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Diversity Patterns of Ants (Hymenoptera: Formicidae) Along an Elevational Gradient on Monts Doudou in Southwestern Gabon

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Ants were collected at three elevations (110 m, 375 m, 640 m) using the following methods: litter sifting, sweeping, beating, yellow pan traps, pitfall, Malaise traps, and hand collecting. A total of 310 species in 56 genera were recorded from Monts Doudou. This is the highest species richness of ants yet recorded in Africa. Species richness was relatively constant along the elevational gradient surveyed (210 species at 110 m and 206 species at 375 m and 640 m). Comparison of ant species turnover along the gradient did not show evidence of variation with respect to elevation. Based on one well-studied group, Dacetonini, most species have previously been recorded from Gabon and have broad distribution ranges across the western Congo Basin. Leaf litter methods captured the greatest number of species followed by sweeping, beating, and general collecting. Yellow pan, pitfall, and Malaise traps collected the fewest species. Sweeping is rarely conducted in ant inventories, but these results suggest it should be included in the Afrotropical region.

RÉSUMÉ

Les fourmis ont été récoltées à trois altitudes (110 m, 375 m, et 640 m) en utilisant les méthodes suivantes: tamisage de litières, filet de fauchage, pièges bac jaunes, trous pièges, parapluie japonais, piège Malaise et récoltes à vue. Un total de 310 espèces dans 56 genres sont mentionnées des monts Doudou. Ceci représente le nombre d'espèces de fourmis le plus élevé en Afrique. Les nombres d'espèces sont relativement constants sur tout le gradient d'élévations étudiées (210 espèces pour le site à 110 m, 206 espèces pour les sites à 375 et 640 m). La comparaison de la succession des espèces le long du gradient n'a pas mis en évidence de variation liée à l'altitude. A partir d'un groupe très connu, Dacetonini, la plupart des espèces ont déjà été mentionnées au Gabon et ont une vaste distribution le long de l'ouest du bassin du Congo. La méthode de tamisage de litières a permis de capturer le plus grand nombre d'espèces suivie par le filet de fauchage, le parapluie japonais et la récolte à vue. Les pièges bac jaunes, trous pièges et pièges Malaise ont permis de récolter un plus faible nombre d'espèces. Le filet de fauchage est rarement utilisé pour la récolte des fourmis mais ces résultats suggèrent que cette méthode devrait être davantage utilisée.

INTRODUCTION

Systematics provides an essential foundation for understanding, conserving, and using biodiversity in the Congo Basin. Yet for many groups of organisms we lack even such basic information as the identity and numbers of species found in the region. This is espe-

cially true for hyperdiverse groups of Arthropods such as ants (Hymenoptera: Formicidae), for which even approximate estimates of species richness and distribution patterns remain difficult to ascertain (Robertson 2000a).

Ants are an especially diverse and ecologically important group whose social behavior and ecological dominance have been the subjects of intense biological study (Hölldobler and Wilson 1990). Despite this long history of research and their ecological importance, considerable gaps remain in our understanding of the African ant fauna (Robertson 2000a and included references). For example, the species-level taxonomy of driver ants (*Aenictus* and *Dorylus*) is fragmentary and out-of-date, despite their spectacular predatory and nomadic behavior and the evidence that certain "keystone" species exert a major influence on the composition of forest arthropod communities (Franks and Bossert 1983; Gotwald 1995). A more complete inventory of African ants is essential to advance understanding of their ecology, evolution, and behavior, and to take full advantage of their demonstrated value in conservation priority setting, biomonitoring, and biological control (Agosti et al. 2000).

Quantitative sampling of ants has been conducted in Ghana (Belshaw and Bolton 1994), South Africa (Majer and de Kock 1994), Tanzania (Robertson 1999), and Namibia (Robertson 2000b). In this paper, I report the first quantitative survey of ants in the Congo Basin. Inventories were conducted along an elevational gradient at three sites: 110 m, 375 m, and 640 m on Monts Doudou, in southwestern Gabon. Information is presented on the species composition along the gradient and the relative efficiency of methods to capture ants.

METHODS

Study sites

Ants were intensively surveyed from 24 February to 21 March 2000 at three principal localities along an elevational gradient on Monts Doudou. The reserve is located in southwestern Gabon in the Province de Ogooué-Maritime. The inventories were conducted at the following sites and habitats within the Reserve:

Camp 1. Reserve de Faune de la Moukalaba-Douboua, 12.2 km 305° NW Doussala, 40.2 km 324° NW Mourindi, 2°17.00′S, 10°29.83′E, 110 m, lowland rainforest, 24 February–4 March 2000.

Camp 2. Aire d'Exploitation Rationnelle de Faune des Monts Doudou, 24.3 km 307° NW Doussala, 52.1 km 321° NW Mourindi, 2°13.35′S, 10°24.35′E, elevation zone 350–425 m, with principal collection conducted at 375 m; mid-elevation rainforest, 5 March–12 March 2000.

Camp 3. Aire d'Exploitation Rationnelle de Faune des Monts Doudou, 25.2 km 304° NW Doussala, 52.6 km 321° NW Mourindi, 2°13.63′S, 10°23.67′E, elevation zone 585–660 m, with principal collections conducted at 640 m; mid-elevation rainforest, 14 March–21 March 2000.

In addition, a second low elevation site (110 m) was visited on February 29, 2000 (Reserve de Faune de la Moukalaba-Douboua, 10.8 km 214° SW Doussala 2°25.4′S, 10°32.7′E). This site was located 16.4 km SSE of Camp 1. In this paper, Camp 1 along with this additional 110-meter site is referred to as the 110-meter site, Camp 2 as the 375-meter site, and Camp 3 as the 640-meter site.

The habitat of all sites was lowland rainforest. The 110-meter sites had been selectively logged until 1992. Camp 2 and Camp 3 did not show any signs of previous logging.

During a 10-day reconnaissance in the region before the expedition, the 660 m summit near Camp 3 was the highest point encountered on Monts Doudou.

Survey methods

In each elevational zone, ants were surveyed using seven principal methods: leaf litter sifting, pitfall, yellow pan, beating, sweeping, Malaise, and general (hand) collecting methods. Simon van Noort conducted the yellow pan, sweeping, and Malaise traps as part of his study on Ichneumonidae. [See Chapter on Ichneumonid (Hymenoptera) diversity, by Simon van Noort in this volume for additional details.] These methods are described below:

(1) Leaf litter sifting (L). Invertebrates were extracted from samples of leaf litter (leaf mold, rotten wood) using a modified form of the Winkler extractor (see Fig. 2 in Fisher 1998). The leaf litter samples involved establishing 50, 1 m^2 plots, separated by 5 m intervals, along a 250-meter transect line. The leaf litter inside each plot was collected and sifted through a wire sieve with square holes of 1 cm × 1 cm. Before sifting, the material was chopped with a machete to disturb ant nests in small twigs and decayed logs. Ants and other invertebrates were extracted from the sifted litter during a 48-hour period in mini-Winkler sacks (for a detailed discussion of the mini-Winkler method, see Fisher 1998, 1999). At each elevation zone, two transects were conducted, each with 50 litter samples. At 110 m, the second litter transect was located 16.4 km from the first. At the 375 m and 640 m camps, the litter transects were placed less than 1 km apart.

(2) Beating low vegetation (B). Along the 50-sample leaf litter transect, 25 beating stations were established 10 m apart. Ants on low vegetation and arboreal ants were sampled by holding a stretched 1 m × 1 m white nylon platform below the undergrowth and beating the trunk or a branch three times with a stick. The dislodged ants were aspirated and placed in ethanol. This process was repeated six times for each of the 25 beating samples. Therefore each beating sample consisted of six different plant subsamples, each beaten three times with a stick. The six beating subsamples were taken within a 5 m radius of the beating station along the leaf litter transect.

(3) Pitfall traps (P). In each elevational zone, three pitfall transects with 11 buckets per transect were surveyed each morning for ants. The pitfall traps (275 mm deep, 285 mm top internal diameter, 220 mm bottom internal diameter) were sunk with their rims flush with ground level. Pitfall trap lines were set for eight days at Camp 1 and for seven days each at Camps II and III. (See detailed description in Burger et al. this volume).

(4) Malaise traps (M). Four Malaise traps were deployed in each elevation zone and serviced each day for a period of seven days. [See Chapter on Ichneumonid (Hymenoptera) diversity, by Simon van Noort in this volume for additional details.]

(5) Yellow pan traps (Y). A transect consisting of 25 stations spaced at 5 m intervals was laid out at each sampled elevation. At each station a yellow plastic bowl (165 mm diameter × 40 mm depth) was placed on the forest floor and charged with propylene glycol. These yellow pan traps were left for seven days and serviced at the end of this period, with each station being retained as a separate sample. [See Chapter on Ichneumonid (Hymenoptera) diversity, by Simon van Noort in this volume for additional details.]

(6) Sweep netting (S). Fifty samples, each sample comprising 20 net sweeps (each sweep encompassing an arc of 180°) i.e., 1,000 sweeps, were taken at each elevation. The collection of these samples was spaced over a period of seven days at each elevation. Each sweep was conducted in previously unsampled vegetation. [See Chapter on Ichneumonid (Hymenoptera) diversity, by Simon van Noort in this volume for additional details.]

(7) General collecting (G). Ants were also surveyed through general collecting, defined as any collection method that was separate from the quantitative transect and Malaise trap methods described above. It included searching rotten logs and stumps, dead and live branches and twigs, low vegetation, termite mounds, and under stones.

Data analysis

Only records of ant workers were used in data analysis since the presence of queens or males in samples does not necessarily signify the establishment of a colony of that species within the transect habitat type. Voucher specimens for this study have been deposited at the California Academy of Sciences, San Francisco, California, U.S.A.

Overlap and complementarity (distinctness or dissimilarity, *sensu* Colwell and Coddington 1994) of the ant assemblages at different elevations were assessed using distinctness and beta-diversity indices. Complementarity of ant assemblages at different elevations was assessed using the proportion of all species in two sites that occurred at only one site. Complementarity was calculated using the Marczewski-Steinhaus (M-S) distance index: $C_{MS} = (a + b - 2j)/(a + b - j)$ where j = number of species found at both elevations, a = number of species at elevation A, and b = number of species at elevation B (Colwell and Coddington 1994). M-S was chosen because of its simple and statistically valid approach to comparing two biotas (Colwell and Coddington 1994).

Beta-diversity (species turnover between elevations) was calculated using the measure of beta-diversity developed by Harrison et al. (1992), because it distinguishes between species turnover and the loss of species along a gradient without adding new species. Beta = (S/a_{max}) 1, where S = the total number of species in the two elevations combined, and a_{max} = the maximum value of alpha-diversity (i.e., number of species) between the elevations compared. The number of species unique to an elevation and the number of species shared between elevations were also compared.

The redundancy of quantitative methods to capture the same portion of the fauna was evaluated using the redundancy index (R): $R = 1 - u/a$, where u = the number of species found only by method *min*, where *min* is the method that collected the fewest number of species, and a = the total number of species collected by the method that captured the fewest species (Fisher 2002). Higher values represent greater redundancy: a value of 1 represents complete redundancy, where all species collected by the method that captured the fewest species are also collected by the other method, and a value of 0 represents no overlap between species captured by each method.

RESULTS

Three hundred and ten species of ants in 56 genera, were collected on Monts Doudou (Table 1). Genera with 10 or more species were: *Tetramorium* (34 species), *Pyramica* (23), *Monomorium* (21), *Camponotus* (16), *Pheidole* (15), *Crematogaster* (13), *Oligomyrmex* (12), *Strumigenys* (12), *Technomyrmex* (12), *Cataulacus* (11), *Polyrhachis* (11) and *Pachycondyla* (10). Strictly arboreal species constituted approximately 27% of the total species richness (assessed from Table 1 on the basis of collecting method and previous knowledge of biology).

Elevation had no measurable effect on species richness, with the number of species at the two upper elevations being identical (206 species) and only four less than the number at the lowest elevation (210 species) (Table 2). The number of species unique to 640 m (34) was similar to 375 m (31) but less than 110 m (50).

TABLE 1. Species list of ants for collections on Monts Doudou based on two leaf litter sifting transects (L1, L2) beating (B), pitfall traps (P), sweeping (S), yellow pan traps (Y), Malaise traps (M), and general collecting (G). A total of 310 ant species were collected.

Species	110 m	375 m	640 m
AENICTINAE			
Aenictus sp. 03	Y	Y	–
Aenictus sp. 05	–	–	L1
CERAPACHYINAE			
Cerapachys sp. 01	G	–	–
Cerapachys sp. 02	L1, L2, Y	L1, L2, G, S	L1, L2, Y
Cerapachys sp. 03	L1, L2	L1, L2	L1, M
Cerapachys sp. 05	L1	L1	L2,
Cerapachys sp. 06	L2	L2	L2
Cerapachys sp. 10	L2	–	L2
Cerapachys sp. 11	–	L1	–
Cerapachys sp. 12	G		–
Cerapachys sp. 13	–	L2	L1, L2
Simopone conradti	–	M	–
Simopone sp. 03	–	L2, M	B
DOLICHODERINAE			
Axinidris sp. 01	G	–	B
Axinidris cf. *murielae*	B, S	–	B, S
Tapinoma sp. 02	B	L1, B, M, S	S, M
Tapinoma sp. 04	S	–	–
Technomyrmex sp. 01	B	–	B, M
Technomyrmex sp. 02	L1, S	L1, L2, B, S	L1, L2, B, M, S
Technomyrmex sp. 03	L1, L2, Y	L1, L2, G, Y	L1
Technomyrmex sp. 04	–	–	L2, B, S, Y
Technomyrmex sp. 06	–	–	B, S
Technomyrmex sp. 08	L2	L1, L2	–
Technomyrmex sp. 09	–	L1	–
Technomyrmex sp. 10	L1	L1, L2, B, S	–
Technomyrmex sp. 11	M	L1	B
Technomyrmex sp. 12	–	–	L1, B, G, S
Technomyrmex sp. 13	–	L2, S	S
Technomyrmex sp. 14	S	–	–
DORYLINAE			
Dorylus fulvus	–	L1	–
Dorylus sp. 01	P	P	G
Dorylus sp. 04	–	–	P
Dorylus sp. 06	L2	L1, G	G
Dorylus sp. 07	L1, L2	L1, Y	–

Species	110 m	375 m	640 m
FORMICINAE			
Acropyga sp. 02	L1	L2	L2
Acropyga sp. 07	–	–	L2
Anoplolepis sp. 01	L1	–	L2
Brachymyrmex sp. 01	S	–	–
Camponotus sp. 03	–	P	L2, P, G, M
Camponotus sp. 04	–	B	G, S
Camponotus sp. 05	–	B	S
Camponotus sp. 09	–	P	B
Camponotus sp. 13	–	–	G
Camponotus sp. 16	P, M, Y, S	B, P, Y, M, S	P, G, M
Camponotus sp. 18	–	B, G	G
Camponotus sp. 19	–	S	B
Camponotus sp. 20	B	–	B, M
Camponotus sp. 23	L2, B, G, M, S	S	–
Camponotus sp. 24	M, S	–	–
Camponotus sp. 25	S	–	–
Camponotus sp. 29	–	–	G
Camponotus sp. 30	–	–	L2
Camponotus sp. 37	–	–	G
Camponotus sp. 38	B	B, G	B
Lepisiota sp. 01	–	–	S
Lepisiota sp. 02	S	–	–
Lepisiota sp. 03	–	S	–
Lepisiota sp. 04	S	–	M
Lepisiota sp. 05	–	L2	B, S
Lepisiota sp. 06	–	–	G, S
Lepisiota sp. 07	–	–	S
Lepisiota sp. 09	–	L2, S	–
Ocecophylla longinoda	G	B, M, S	B, S
Paratrechina sp. 01	S	L1, L2, B, S	L1, L2, Y, S
Paratrechina sp. 02	–	–	S
Paratrechina sp. 03	G, S	L1, P, S	L1, L2
Paratrechina sp. 04	–	–	L2
Paratrechina sp. 06	S	L1	S
Paratrechina sp. 09	L2, S	L2, B, S	L1, L2, S
Paratrechina sp. 10	B, S	–	B, S
Paratrechina sp. 11	–	L1, Y	L1, B
Paratrechina sp. 13	S, M	–	–
Plagiolepis sp. 01	S	–	–
Plagiolepis sp. 02	SY	–	–
Plagiolepis sp. 03	S	–	–

Species	110 m	375 m	640 m
Plagiolepis sp. 09	B	–	–
Polyrhachis alexisi	S	–	–
Polyrhachis concava	S	B, S	–
Polyrhachis decemdentata	S	L2, P, S, M	–
Polyrhachis fissa	B	B, S, M	S
Polyrhachis laboriosa	S	–	–
Polyrhachis latispina	–	B	L2
Polyrhachis lestoni	–	B	–
Polyrhachis militaris	L2, B, P, G, Y, S	B, S	P, G, S
Polyrhachis monista	–	S	–
Polyrhachis revoili	B, S	B, S	B, S
Polyrhachis rutipalpis	G, S	L1, L2, S	G, S
Pseudolasius sp. 01	G	L1, L2	L1
Pseudolasius sp. 03	G	–	–
Pseudolasius sp. 05	L1	–	–
Santschiella kohli	–	S	–
MYRMICINAE			
Ankylomyrma corona-acantha	–	–	B
Atopomyrmex calpo-calycola	S, M	–	–
Atopomyrmex mocquerysi	–	–	G
Baracidris sitra	L1, L2	L2	–
Calyptomyrmex barak	L2, G	–	–
Calyptomyrmex brevis	–	L2	–
Calyptomyrmex kaurus	L1, L2	L1, L2	L1, L2
Cardiocondyla emeryi	S	–	–
Cataulacus sp. 01	B, G, S	B	B, S
Cataulacus sp. 02	–	B, S	–
Cataulacus sp. 03	B	–	–
Cataulacus sp. 04	–	–	B,
Cataulacus sp. 05	G, S	–	–
Cataulacus sp. 06	–	L2, B, G, S, M	B, S, Y
Cataulacus sp. 07	B, S	S, M	S
Cataulacus sp. 08	B, G	S	G, M, S
Cataulacus sp. 09	–	S, M	M, S
Cataulacus sp. 11	B	–	M
Cataulacus sp. 12	–	L1, B	–
Crematogaster sp. 01	L2, S	–	–
Crematogaster sp. 03	L1, L2, B, G, M, Y, S	L1, L2, B, P, G, M, S, Y	L1, L2, B, M, Y, S
Crematogaster sp. 04	S	–	–
Crematogaster sp. 05	S	S, M	–

Species	110 m	375 m	640 m
Crematogaster sp. 07	L2	–	–
Crematogaster sp. 08	S, Y	L2, B	–
Crematogaster sp. 10	–	–	M, S
Crematogaster sp. 11	L1, M, S	S	L1, L2, B, S
Crematogaster sp. 12	B, M, S, Y	M, S	L1, M, S
Crematogaster sp. 13	B, S	–	–
Crematogaster sp. 14	S	–	S
Crematogaster sp. 15	B	B, S, M	G
Crematogaster sp. 18	S	–	B
Cyphoidris exalta	–	–	P
Decamorium decem	L1, L2, G, Y	L1, L2, Y	
Dicroaspis laevidens	L1, L2, G	–	G
Melissotarsus emeryi	L2	–	–
Meranoplus nanus	S	–	B
Microdaceton tibialis	–	L1	L1, L2
Monomorium thrascoleptum	–	L1, L2	L1, L2
Monomorium cf. cryptobium	L1, L2	L1, L2	L1, L2
Monomorium cf. tanysum	L1, B, S	B	B
Monomorium cryptobium	L1, L2, G	L1, L2	L1, L2
Monomorium draxocum	–	L2, S	L1, L2, M, S
Monomorium egens	L1, B, S	S	L1, B, S
Monomorium exiguum	L2, B, S	B, G, S	B
Monomorium guineense	L2	–	–
Monomorium invidium	L1, L2	–	–
Monomorium nr. invidium	L1, L2	L1, L2	L1, L2
Monomorium spectrum	L1, L2, S	L1, L2, G, S	L1, L2, S
Monomorium strangulatum	L1, S	L2, B, S	
Monomorium sp. 01	B, S	B, S	B, S
Monomorium sp. 02	–	–	L1
Monomorium sp. 03	L1		L1, L2
Monomorium sp. 04	L1	M	B, S
Monomorium sp. 05	L2	–	B
Monomorium sp. 06	–	B	–
Monomorium sp. 07	–	B	–
Monomorium sp. 08	S	–	–
Monomorium sp. 09	–	–	L1, M
Myrmicaria exigua	L, S	M	M
Myrmicaria sp. 01	G, S, M	L1, L2, G, S, Y	–
Oligomyrmex nr. viliersi	L1	–	L2
Oligomyrmex sp. 01	L1	L1, L2, G	L1, L2
Oligomyrmex sp. 02	L1, L2	L1	L1, L2, S
Oligomyrmex sp. 03	L1, L2	L1, L2	L1, L2, G

Species	110 m	375 m	640 m
Oligomyrmex sp. 04	–	L1, L2, G	L1, L2, G
Oligomyrmex sp. 05	L1, L2	L1, L2	L1, L2
Oligomyrmex sp. 06	L1	L1, L2	L1, L2
Oligomyrmex sp. 07	L1, L2	L1	L1, L2
Oligomyrmex sp. 08	L2, S	L1	–
Oligomyrmex sp. 09	L1, L2	–	–
Oligomyrmex sp. 10	L1, L2	L1, L2	L1
Oligomyrmex sp. 11	–	–	L2
Paedalgus cf. rarus	–	–	L2
Pheidole megacephala	L1, B, G, S, M	L2, B, M, S, Y	L1, L2, B, S, Y, M
Pheidole nr. pulchella	G, Y	L2, S, Y	L1, L2
Pheidole speculifera	L1, L2, G, Y	L1, L2, G, Y, M	L2, G
Pheidole sp. 02	L1, L2, B, G, S, M, Y	L1, L2, B, G, S, Y	L1, B, M, S
Pheidole sp. 03	–	L2, G	–
Pheidole sp. 04	–	L1, G, S, Y	L1, L2
Pheidole sp. 05	L1	L1, L2	L1, L2, S
Pheidole sp. 06	L1, Y	L1, L2, G, S	L1, L2, S
Pheidole sp. 07	L1, L2	L1, L2	L1, L2
Pheidole sp. 08	Y	G	–
Pheidole sp. 09	L1, L2	L1, L2, Y	L1, L2
Pheidole sp. 10	L1, L2	L2	–
Pheidole sp. 11	–	L1, L2, G	L1, L2, G
Pheidole sp. 12	L1, L2	L1, L2	L1, L2
Pheidole sp. 13	L1, L2, G	L1, L2, G, Y	L1, L2
Pristomyrmex africanus	L1, L2, G	L1, L2, G	L1, L2, M
Pristomyrmex orbiceps	L1, L2, S	L1, L2, G	L1, L2
Pyramica behasyla	L2	L1, L2	L2
Pyramica belial	L2	–	–
Pyramica concolor	L1	L1, L2	L1, L2
Pyramica convinasis	–	–	L2
Pyramica depilosa	L2, S	L1, L2	L1
Pyramica dotaja	L1, L2	L1, L2	L1, L2
Pyramica enkara	L1, L2	L1, L2	L1, L2
Pyramica hensekta	–	L1	L2
Pyramica kerasma	L2	–	L1, L2
Pyramica lasia	–	–	L2
Pyramica laticeps	L1, L2	–	–
Pyramica ludovici	L1, L2	L1, L2, G	L1, L2
Pyramica lujae	–	L1	L1, L2, G
Pyramica ninda	L1	L1, L2	L1, L2
Pyramica placora	L1, L2	L1	L2
Pyramica ravidura	L1	L1, L2	L2

Species	110 m	375 m	640 m
Pyramica roomi	–	L2	–
Pyramica serrula	L1, L2	L1, L2	L1, L2, S
Pyramica sharra	L1, L2	–	L2
Pyramica synkara	L1, L2	L1	L2
Pyramica tacta	–	L1	L1, L2
Pyramica tethapa	–	L2	–
Pyramica tetragnatha	L1, L2	L1, L2, S	L1, L2, S
Strumigenys bernardi	L1, L2	L1, L2	L1, L2
Strumigenys cacaoensis	–	–	L2, S
Strumigenys dextra	L1, L2	L1, L2	L1, L2
Strumigenys korahyla	–	–	L2
Strumigenys petiolata	L1, L2, Y	L1, L2	L1, L2
Strumigenys rogeri	L1	L1	–
Strumigenys spathoda	–	L2	–
Strumigenys tetraphanes	L2	L1, L2	L1, L2
Strumigenys totyla	–	–	L2
Strumigenys ultromalyx	–	L2	L1
Strumigenys sp. 01	–	L2	–
Strumigenys sp. 02	–	–	L1, L2
Tetramorium sp. 01	–	L1, L2	–
Tetramorium sp. 02	–	L2	S
Tetramorium sp. 03	L1, L2, S	L2	L1, L2
Tetramorium sp. 04	L1	L2, S, Y	L1, L2
Tetramorium sp. 05	L1, L2	L1, L2	L1, L2
Tetramorium sp. 07	–	L2, S	–
Tetramorium sp. 08	–	L1	–
Tetramorium sp. 09	L1, S	L1, L2, B, G, S	L1, L2, B, G, S, Y
Tetramorium sp. 10	L1	L2, S	L1, L2, Y
Tetramorium sp. 11	L1, L2, S	L1, G, S	L2
Tetramorium sp. 12	L1, L2	L1, L2, G	L1, L2
Tetramorium sp. 13	L1, L2	L2	–
Tetramorium sp. 14	L1, L2	L1, L2, Y	L1, L2
Tetramorium sp. 15	–	L1	L1
Tetramorium sp. 16	L1, L2, B	L1, B, G	B
Tetramorium sp. 17	L1, L2	L1	L1, Y
Tetramorium sp. 18	L1	–	–
Tetramorium sp. 19	L1, L2	L1, B	L1, L2, G
Tetramorium sp. 21	L1, L2, Y, S	L1, L2, B, G, Y	L1, L2
Tetramorium sp. 22	B	B	B
Tetramorium sp. 23	–	B	–
Tetramorium sp. 24	B, S	B, S	S
Tetramorium sp. 25	–	–	G

Species	110 m	375 m	640 m
Tetramorium sp. 26	S	L2, G, S	L1, L2, G, S
Tetramorium sp. 27	L1, L2, S	L1, L2, B, S	S
Tetramorium sp. 28	L1, B, S	B, M, S	B, G, S
Tetramorium sp. 30	–	L1, L2	L1, L2, G
Tetramorium sp. 31	–	G	–
Tetramorium sp. 32	–	–	L2
Tetramorium sp. 33	L1, L2, S	L1	L2, G
Tetramorium sp. 34	L1, L2, G	L1, G, Y	–
Tetramorium sp. 35	–	L1	L2
Tetramorium sp. 36	S	L1, L2, S, Y	S
Tetramorium sp. 37	–	S	–
PONERINAE			
Amblyopone sp. 01	L1	G	–
Anochetus africanus	L1, L2	L1, L2, P, G	L1, L2
Anochetus nr. africanus	L2, G	L1, G	L1,
Anochetus katonae	L1, L2, G	L1, L2	L1, L2
Anochetus sp. 01	–	L1, L2	L1, L2
Anochetus sp. 02	–	L1, L2, G	–
Anochetus sp. 03	L1, L2, G	L2	–
Anochetus sp. 04	L1	L1, L2	–
Anochetus sp. 05	L1, G, S	L1, L2, B	L1, L2
Centromyrmex bequaerti	–	L1, G	–
Centromyrmex sellaris	L2, G	–	–
Discothyrea sp. 01	L2	L1, L2	L1, L2
Discothyrea sp. 03	L1, L2	L1, L2	L1
Hypoponera sp. 01	L1	L1, L2, G	L1, L2
Hypoponera sp. 02	L2	–	–
Hypoponera sp. 03	L1, L2, G	L1, L2	L1, L2, G
Hypoponera sp. 04	–	L1, L2, G	L1, L2, G
Hypoponera sp. 06	–	G	–
Leptogenys amon	–	L1	–
Leptogenys bubastis	L1	–	–
Leptogenys camerunensis	P	–	–
Leptogenys conradti	L1, G	–	–
Leptogenys occidentalis	L1, L2	L1, L2, G	L1, L2
Leptogenys sp. 05	–	L1	–
Leptogenys sp. 07	L1, L2	–	–
Loboponera basalis	L2	–	–
Loboponera vigilans	G	–	–
Odontomachus assiniensis	P	L1, L2, P, G	L1
Odontomachus troglodytes	L2, G, Y	–	P
Pachycondyla ambigua	L1, L2	L1	L1, L2

Species	110 m	375 m	640 m
Pachycondyla cattvaria	L1, L2	L1, L2	L1, L2
Pachycondyla cf. sharpi	L1, L2, G	L1, L2	L1, L2
Pachycondyla pachyderma	P, Y	L1, L2, G	L1, L2, P, G, Y
Pachycondyla sjostedti	L1, G	G	G
Pachycondyla tarsata	L1, L2, L, P, Y	L2, P, Y	L1, L2, P, Y
Pachycondyla sp. 01	L1, L2, P	L1, P, G	L1, P, G, S
Pachycondyla sp. 02	–	L1	L1, L2
Pachycondyla sp. 03	–	L1, L2	L1, L2
Pachycondyla sp. 04	L1, L2	L1, L2	L1, L2
Phrynoponera bequaerti	L1, L2, G	L1, L2	L1, L2, P,
Phrynoponera gabonensis	L1, L2, P	L1, P	L1, P, Y, Y
Phrynoponera heterodus	P	L1, L2, P	L1, L2, P
Phrynoponera sveni	G	–	–
Platythyrea conradti	G	–	–
Platythyrea gracillima	–	G	–
Platythyrea modesta	M	–	M, S
Plectroctena minor	G	–	–
Plectroctena ugandensis	G	–	–
Prionopelta sp. 01	L2	L1, L2	L1, L2
Prionopelta sp. 02	–	L2	L1, L2
Prionopelta sp. 03	–	–	L2
Probolomyrmex sp. 01	L1, L2	L1, L2	L2
Psalidomyrmex procerus	–	G	L1
PSEUDOMYRMICINAE			
Tetraponera aethiops	–	P, G	–
Tetraponera anthracina	G, S	–	–
Tetraponera cf. liengmei	–	–	S
Tetraponera mocquerysi	G, S	–	–
Tetraponera ophthalmica	M	–	–
Tetraponera sp. 03	S	–	–

TABLE 2. Complementarity and species turnover between the three elevational zones based on all methods sampled in Monts Doudou. The Marczewski-Steinhaus (M-S) complementarity measure is above the diagonal and Harrison index of Beta diversity is below. Higher values represent greater distinctness (M-S) or turnover (Beta). The number of species shared between elevations is presented in parentheses.

Elevation	110 m	375 m	640 m
110 m (210 spp.)	–	0.489 (141)	0.505 (138)
375 m (206 spp.)	0.308	–	0.415 (152)
640 m (206 spp.)	0.322	0.262	–

Measures of species turnover (beta) and distinctness (M-S) between elevations were very similar overall (Table 2). The 110-meter and 640-meter sites had the greatest species turnover (beta) and distinctness (M-S), while the 375-meter and 640-meter sites had the lowest (Table 2).

The two litter transects at 110 m, which were located 16.4 km apart, did not have the greatest distinctness and species turnover (M-S) compared to transects located closer than 1 km at 375 m and 640 m (Table 3). Transects at 640 m had the lowest distinctness and turnover.

Leaf litter samples captured the greatest number of species at each elevation followed by sweeping (Table 4). Yellow pan, pitfall and Malaise traps collected the fewest species.

Based on the collecting protocols employed in this study, the optimal sequence of collecting methods to maximize species capture is listed in Table 5. Litter + Sweeping + 2nd transect of Litter sampling was the most productive sequence of methods at all elevations. The next most productive was beating and general collecting but their rank changed with elevation.

TABLE 3. Complementarity and species turnover between the two 50-sample leaf litter transects at each elevation. Higher values represent greater distinctness (M-S) or turnover (Beta).

	110 m	375 m	640 m
Number species shared	70	80	84
M-S	0.466	0.491	0.387
Beta	0.260	0.283	0.181
Total number species	131	154	137

TABLE 4. Number of species collected in Monts Doudou by each collecting method at each elevation. Numbers of species unique to each elevation are in parentheses.

	Elevation		
Method	110 m	375 m	640 m
Litter sifting: transect 1	104	120	105
Litter sifting: transect 2	97	114	116
Sweeping	71	56	56
General collecting	44	47	36
Beating	32	42	38
Matlaise traps	14	19	21
Yellow pan traps	20	21	12
Pitfall traps	10	14	12
All methods	210 (50)	206 (31)	206 (34)

TABLE 5. Optimal order of methods to capture the greatest number of species for each elevation, based on the 8 methods used in this survey. The cumulative number of species captured is in parentheses. L1, L2 = leaf litter sifting transects; B = beating; S = sweeping G = general collecting (G). Yellow pan traps, Malaise, and pitfall added very few new species.

Elevation	Method
110 m	L1 (104)+ S (157) +L2 (177) + G (190) + B (200)
375 m	L1 (120)+ S (158) + L2 (177) + B (191) + G (199)
640 m	L1 (105)+ S (141) + L2 (177) + B (188) + G (200)

The analysis of redundancy clearly shows a division in methods to either capture species living or foraging on the ground or soil versus species foraging and nesting above ground (Table 6). Leaf litter, pitfall and yellow pan traps formed one group with high redundancy that captured the ground assemblage, while sweeping, beating and Malaise traps had high redundancy and captured the arboreal assemblage. General collecting was more redundant with the methods that captured the ground community than with methods that trapped the arboreal community. Of note was that even though the two leaf-litter transects conducted at each elevational zone were highly redundant (R = 0.695–0.722), the second transect still captured a greater number of new species than all less redundant methods except sweeping (Table 5, 6).

DISCUSSION

Species richness

The 310 species of ants recorded in Monts Doudou represent the greatest ant species richness yet recorded for a single region on the continent. In Tanzania, Robertson (1999) recorded 232 species, and in Ghana Belshaw and Bolton (1994) recorded 176 species, whilst Room recorded 128 species (Room 1971). The species count from Monts Doudou is also greater than any locations surveyed in Madagascar (Fisher 1996, 1998, 1999a, 2002; Fisher and Robertson 2002). The highest recorded species richness in Madagascar was 215 species at the Anjanaharibe-Sud Reserve in northeastern Madagascar (Fisher 1998). A comparison between 50-sample, leaf litter transects on Monts Doudou and low elevation sites in Madagascar (25–1240 m) also shows greater richness in Gabon than in Madagascar. In this study, the average number of species captured in a 50-sample, leaf litter transect in Gabon was 109.3 species (SD ± 8.7, N = 6) while in Madagascar an average of 80.3 species were captured in a similar area. (SD ± 16.2, N = 12).

The recorded species richness on Monts Doudou, however, is inferior to inventories conducted in the wet tropics in Central America, South America, and in southeast Asia. Longino and colleagues (2002) reported 437 species from La Selva Biological Station, Costa Rica. Brühl and colleagues (1998) found 524 species in Kinabaloo National Park, Borneo. Verhaagh (1990, 1991) reported 520 species in Panguana Reserve, Peru. All of these inventories employed a complement of collecting methods and strongly suggest that the wet forest in Africa has lower ant diversity than similar habitat in Southeast Asia and the New World. Future work comparing studies that include measures of inventory completeness will be necessary to confirm this preliminary result.

TABLE 6. Redundancy of quantitative methods used to capture the same portion of the fauna. See text for explanation of redundancy index (R). Higher values represent greater redundancy. Leaf litter sifting transects (L1, L2), beating (B), pitfall traps (P), general collecting (G), sweeping (S), yellow pan traps (Y), and Malaise traps (M).

(a) Elevation 110 m (above diagonal) and 375 m (below)

	L1	L2	B	P	G	S	Y	M
L1	–	0.722	0.250	0.300	0.409	0.254	0.500	0.286
L2	0.702	–	0.219	0.400	0.455	0.183	0.550	0.214
B	0.310	0.333	–	0.200	0.219	0.594	0.250	0.357
P	0.500	0.429	0.143	–	0.100	0.200	0.400	0.100
G	0.702	0.596	0.214	0.357	–	0.295	0.350	0.357
S	0.321	0.214	0.571	0.286	0.255	–	0.400	0.786
Y	0.714	0.714	0.238	0.214	0.429	0.429	–	0.286
M	0.158	0.316	0.474	0.214	0.158	0.737	0.211	–

(b) Elevation 640 m

	L1	L2	B	P	G	S	Y	M
L1	–	0.695	0.237	0.500	0.382	0.357	0.833	0.429
L2		–	0.158	0.417	0.412	0.179	0.750	0.286
B			–	0.000	0.088	0.526	0.417	0.286
P				–	0.417	0.167	0.250	0.167
G					–	0.294	0.167	0.143
S						–	0.500	0.524
Y							–	0.167

Productive methods

The survey on Monts Doudou is the most thorough inventory conducted in Africa to date. The high species richness of this study is due in part to the variety of methods used to capture ants. Every method employed captured additional species. A critical issue associated with invertebrate inventories is determining which method and sampling design is the most efficient. As reported in other studies (Fisher 1999b; Fisher and Robertson 2002), litter sifting captured the most species. Based upon the number of species captured, Malaise, yellow pan, and pitfall were the least productive methods. Sweeping is rarely used in ant inventories but these results suggest that it should be included to complement litter sampling. Sweeping also collected rare ants such as *Santschiella kohli* (Fig. 1), which had yet to be recorded in Gabon.

Elevational variation

Elevation had no measurable effect on species richness and composition. In studies in Madagascar (Fisher 1996, 1998, 1999a, 1999b, 2002) along an elevational gradient from approximately 25 m to 2,000 m, species richness peaked at mid-elevation (800 m) and declined rapidly after 1,200 m. In addition, these studies in Madagascar showed distinct montane and lowland ant assemblages. The results from this study suggest that Monts Doudou does not have a unique mountain ant fauna at the 640-meter site. Mountains with higher elevation such as Monts Cristal, which reaches just over 1,000 m, should be investigated for possible montane elements in Gabon.

FIGURE 1. *Santschiella kohli*, a rare species, collected by sweeping at 375 m.

There is limited information on the distribution pattern of ants in the Congo Basin. Thanks to the recent work of Bolton (2000) there is one diverse group, the tribe Dacetonini, which has been sufficiently documented to permit an evaluation of the uniqueness of the ant fauna on Monts Doudou. The Dacetonini (*Microdaceton*, *Pyramica*, and *Strumigenys*) on Monts Doudou comprised 36 species, all but two of which have previously been recorded from Gabon or in neighboring countries and have broad distribution ranges across the western Congo Basin.

The 110-meter zone was the only site surveyed that showed signs of habitat disturbance. This site was selectively logged for a few species. This activity seemed to have little effect on the ant fauna in the areas surveyed. Along the roads that were established to extract logs, however, the invasive exotic ant *Wasmannia auropunctata* was seen. It is possible that with time, this invasive ant will penetrate the forest away from the road edges. *Wasmannia auropunctata* was first recorded in Gabon in 1914 in Libreville, Gabon (Santschi 1914) and has recently been recorded from réserve de la Lopé (Wetterer et al. 1999).

Inventories are a crucial step in the conservation process and provide the baseline documentation of species and their natural occurrence. Patterns of species richness, turnover, and endemism are three criteria for conservation assessment that require knowledge of species' spatial distributions. There are arguments to base conservation decisions on alternative criteria (such as threat or uniqueness of habitat or ecosystem), but there is still a critical need to define areas of high endemism and species richness if the maximum diversity is to be preserved. The best sustainable management decisions are based on thorough knowledge of the inhabitants to be conserved. Accurate environmental information is important for land management in Gabon and this requires taxonomic knowledge. We must continue to develop the taxonomic capacity of African scientists to ensure that baseline biodiversity data is available for sound conservation and sustainable use planning.

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Leptogenys; Brian Heterick identified *Pheidole* and *Monomorium*; Helian Ratsirarson sorted *Tetramorium*; Rudy Kohout identified *Polyrhachis*; and Philip Ward identified *Tetraponera*.

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