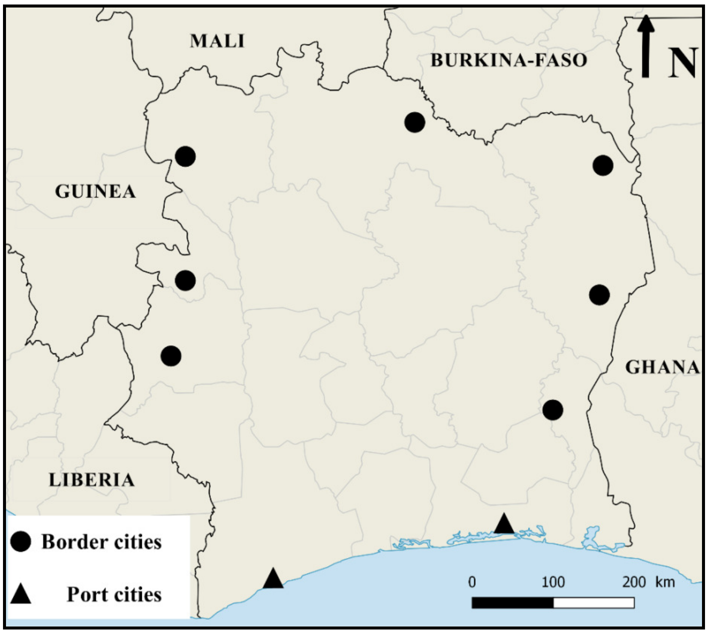

Figure 1: Location of the cities screened for potential invasive ant species in Côte d'Ivoire.

3.1 Sampling design and identification of ants:

Sampling was conducted from September 2014 to December 2015 between 8:00 am and 12:00 am. Transects were selected in order to survey ant community in areas where trade, transport of goods and human settlement is high, *i.e.* in the port zones, industrial zones, markets, residential, asphalted streets, transport stations and domestic streets. Three transects (sampling sites) were selected from each city except in the port zone of Treichville where we sampled five transects. The ants were collected using tuna baits

(Bestelmeyer *et al.,* 2000; Yeo *et al.,* 2016) along a linear transect of 200 metres at 15, 30, 45 and 60 minutes after the installation of 20 baits separated by 10 meters from each other along each transect. The transects were geo-referenced with a Garmin GPSMAP 64S (Appendix, Table S1). Ant workers were firstly identified to the genus following Bolton (1994), the name of genus was then updated using Fisher and Bolton (2016). Species were named using Bolton (1976, 1980, 1982, and 1987), and Doctor Yeo's ant collection in Lamto Ecological Station (Yeo, 2006). Vouncher specimens of identified ant species were deposited at Lamto Ecology Research Station, Côte d'Ivoire and at the Royal Belgian Institute of Natural Sciences (RBINS) (Brussels, Belgium). Species were classified either introduced or potential invasive status following McGlynn (1999); Holway *et al.,* (2002) and Wetterer (2015). Online resources such as Global Biodiversity Information Facilities, Encyclopedia of Life and PIA key (Sarnat, 2008) were also used to find out what the status of several ant species in Western Africa might be.

3.2 Data analysis: Forty-one transects were used for statistical analysis (n = 20 in port cities, n = 21 in border cities; Table 1). Our estimates of species abundance are based on the occurrences of individual workers rather than the number of individuals. This measure was preferred because of the patchy distribution of ants due to their social organization and due to great differences in colony sizes (Longino, 2000). Because our sampling unit was transects, we pooled samples of 15, 30, 45 and 60 minutes from the same bait to get a total of 20 samples per transect. Therefore, we had 41 transects x 20 samples = 820 samples in total (i.e.400 and 420 samples for port cities and border cities, respectively). Arbitrarily, species present on 10 over 20 samples were assumed to be numerically dominant at transect level. Curves of observed species accumulation (Mao Tau) and Chao 2 estimated species richness were plotted using EstimateS v9.1 (Colwell, 2005) using total number of transects for each main habitat. Local diversity was estimated with Shannon's index (H') and Evenness using EstimateS v9.1. Levene's test for homogeneity of variance was used to test the distribution of our data before comparison between transects. In case of normal distribution, one-way analysis of variance (ANOVA) on repeated measure and Tukey tests were used for multiple comparison and pairwise comparison, respectively. If not, the Friedman and Wilcoxon tests were used for comparison. T-test mean comparison was also used to examine the variation of common ant species and potential invasive ant abundance between transects of the microhabitats. Finally, the Bray-Curtis index was calculated to quantify the similarity of species composition between transects of each main habitat (border cities and port cities). We then plotted a two-dimensional map with non-metric multidimensional scaling (NMDS) to display the ant species composition similarities among the sampled sites. An analysis of similarities (ANOSIM) by 10,000 permutations was conducted to test significant differences in species composition between border cities and port cities. All these statistical analyses were made using Past Software v3.09 and $p \leq 0.05$ was taken as an indicator of statistical significance.

4 RESULTS

4.1 Ant species richness and diversity: A total of 83 ant species belonging to 20 genera and 5 subfamilies were recorded for the whole sampling campaign (Table 1).The subfamilies with high number of species were Myrmicinae (58 species) and Formicinae (15 species). The remaining subfamilies had fewer species with Ponerinae 4 species; Dolichoderinae 3 species and Dorylinae only 1 species. Sixty-three and 50 ant species were collected in the border cities and in the port cities, respectively. In addition, the curves of Chao 2 estimated species richness also supported high species richness for both border and port cities (Figure 2). This trend was also supported by the similar values of the Shannon diversity index of border cities (3.27) and port cities (3.03), and nearly identical Evenness (0.42 and 0.41, respectively). At city level, ant species richness was high in Odienne (36 species) and Ouangolodougou (33 species) while the lowest species richness was recorded in the city of Bouna (19 species) (Table 2). The comparison of species richness between transects showed a significant difference between border cities and port cities (ANOVA: F=2.176, df =12, p = 0.011). Post-hoc pairwise comparisons based on Turkey's HSD indicated only a significant difference between Ouangolodougou and Bouna (Q = 4.79; p = 0.038, respectively). Specifically, the results indicated a significant difference in ant species richness between border cities (ANOVA: F = 3.685, df = 6, p = 0.001) in contrast to port cities where no significant variation was observed (ANOVA: F = 0.864, df = 5, p = 0.504). Tukey's HSD post-hoc pairwise comparison of species richness in border cities indicated that the city of Ouangolodougou differed from Man (Q = 4.173, p = 0.049); from Bouna (Q = 4.769, p = 0.013) and from Abengourou (Q = 3.279, p = 0.049). A significant difference was also observed between Odienné and Bouna (Q = 4.173, p = 0.049). The diversity indices ranged from 2.1±0.01 to 2.8±0.13 for Shannon's index (±SE) and from 0.41±0.10 to 0.58±0.01 for Evenness (±SE) in border cities. Regarding port cities, the diversity indices ranged from2.2±0.13 to 2.7±0.1 for Shannon's index (±SE) and from 0.35±0.11 to 0.58±0.12 for Evenness (±SE). Out of 83 ant species collected, 9 were potential invasive (Table 3) species with 7 species records for Myrmicinae and 1 species record for Dolichoderinae and Formicinae. The number of potential invasive ant species detected, differed slightly between port cities and border cities (ANOVA: F = 1.91; df = 12; p = 0.031). Tukey's HSD post-hoc pairwise comparison indicated that the number of invasive species from the border city of Bouna differed from these from Abobo (Q = 4.88; p = 0.031) and San Pedro (Q = 5.377; p = 0.009). Our results showed that potential invasive ant species contributed importantly to the ant species richness in each habitat surveyed. They represented at least 20 % of the total number of species collected (Table 2). Their percentage was 23.95±2.7 % in port cities and reached 20.17±4.7 % in border cities. The city of San-Pedro (28.6 %) and Man (26.3 %) recorded the highest percentage of contributions for potential invasive ant species. The city of Ouangolodougou (14.3%) and Odienné (15.6) recorded the lowest percentage of potential invasive ant species.

Table 1: Abundance (frequencies of occurrences) of ant species occurring in border cities and port cities. The abundance values and potential invasive ants are in bold.

Species	Status	Border cities	Port cities	Total
DOLICHODERINAE				
Tapinoma lugubre SANTSCHI, 1917	Non-invasive	0.28	1.55	1.82
Tapinoma luteum (EMERY, 1895)	Non-invasive	1.37	3.47	4.84
Tapinoma melanocephalum (FABRICIUS, 1793)	Potential invasive	0.2	0.42	0.44
DORYLINAE				
Aenictus sp.01		0.04	-	0.04
FORMICINAE				
Camponotus acvapimensis MAYR, 1862	Non-invasive	0.14	-	0.14
Camponotus maculatus FABRICIUS, 1782	Non-invasive	0.97	0.08	1.05
Camponotus sericeus FABRICUS, 1798	Non-invasive	0.22	-	0.22
Camponotus vividus (SMITH, 1858)	Non-invasive	0.02	-	0.02
Camponotus sp.01		0.02	-	0.02
Camponotus sp.02		0.02	-	0.02
Camponotus sp.03		0.06	-	0.06
Camponotus sp.04		0.02	-	0.02
Lepisiota capensis MAYR, 1862	Non-invasive	0.71	-	0.71
Lepisiota sp.01		1.19	0.38	1.57
Lepisiota sp.02		0.08	0.65	0.73

Nylanderia scintilla LAPOLLA, HAWKES & FISHER, 2011	Non-invasive	-	0.10	0.10
Nylanderia boltoni LAPOLLA, HAWKES & FISHER, 2011	Non-invasive	0.87	1.76	2.64
Oecophylla longinoda var. Claridens SANTSCHI, 1928	Non-invasive	-	0.02	0.02
Paratrechina longicornis (LATREILLE, 1802)	Potential invasive	4.92	5.55	10.47
MYRMICINAE				
Cardiocondyla emeryi FOREL, 1881	Potential invasive	0.50	0.46	0.95
Cardiocondyla shuckardi FOREL, 1891	Non-invasive	0.30	0.16	0.46
Cardiocondyla sp.01		0.10	-	0.10
Cardiocondyla sp.02		0.28	-	0.28
Carebara distincta (BOLTON & BELSHAW, 1993)	Non-invasive	0.02	-	0.02
Messor galla (MAYR, 1904)	Non-invasive	0.10	-	0.10
Monomorium afrum ANDRE, 1884	Non-invasive	0.28	-	0.28
Monomorium bicolor EMERY, 1877	Non-invasive	7.16	8.88	16.04
Monomorium dolatu BOLTON, 1987	Non-invasive	0.75	0.46	1.21
Monomorium exiguum FOREL, 1894	Non-invasive	0.12	-	0.12
Monomorium invidium BOLTON, 1987	Non-invasive	0.08	0.02	0.10
Monomorium occidentale BERNARD, 1953	Non-invasive	1.47	1.09	2.56
Monomorium pharaonis (LINNAEUS, 1758)	Potential invasive	0.30	0.77	1.07
Monomorium rosae SANTSCHI, 1920	Non-invasive	0.56	-	0.56
Monomorium sp.01		0.16	0.59	0.75
Monomorium sp.02		0.02	-	0.02
Monomorium sp.03		0.02	-	0.02
*Monomorium*sp.04		0.06	-	0.06
Monomorium sp.05		0.22	-	0.22
*Monomorium*sp.06		-	-	0
Monomorium sp.07		-	0.20	0.20
Myrmicaria sp.01		0.02	-	0.02
Pheidole termitophila FOREL, 1904	Non-invasive	2.00	3.73	5.73
Pheidole excellens MAYR, 1862	Non-invasive	2.12	0.99	3.11
Pheidole megacephala FABRICIUS, 1793	Potential invasive	0.85	0.14	0.99
Pheidole sp.01		2.72	-	2.72
Pheidole sp.02		0.04	0.14	0.18
Pheidole sp.03		-	0.10	0.10
Pheidole sp.04		-	0.08	0.08
Pheidole sp.05		-	0.02	0.02
Pheidole sp.06		0.02	0.91	0.93
Pheidole sp.07		1.37	6.09	7.45
Pheidole sp.08		1.67	2.58	4.24
Pheidole sp.09		-	0.63	0.63
Pheidole sp.10		-	0.28	0.28
Pheidole sp.11		0.22	-	0.22
Pheidole sp.12		0.57	-	0.57
Pheidole sp.13		-	0.85	0.85
Pheidole sp.14		0.06	-	0.06
Pheidole sp.19		0.59	2.00	2.60
*Pyramica*sp.01		-	0.02	0.02
Solenopsis geminata (FABRICIUS, 1804)	Potential invasive	-	0.44	0.44
Solenopsis sp. 02	Non-invasive	0.32	1.59	1.90
Tetramorium caldarium (ROGER, 1857)	Potential invasive	0.06	0.06	0.12
Tetramorium calinum BOLTON, 1980	Non-invasive	0.18	-	0.18

Tetramorium eminii (FOREL, 1894)	Non-invasive	0.08	0.04	0.12
Tetramorium minusculum SANTSCHI, 1914	Non-invasive	-	0.22	0.22
Tetramorium rhetidum BOLTON, 1980	Non-invasive	-	0.20	0.20
Tetramorium sepositum SANTSCHI,1918	Non-invasive	0.04	-	0.04
Tetramorium sericeiventre EMERY, 1877	Non-invasive	0.79	0.48	1.27
Tetramorium simillimum SMITH, 1851	Potential invasive	2.38	2.85	5.23
Tetramorium sp.01		-	0.02	0.02
Tetramorium sp.02		0.04	-	0.04
Tetramorium sp.03		-	0.08	0.08
*Tetramorium*sp.04		-	0.06	0.06
Tetramorium sp.05		-	0.08	0.08
Tetramorium sp.06		-	0.04	0.04
Trichomyrmex abyssinicus (FOREL, 1894)	Non-invasive	0.04	-	0.04
Trichomyrmex destructor (JERDON, 1851)	Potential invasive	2.20	2.87	5.08
Trichomyrmex oscaris (FOREL, 1894)	Non-invasive	0.30	-	0.30
PONERINAE				
Brachyponera sennaarensis (MAYR, 1862)	Non-invasive	1.86	-	1.86
Mesoponera ambigua (ANDRE, 1890)	Non-invasive	-	0.02	0.02
Mesoponera caffraria (SMITH, 1858)	Non-invasive	0.38	-	0.38
Odontomachus troglodytes SANTSCHI, 1914	Non-invasive	1.09	0.38	1.47

*Sites located in the district of Abidjan

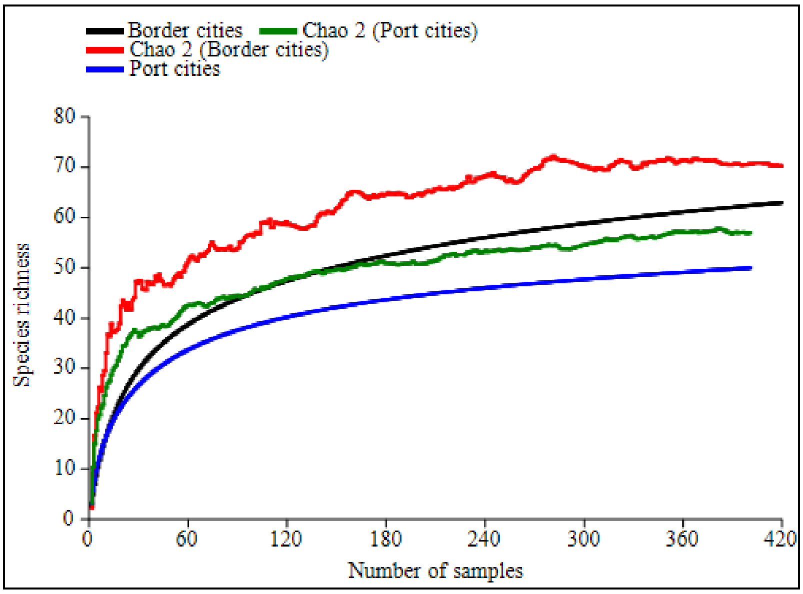

Figure 2: Observed and estimated accumulation curves of ant species for all transects for Border zones and Port cities.

Table 2: Diversity, Mean number ± (SE) and proportion of potential invasive species compared to the total species richness and abundance of ant assemblages in border and port cities.

Cities	Observed ant species	Contribution of potential invasive species richness (%)	Contribution of potential invasive species abundance (%)	Shannon's index (H') ± SE	Evenness (exp (H'/S)) ± SE
Man	18	26.3	44.2	2.4±0.14	0.58±0.01
Touba	29	20.6	10.1	2.7±0.12	0.50±0.15
Odienné	36	15.6	24.2	2.8±0.13	0.51±0.07
Ouangolodougou	33	14.3	35.6	2.6±0.12	0.41±0.10
Bouna	19	22.7	8.1	2.1±0.01	0.45±0.08
Bondoukou	23	21.7	32.5	2.4±0	0.50±0.08
Abengourou	20	20	59.8	2.4±0.13	0.55±0.10
Mean Border cities	25.42±6.4	20.17±4.7	30.6±7	2.5±0.22	0.5±0.05
San Pedro	20	28.6	15.1	2.5±0.01	0.58±0.12
Abobo	26	24	36.4	2.7±0.1	0.56±0.13
Adjamé	21	20	57.8	2.4±0.11	0.55±0.10
Attécoubé	25	24	49.1	2.2±0.13	0.35±0.11
Yopougon	24	24	31.4	2.6±0.1	0.56±0.13
Treichville	28	23.1	32.4	2.6±0.07	0.47±.07
Mean Port cities	24±2.7	23.95±2.7	37±6.1	2.4±0.21	0.51±0.09

Table 3: Averages of occurrences (±SE) of potential invasive species in the specific microhabitat identified in border and port cities.

Species	Domestic streets (n=20)	Markets (n=4)	Residential (n=6)	Asphalted streets (n=2)	Transport stations (n=2)	Industrial zone (n=1)	Port zones (n=6)	*t* (*P*)
Cardiocondyla emeryi	1.7±0.5	0.7±0.4	1±1	3±1	0.5±0.5	0	0.5±0.3	2.61 (0.04)
Monomorium pharaonis	1.9±0.8	1±1	1±0.6	0.5±0.5	0	0	0.8±0.6	3.05 (0.02)
Paratrechina longicornis	14.2±2.3	16±6.1	7.8±3.1	14±5	10±1	4	17±5.7	6.93 (0.00)
Pheidole megacephala	1.7±0.9	0	1.8±1.8	0	0.5±0.5	0	0.7±0.6	2.29 (0.06)
Solenopsis geminata	0	0	0	0	0	22	0	1 (0.35)
Tapinoma melanocephalum	0.9±0.4	0	0	1±1	0	0	0.3±0.3	1.93 (0.10)
Tetramorium caldarium	0	0.7±0.7	0	0	0	0	0.5±0.5	1.53 (0.17)
Tetramorium simillimum	7.8±1.8	3.5±0.6	9±3	6.5±1.5	0	2	5.7±5.7	4.07 (0.01)
Trichomyrmex destructor	4.9±3.5	11.2±11.2	2.3±2.3	13±8	22±22	0	4.7±4.7	2.78 (0.03)

4.2 Abundance and species composition: Overall, this study found no significant difference in ant species abundance between border and port cities (ANOVA, $F = 1.281$, $df = 12$, $p = 0.223$) . However, a slight difference was observed when comparing border cities between them (Friedman test: $\chi2 = 6.136$, $df = 6$, $p = 0.05$) in contrast to port cities where no significant difference was observed after comparison of ant species abundance ($\chi2 = 1.822$, $df = 5$, $p = 0.51$). A significant difference of the proportion of abundance for potential invasive ant species was found between border cities ($\chi2 = 6.46$, $df = 6$, $p = 0.044$). In border cities, the potential invasive ant proportion was the lowest in Bouna (8.1%) whereas in Man it was the highest (44.1%)(Figure 3A).On the other hand, the proportion of potential invasive did not vary significantly in port cities ($\chi2 = 1.635$, $df = 5$, $p = 0.57$). Even though, potential invasive ant abundance was high in Adjamé (57.8%) and Attécoubé (49.1%) but low in San Pedro (15.1%) and moderate in Abobo (36.4%), Treichville (32.4%) and Yopougon (31.4%) (Figure 3B). On the 83 ant species collected, we identified 30 common species, which constituted 91.27% (4604 of 5044) of the total abundance recorded in the whole study. Among these common ant species, *Monomorium bicolor* Emery, 1877 (16.04% of 5044), *Paratrechina longicornis* (Latreille, 1802)(10.47%), *Pheidole* sp.07 (7.45%), *Pheidole termitophila* Forel (5.73%), *Tetramorium simillimum* (Smith, 1851) (5.23%), *Trichomyrmex destructor*(Jerdon, 1851) (5.08%), *Tapinoma luteum* (Emery, 1895) (4.84%), *Pheidole* sp.08 (4.24%), and *Pheidole excellens* Mayr, 1862 (3.11%) were the most abundant species. Table 3 indicates the distribution of the average ant abundance recorded in the seven microhabitats encountered in border and port cities. We found that potential invasive ant species were especially detected in the port zone, the markets, on the domestic streets and the Asphalted roads. The t-test comparison of the mean abundance revealed that the abundance of *P. longicornis*, *T. simillimum*, *T. destructor*, *Monomorium pharaonis* (Linnaeus, 1758) and *Cardiocondyla emeryi* Forel, 1881 differed significantly between the sampled microhabitats in contrast to the abundances of the other dominant species. The comparison of ant species composition indicated that border and port cities shared 31 ant species. Non-metric multidimensional scaling ordination (NMDS) based on ant species composition of transects did not illustrate a clear distinction between ant assemblages of the border and port cities (Figure 4A). However, the analysis of similarity indicated a low and significant difference in ant species composition between border and port cities (ANOSIM: $R = 0.22$; $p = 0.0001$). Furthermore, the introduced or potential invasive ants assemblage was almost similar overall transects of border cities ant port cities, except one transect in the city of Bouna (Figure 4B; ANOSIM: $R = 0.04$; $p = 0.09$).

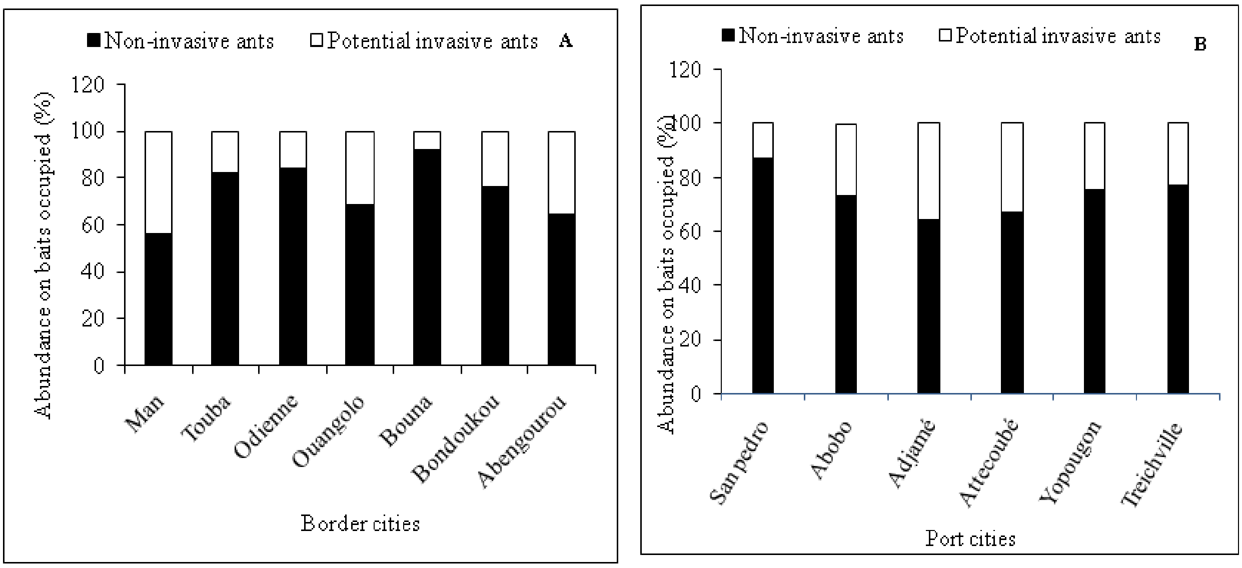

Figure 3: Abundance of potential invasive and non-invasive ant species on baits occupied. (A) border cities, (B) port cities

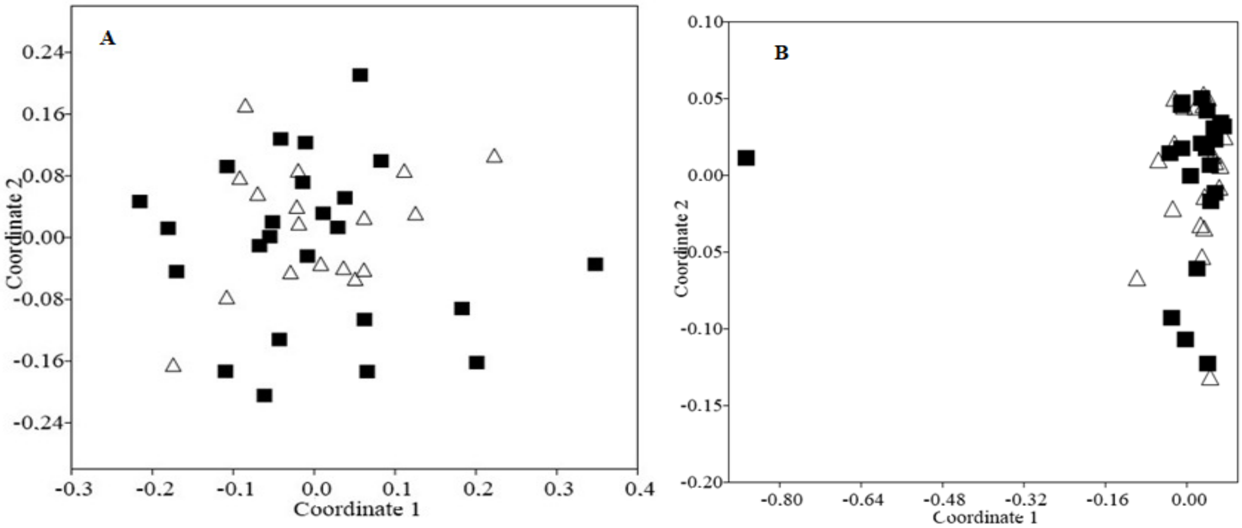

Figure 4: Non-metric multidimensional scaling plot indicating the similarity among transects from border cities (filled squares) and port cities (triangles). (**A**) Composition of the whole ant community. Stress = 0.2, (Eigenvalues of axes: first = 0.43; second =0.28). (**B**) Composition of introduced or potential invasive ant species. Stress= 0.20, (Eigenvalues of axes: first = 0.19; second = 0.27).

5 DISCUSSION

5.1 Species richness and diversity: Among the 83 ant species collected in this survey two species (*S. geminata* and *Tapinoma melanocephalum* (Fabricius, 1793)) were new records of invasive species for Côte d'Ivoire (see also Kouakou *et al.*, 2017). The study results confirmed the hypothesis that potential introduced or invasive ant species do occur in border and port cities of Côte d'Ivoire. The spread of invasive species results from accidental introductions of these species by humans via commercial trade, transport hubs and tourism (Mack *et al.*, 2000; Essl *et al.*, 2011**).** Likewise, it is possible that other invasive species were collected but not discovered as such because of the important number of morphospecies and this number might be higher because of the rarity of research conducted on ant fauna in urban areas. Moreover, this study shows that urban areas of Côte d'Ivoire might support high ant species richness. Also Yeo *et al.* (2016) assumed that urban landscape myrmecofauna in Côte d'Ivoire could be very diverse. Here the urban myrmecofauna was composed of Myrmicinae, Formicinae, Dolichoderinae, Ponerinae and rarely Dorylinae, with a large dominance of the first two subfamilies. We noted a low but significant difference of ant diversity and species richness between border and port cities. This pattern might be explained by the level of urban land development, which can affect negatively ant species richness and diversity (Sanford *et al.,* 2009). In fact, although border cities might be important corridors because of their geographical location, they are characterized by moderate urbanization and low urban land development, which tolerates bushy areas and an important number of vacant lots with grass. These characteristics might offer a suitable habitat for any native ant species. For example, we found that the ant genus *Camponotus* (Hymenoptera: Formicidae) (Carpenter ants) generally abundant in open areas like natural savannah bushes (Yeo *et al.,* 2017), was abundant in border cities and this is probably due to the dominance of bushy areas. On the other hand, in port cities intensive urbanization could have led to a large surface of paved areas and consequently the reduction and the homogenization of ant species richness and diversity (Buczkowski and Richmond, 2012). Obviously, the results of this study support that none of the main habitats surveyed were free of potential introduced or invasive ants. They constituted on average at least 20% of the observed ant species richness in both border and port cities. The potential invasive ant species here recorded are: *P. longicornis*, *T. destructor*, *T. simillimum*, *P. megacephala*, *M. pharaonis*, *C. emeryi*, *S. geminata*, *T. melanocephalum* and *Tetramorium caldarium* (Roger, 1857). Many among them were probably introduced as they are widely known as tramp species (McGlynn, 1999; Holway *et al.,* 2002; Wetterer, 2015), as it is the case for *S. geminata*. This invasive species was collected only in the Industrial zone of Yopougon in Abidjan. Its introduction might be recent, as described by Kouakou et al. (2017). *S. geminata* could pose a problem since it has been reported as highly invasive with a good resource monopoly rate, both in disturbed and natural areas in other tropical regions (Herrera and Causton, 2008; Wauters *et al.,* 2014). Another potential invasive species abundant in our study was *P. megacephala.* This invasive ant species (Lowe *et al.,* 2000) was recently found to be associated to open areas like wet and dry natural savannah of Lamto (Yeo *et al.,* 2017) and now urban areas in this study. These findings are consistent with Wetterer (2012) who suspected *P. megacephala* to be native in Côte d'Ivoire. It is also important to mention that in this study, except the city of Bouna, the findings support a pattern, which may suggest that potential invasive ant species become established in cities supporting low ant species diversity and richness maybe due to high human disturbance.

5.2 Abundance and species composition: Globally, the comparison of ant species abundances between border and port cities did not indicate a significant difference, although the value of Evenness suggested irregular distribution of the ant species abundance among these communities. This irregular distribution of species abundance matched with the variation of ant species abundance at city levels and the difference in the abundances between non-invasive and potential invasive ant species. Furthermore, potential invasive ant species highly contribute to the ant abundance in border and port cities (up to 30% of total Abundance). The indifference in the abundance might be explained firstly by the prevalence of potential invasive ants in urban areas because of their tramp behaviour. As second, reason mentioned was that here that port and border cities are equipped with infrastructures, which promote the introduction of potential invasive ant species. In fact, in addition to serve as cross-border corridor and transit way for merchandises and goods, border and port cities house trade and transport infrastructures such warehouse, industries and transport stations which contribute to the introduction and the spreading of potential invasive ants (Floerl and Inglis, 2005; Ward *et al.,* 2006; Molina-Montenegro *et al.,* 2012). In addition, microhabitats of urban areas seem to influence the distribution of potential invasive ant species. This pattern suggests that on the one hand, certain potential invasive ant species might have the advantage to be easily transported and spread more rapidly than other. For example, most abundant potential invasive ant species like *P. longicornis*, *T. simillimum*, *T. destructor*, and *C. Emeryi* where detected in areas where the likelihood to be transported easily by human, is high. The target microhabitats where this happens are markets, residential; industrial zones, transport station and port zones. These microhabitats, commonly characterized by heavy trading activities and transport of commodities and goods, may contribute to spread rapidly potential introduced or invasive ant species. On the other hand, microhabitats can serve as nesting area during early stages of establishment both for outdoor and indoor ant species. For example, domestic and asphalted streets could play a basic role for nesting of outdoor tramp ant species like *P. megacephala, S. geminata* and serve as foraging field for indoor tramp ants such *T. destructor, P. longicornis* and *T. melanocephalum*. It is also possible that this unequal distribution in abundance of these species will be due to the availability of resources as reported in Rizali *et al.* (2008). We found that ant species compositions from border cities and port cities seem relatively similar and this is obvious for the present potential invasive ant species. This trend could be due to the low variation in overall ant species composition. This can be explained by the biotic homogenization of ant communities, which generally leads the reduction in the biological uniqueness of native ant communities and favours the prominence of well-adapted anthropogenic ant species (Vepsäläinen *et al.,* 2008; Buczkowski and Richmond, 2012). In conclusion, the present study allowed us to show that border and port cities in Côte d'Ivoire might generate invaders or be particularly prone to the spread of invasive ant species. The data produced here also indicated that most of the potential introduced or invasive ants seem particularly well established in microhabitats like port zones, markets, domestic streets and residential. Moreover, many of the suspected potential invasive ant species detected in this study are invasive and raise important problems in other regions of the world (Herrera *et al.,* 2013; Bertelsmeier *et al.,* 2015; Klimeš and Okrouhlìk, 2015). Some potential introduced or invasive species like *Paratrechina longicornis, Monomorium pharaonis*, *Pheidole megacephala* and *Cardiocondyla emeryi* identified in this study have been already been found associated to land-use in cocoa and teak plantations (Yeo *et al.,* 2011; Koné *et al.,* 2014). So further studies should pay attention to the survey of ant fauna in agroecosystems and their interaction with others arthropods, as the introduction of species such *Paratrechina longicornis*, *Tapinoma melanocephalum*, *Solenopsis geminata* in disturbed area like agroecosystems could have important consequences on crops, specifically on vegetable crops because of mutualistic relationships with aphids, mealbugs and Honeydews (Jahn *et al.,* 2003; Zhou *et al.,* 2012; Shik *et al.,* 2014). Likewise, future studies on ant community in urban landscapes should also take into consideration green spaces and urban parks in order to assess the biodiversity conservation value of these areas in urban area**.**

6 ACKNOWLEDGMENTS

The work was supported by funding from the Belgian Directorate-General for Development Cooperation (DGD) within the framework of the CEBioS program (CBD/GTI-02/MLS/2015.53). We are grateful to Konan Yao Marius, Kouakou Evelyn and Yodé Christine for their assistance during the field. We are also grateful to the anonymous reviewer which the positive suggestions improve the quality of this paper.

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Publication date 29/04/2018, http://www.m.elewa.org/JAPS; ISSN 2071-7024

8 APPENDIX

Table S1: Coordinates and brief description of all transects in the surveyed cities with Domestic Street: roads, streets and spaces between buildings; Market: sites near traditional daily markets; Transport Station: sites of transport of people and goods mostly located at the entrance of cities; Industrial Zone: areas dominated by industrial activities such as production, transformation, exportation and importation of goods; Port Zone: Port areas of Abidjan and San-Pedro.

Cities	Sites	Coordinates	of Habitat types	Description
Man	Gare	N: 07°24'48.0" W: 007°32'51.9"	Transport station	Open area
	Justice	N: 07°24'23.4" W: 007°33'15.2"	Domestic Street	Open area
	Cafop	N: 07°23'43.2" W: 007°33'32.9"	Domestic Street	Open area with lawn
Touba	Marché	N: 08°17'14.8" W: 007°40'53.7"	Market	Open area
	Sokoura 2	N: 08°17'48.7" W: 007°40'47.6"	Domestic Street	High grass
	Résidentiel	N: 08°17'08.7" W: 007°41'26.3"	Residential	Open area; short grass
Odienné	Résidentiel Sud	N: 09°30'15.2" W: 007°33'09.4"	Residential	bush; trees with shade
	Libreville	N: 09°30'41.4" W: 007°33'55.3"	Domestic Street	Open area
	Marché	N: 09°30'07.3" W: 007°33'48.9"	Market	Open area with lawn
Ouangolodougou	Gare de train	N: 09°57'53.9" W: 005°08'37.9"	Domestic Street	Open area; grass; trees
	Marché	N: 09°58'01.3" W: 005°09'09.3"	Market	Open area
	Résidentiel	N: 09°58'19.4" W: 005°09'18.0"	Residential	High grass and lawn
Bouna	Stade	N: 09°16'19.7" W: 002°59'33.3"	Domestic Street	Open area
	Résidentiel	N: 09°15'39.4" W: 003°00'07.2"	Residential	bush; lawn

Journal of Animal &Plant Sciences, 2018. Vol.36, Issue 1: 5793-5811
Publication date 29/04/2018, http://www.m.elewa.org/JAPS; ISSN 2071-7024

	Gareroutière	N: 09°16'16.9" W: 003°00'037.8"	Transport station	Open area with lawn
Bondoukou	Impôt	N: 08°02'16.4" W:002°48'06.7"	Domestic Street	Open area
	Justice	N: 08°02'34.0" W: 002°47'40.9"	Domestic Street	Open area with lawn
	Hôtel la paix	N: 08°02'52.3" W: 002°48'11.4"	Domestic Street	Hollow; grass and trees
Abengourou	Mosquée	N: 06°43'47.6" W: 003°29'42.1"	Domestic Street	Open area; short grass
	Affetou	N: 06°43'16.2" W: 003°29'46.8"	Domestic Street	Open area
	Cathédrale	N: 06°43'43.8" W: 003°29'03.1"	Asphalted street	Grass with trees, shade
San-Pedro	LycéeModerne	N: 04°45'29.2" W: 006°40'50.2"	Domestic Street	Open area
	CMA	N: 04°46'26.0" W: 006°40'23.2"	Domestic Street	Open area
	Millionnaire	N: 04°44'42.0" W: 006°38'06.6"	Port zone	Open area, lawn
Abobo*	N'Dotré	N:05°26'43.4" W: 004°04'01.8	Domestic Street	Open area
	Baoulé	N: 05°25'02.9" W: 003°59'48.6"	Domestic Street	Open area
	Anador	N: 05°24'35.5" W: 004°00'49.9"	Domestic Street	Open area
Adjame*	Pailler	N: 05°22'27.1" W: 004°00'46.8"	Residential	Open area
	Bracodi	N: 05°21'37.4" W: 004°01'16.5"	Domestic Street	Open area
	220 Logements	N: 05°20'48.2" W: 004°01'01.1"	Residential	Open area with lawn
	Fermont	N: 05°21'28.7" W: 004°02'09.2"	Domestic Street	Open area

Journal of Animal &Plant Sciences, 2018. Vol.36, Issue 1: 5793-5811
Publication date 29/04/2018, http://www.m.elewa.org/JAPS; ISSN 2071-7024

Attecoubé*	Marché	N: 05°20'58.0" W: 004°02'08.2"	Market	Open area
	Marine	N: 05°20'41.6" W: 004°02'17.1"	Asphalted street	Open area
Yopougon*	Zone Industrielle	N: 05°22'12.9" W: 004°05'29.9"	Industrial zone	Open area
	Aimé Cesaire	N: 05°20'40.9" W: 004°05'00.4"	Domestic Street	Open area: garden
	Niangon Nord	N: 05°19'51.4" W: 004°06'06.0"	Domestic Street	Open area
Treichville*	Port 1	N: 05°17'32.6" W: 004°00'29.4"	Port zone	Open area
	Port 2	N: 05°17'23.9" W:004°00'29.7"	Port zone	Open area
	Port 3	N: 05°16'22.7" W:004°00'29.2"	Port zone	Open area
	Port 4	N: 05°16'47.2" W:004°00'31.6"	Port zone	Open area
	Port 5	N: 05°18'56.6" W: 004°01'20.4"	Port zone	Open area with lawn

Footnote
*Sites located in the district of Abidjan (see Table 1)