

Review Article

Ants as Indicators in Brazil: A Review with Suggestions to Improve the Use of Ants in Environmental Monitoring Programs

Carla R. Ribas,¹ Renata B. F. Campos,² Fernando A. Schmidt,³ and Ricardo R. C. Solar³

¹Laboratory of Ant Ecology, Sector of Ecology, Department of Biology, Federal University of Lavras, 37200-000 Lavras, MG, Brazil

²Institute of Education of Divinópolis, Educational Foundation of Divinópolis, 35501-170 Divinópolis, MG, Brazil

³Post-Graduate Program in Entomology, Department of Entomology, Federal University of Viçosa, 36570-000, Viçosa, MG, Brazil

Correspondence should be addressed to Carla R. Ribas, crribas@gmail.com

Received 31 May 2011; Revised 11 August 2011; Accepted 16 August 2011

Academic Editor: Jonathan D. Majer

Copyright © 2012 Carla R. Ribas et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

We describe the use of ants as indicators in Brazil, based on a critical review of published articles. The analysis of fifty-eight papers, encompassing a range of almost 25 years, indicates an increased number of studies using ants as indicators in the last decade. Among the parameters analyzed in the papers, species composition is the most suitable to evaluate the effect of the disturbance on ant communities. The use of other metrics that consider the specificity and fidelity (e.g., IndVal index) of ant species to a level or state of disturbance is also highly desirable. We discuss several alternative ways of overcoming many of the drawbacks related to the robustness of the results and to reduce the financial, logistic, and time costs involved with the use of ants as indicators in monitoring programs. By doing so, we expect to encourage new research on ants as bioindicators as well as to summarize current knowledge, facilitating further research.

1. Introduction

Intensive exploitation of natural resources and the resulting impacts on pristine habitats have led to calls from the scientific community and the general public to measure or monitor the level of these environmental impacts [1–3]. Bioindicators are a useful way to evaluate such impacts, since changes in their population dynamics or community parameters can indicate an environmental state more easily, quickly, and safely and with lower financial and labour inputs than direct measurements [4–6].

McGeoch [7] divided the general use of the term bioindication into three categories according to the three main applications: (i) environmental indicators: used to detect or monitor changes in the environmental state, (ii) ecological indicators: used to demonstrate the impact of an environmental stress on the biota or monitor longer-term stress-induced changes in the biota, and (iii) biodiversity indicators: used to identify the diversity of a taxa in a specified area or to monitor changes in biodiversity.

Therefore, there are several characteristics that an indicator species must have, the most notable being ease of measurement, sensitivity to environmental stress, and predictable responses to environmental stress [4, 8]. The use of certain species or groups of species as indicators of successful rehabilitation practices or for environmental monitoring has been recommended in recent years (e.g., [5, 6, 9]).

Ants have been used as a powerful tool in several ecological studies [10, 11]. This group has useful characteristics for successful indication and monitoring of environmental impacts, including widespread distribution, high abundance, importance in ecosystem functioning, ease of sampling, and relatively well-known taxonomy and ecology [12].

Thus, ants have been used as indicators of several environmental impacts, such as fire, deforestation and logging, agricultural intensification, mining, and urbanization [13, 14]. The first study suggesting the use of ants as indicators was in the early 1980s [15], and the use of ants as indicators is now widespread in Australia (e.g., [16–19]) and is becoming

a major focus of myrmecological research worldwide (e.g., [20–25]).

Although ants are a simple, cheap, and powerful indicator of environmental impacts and rehabilitation (e.g., in Australia [17]), in Brazil, a country which harbours enormous diversity and complexity of habitats, the standard use of ants as indicators is still relatively new and should be evaluated in greater detail (see [26, 27]). According to Philpott et al. [14] and Gardner [6], a critical need is the selection of ant species that are affected by distinct types of disturbance in different regions, in order to guarantee their usefulness as good indicators.

Therefore, as we described above, given the international use of ants as indicators, several studies have investigated the use of ants as indicators in Brazil. In order to describe the background of bioindication with ants in Brazil, we carried out a critical review of several studies concerned directly or indirectly with the use of ants as indicators.

Using the three categories proposed by McGeoch [7], environmental, ecological, or biodiversity indicators, we describe the historical development of ants as indicators and evaluate the implications of these studies. Additionally, we highlight ways of overcoming the major challenges to the widespread use of ants as tools in environmental monitoring programs.

2. Methods

We searched for papers regarding ants as indicators, restricting our search to those carried out in Brazil. To encompass a broad time range of papers, we used the following keywords in Portuguese and English, respectively: “formiga,” “ant,” “indicador,” “bioindicador,” “indicator,” “bioindicador,” “Brasil,” “Brazil,” and the combination of the words cited above in the Scielo and in the ISI Web of Knowledge websites. We also used papers from our personal archives, gathered under several keywords.

In all papers, we accessed the following information: the language, the general idea of the paper (i.e., descriptive, a general survey, a test of correlations or hypotheses), if the paper specifically analyzed ants as indicators; the aims; the ant sampling methodology, the parameters of ant fauna which were analyzed (i.e., diversity, composition, population dynamics), the environmental parameters which were observed, the results which were obtained, and the main conclusion reached in the study.

We define the paper as specifically analyzing ants as indicators if it explicitly declared this intention in the aim or the introduction (Explicit indication papers). However, if this criteria was not clear but the article still analyzed ants as indicators, we defined these as “Implicit indication papers.” Papers in which the major aim was not the use of ants as bioindicators, but which presented results that could potentially enable the use of ants as indicators, were considered as “Potential indication papers.” Finally, papers that did not meet any of the above criteria, that is, did not mention in any way the use of ants as indicators, or with results that could not be used to evaluate ants as indicators, were considered as “Indirect bioindication papers.”

The disturbances or aims investigated in the papers were split into the categories “Agriculture,” “Vegetation type,” and “Human land-use,” according to the habitats studied, namely: habitats with agricultural activities only, habitats with natural vegetation only, and habitats with both agricultural activities and natural habitats. Similarly, “Succession” studies were those investigating natural succession, and “Restoration” studies were those evaluating different rehabilitation techniques, such as succession following managed restoration efforts.

We used McGeoch [7] as a reference to decide if the ants were used as environmental, ecological, or biodiversity indicators in the reviewed papers (see McGeoch’s [7] definition in the introduction section). Moreover, we defined ant species as indicators when there was a species list in the paper showing the occurrence of ants in specific sites or when the author considered the ant species to be an indicator elsewhere in the paper. If the ant species occurred in just one habitat, we considered the species to be an indicator of the specific habitat.

We verified the most frequent responses of ants to disturbance, summarizing responses, and relating the most frequent responses to the most frequently used sampling methodologies to determine if there were any trends. To study this relationship, we considered only methodologies that had been used in at least three papers.

3. Results

We analyzed 58 papers, which encompassed a span of almost 25 years (from 1987 to 2010). Among the papers, only one was not classed as an “indication paper” or “Potential indication paper” [83]. The others specifically mentioned the intention to use ants as indicators (either explicitly, using the word “indicator,” or implicitly, using ants as a tool or model to indicate the ecological and environmental parameters) (38 papers) or at least have the Potential to do so (17 papers) (Table 1). Two papers [84, 85] were not included in the table because the scope of the papers was not to analyse ants as indicators but to suggest new tools to simplify their use as indicators.

From the 58 papers, exactly half (29) were published in English and the other half in Portuguese. Among the “Potential indication papers,” 11 were published in English and six in Portuguese, while among the “indication papers” the number of papers written in Portuguese (22) was higher than the papers written in English (18).

Papers directly concerned with the use of ants as bioindicators began almost 10 years after the development of “Potential indication papers”, in which the main focus was the response of ant communities to several disturbances (e.g., logging and land use). Only in the last decade has there been a positive trend of papers using ants as model organisms for bioindication in Brazil (Figure 1).

Regarding ant sampling procedures, 34 studies used only a single sampling method: 14 used two, six used three, and four opted for more than three methods. The methodologies used to capture ants were baits, beating, Berlese extraction,

TABLE 1: Papers reviewed regarding ants as indicators in Brazil, indicating the main disturbance investigated (Disturbance), the aim of the paper (Aim), if the paper was explicitly, implicitly or has the Potential to be used in indicator studies (Indication), the environmental parameters analyzed/sampled (Environmental parameters), the responses of ant community to disturbance that were found to be significant (Effects on ant community), the indicator type used (Indicator type) and the paper (Reference).

Disturbance	Aim	Indication	Environmental parameters	Effects on ant community	Indicator type	Reference
Agriculture	Evaluate the effect of different soil tillage and crop management systems on soil fauna groups	Yes (implicit)	Soil tillage and crop management systems	Change in species dominance (discriminant and correspondence analysis)	Environmental	Baretta et al. [28]
Agriculture	Evaluate the ant diversity in fig crops under different managements	Yes	Types of soil cover plants	Change in density of species ($P < 0.05$, Tukey test)	Environmental	Merlim et al. [29]
Agriculture (forestry practices in <i>Eucalyptus</i>)	Use the ant guild concept to evaluate changes in <i>Eucalyptus</i> plantations following control of leaf-cutting ants	Yes	Forestry practices	Change in species composition—observed frequency of species and guilds (non-statistical test)	Environmental	Lacau et al. [30]
Agriculture (preceded by deforestation and fire)	Assess the recolonization by fauna in areas cleared and burned to plant corn and beans	Yes	Human land-use and resting time	Increase in abundance in the less-disturbed areas (non-statistical test)	Environmental	Nunes et al. [31]
Agriculture (formicid granulated baits)	Evaluate the effect of different applications of formicide baits on nontarget ant community	Yes	Forms and timing of application of formicid-granulated baits	No effect of bait type on ant species richness ($P > 0.05$, ANOVA) Reduction in species richness observed only in control method, systematic application being more harmful ($P < 0.05$, ANOVA)	Environmental	Ramos et al. [32]
Anthropogenic activities	Quantify heavy metals in worker ants of <i>Camponotus rufipes</i> collected in different environments	Yes	Observed human interference	Three groups of ants with different heavy metal concentrations (PCA analyses)	Environmental	Silva et al. [33]
Conservation status	Create an inventory of epigeic ant species that occur in vine forest and use them to indicate the level of conservation of this ecosystem	Yes	None	Inventory (nonstatistical test)	—	Carvalho et al. [34]
Conservation status	Verify the impact of human use in mangroves	Potential	Observed levels of human use	Reduction on species richness ($R^2 = 0.53$, $P = 0.007$)	Environmental	Delabie et al. [35]
Conservation status	Inventory the ant community in the Baturité hills	Yes	None	Inventory (nonstatistical test)*	—	Hites et al. [36]
Conservation status	Study the ant communities in preserved and impacted savanna sites	Yes	Observed human interference	Reduction of diversity in impacted sites ($F = 101.62$, $P < 0.0001$)*	Environmental	Ramos et al. [37]
Fire	Test the negative effect of fire in <i>Restinga</i> environments on the ant community	Potential	Presence of fire	Increase in species richness with presence of fire (mean and confidence intervals of estimated species richness)	Environmental	Endringer et al. [38]

TABLE 1: Continued.

Disturbance	Aim	Indication	Environmental parameters	Effects on ant community	Indicator type	Reference
Fire	Test the hypothesis that ant species richness and composition change after burning sand dunes	Yes	History of fire	More ant species and distinct species composition in the unburned area (non-statistical test)	Environmental	Teixeira et al. [39]
Fragmentation	Verify the responses of ants nesting in twigs in the litter layer to habitat changes associated with forest fragmentation	Potential	Distance to forest edge, remnant isolation, leaf-litter depth, density of dead twigs, and vegetation (three parameters measured)	Higher species richness ($F = 8.56$, $P = 0.006$); most ant species had greater nest densities in continuous areas than in remnants, change in species composition ($F = 8.14$, $P = 0.001$) with forest edge	Ecological	Carvalho and Vasconcelos [40]
Fragmentation	Determine the effect of forest fragmentation on ant communities	Yes	Remnant area, distance to forest edge, vegetation cover of matrix, and vegetation (three parameters measured)	No effect of many fragment characteristics on ant species richness: area ($F = 8.22$, $P = 0.77$), distance core-border ($F = 64.86$, $P = 0.42$). Only tree density had an effect ($F = 46.30$, $R^2 = 23.32$, $P = 0.02$)	Ecological	Gomes et al. [41]
Fragmentation	Know the community of ants in forest fragments	Yes	Remnant area	No change in species richness with remnant area ($R^2 = 0.02$, $F = 0.22$, $P = 0.64$)*	Environmental	Santos et al. [42]
Forestry systems	Describe the epigeic ant communities in <i>Eucalyptus</i> plantations	Yes	<i>Eucalyptus</i> age	No change in species richness with <i>Eucalyptus</i> age ($P = 0.58$)	Environmental	Fonseca and Diehl [43]
Human land-use	Compare the ant community structure between a crop and a secondary forest	Potential	Land use	Reduction of diversity and equitability and change in species composition (non-statistical test)	Environmental	Castro and Queiroz [44]
Human land-use	Compare the impact of different agroecosystems on ant species richness	Yes	Land use	Higher species richness in forest edges and pasture (non-statistical test); coffee crop presented reduced estimated richness ($h = 10.85$, $P > 0.05$)	Environmental	Dias et al. [45]
Human land-use	Survey of ant and termite fauna in four patches with different vegetation structures and in one open field	Potential	Land use	Change in species richness and composition (non-statistical test)	Environmental	Diehl et al. [46]
Human land-use	Test the effects of <i>Restinga</i> soil characteristics on ant communities	Yes (implicit)	Land use, physical and chemical soil properties, and microbial activity	Change in species richness (non-statistical test) and composition (canonical correspondence analysis)	Ecological	Gomes et al. [47]
Human land-use	Elucidate ant species richness and community structure associated with the micro basin of Sanga Caramuru-Chapeçó	Yes	Habitat type, temperature, and rainfall	Change in species composition (Bray-Curtis Cluster Analysis indicated higher similarity for disturbed areas) and higher richness (observed and estimated) in the native area (sample-based accumulation curves)*	Environmental	Ilha et al. [48]

TABLE 1: Continued.

Disturbance	Aim	Indication	Environmental parameters	Effects on ant community	Indicator type	Reference
Human land-use	Determine the level of similarity of ant communities in forest areas (three native forest remnants) and an <i>Eucalyptus</i> reforestation	Yes	Land use	Change in species composition (Jaccard index— $C_j = 0.29 \pm 0.02$ among <i>Eucalyptus</i> crops versus forest remnants and $C_j = 0.40 \pm 0.06$ among forest remnants)	Environmental	Lapola and Fowler [49]
Human land-use	To inventory the ant fauna in a Cerrado area and in <i>Eucalyptus</i> plantations with five classes of understory ages	Yes	Eucalypt age	Higher density of species in Cerrado areas than in <i>Eucalyptus</i> (non-statistical test) and estimated species richness similar between areas ($h = 1.6, P > 0.05$)	Environmental	Marinho et al. [50]
Human land-use	Investigate the effect of structural characteristics of the environment on ant communities	Yes	Habitat type	Change in species richness and composition (non-statistical test)	Environmental	Santana-Reis and Santos [51]
Human land-use	Test the hypotheses that there was a decrease in ant species richness and a change in the species composition in habitats with more intense soil use	Yes	Land use	Sites with distinct soil use host a differential ant species composition (cluster analysis-Euclidean distance)	Environmental	Schmidt and Diehl [52]
Human land-use	Evaluate the effect of collection time (day and night) on ant fauna attracted to baits in areas of <i>Eucalyptus cloeziana</i> (Myrtaceae) and Cerrado (savanna vegetation)	Potential	Land use	Collection time effect was more important to ant fauna structure than the vegetation effect (ordination analyses)	Environmental	Tavares et al. [53]
Human land-use and succession	Compare ant diversity under different land-use systems	Yes	Land use and age of succession	Change in density of species (non-statistical test), species richness (sample-based accumulation curves and χ^2), and composition (cluster analysis)*	Environmental	Braga et al. [54]
Inundation	Document the ant fauna in three different forest types (one annually inundated and two on terra firme)	Potential	Vegetation (several parameters measured)	Change in diversity, similarity, and proportion of different nesting and feeding habitats (non-statistical test)	Ecological	Majer and Delabie [55]
Logging	Test the hypothesis that logging affects forest ant fauna by reducing the species richness and changing the composition of ground-foraging ant communities	Yes	Canopy openness, abundance of understory vegetation, and leaf-litter depth	Change in species composition proportion of <i>Pheidole</i> was reduced from 21.4% and 26% in unlogged forest and low-impact logging, respectively, to 14.8% in high-impact logging ($F = 4.99, P < 0.05$)	Ecological	Kalif et al. [56]

TABLE 1: Continued.

Disturbance	Aim	Indication	Environmental parameters	Effects on ant community	Indicator type	Reference
Mining	Determine the levels of heavy metals in plants and identify soil organisms of the mesofauna that could be biological indicators of soil quality	Yes	Physical and chemical soil properties and heavy metal content	Decrease in abundance and increase in lead (Pb) accumulation (non-statistical test)	Environmental	Barros et al. [57]
Mining	Ant fauna survey and community structure, analyses of the ground-dwelling ants in native vegetation and areas with different inferred copper levels	Yes	Areas with different inferred copper levels	Decrease in species richness with inferred copper levels (non-statistical test)	Environmental	Diehl et al. [58]
Restoration (agriculture)	Investigate the recolonization profile of the restored Atlantic Forest	Yes	Age after planting	Increase in species richness ($P < 0.05$, ANOVA) and change in species composition (ANOSIM, $P < 0.01$)*	Environmental	Pais and Varanda [59]
Restoration (anthropogenic disturbance)	Test the hypothesis that ant fauna is closely related to the structural complexity of habitat	Yes	Age of restoration	Change in species composition (non-statistical test)	Environmental	Coelho et al. [60]
Restoration (dredging disturbance)	Evaluating ant bioindication of impacted habitats	Yes	Time since restoration, distance from the impact, and physical properties of soil	Change in species richness: higher in cerrado than in the restoration habitats, and also higher in the ecotone and intermediate zones than on the beach ($F = 3.95$, $P < 0.05$) and change in abundance ($F = 1.9$, $P < 0.046$) and composition (non-statistical test)	Environmental	Costa et al. [61]
Restoration (mining)	Investigate which ants recolonized reclaimed areas in subtropical regions and evaluate the effect of different rehabilitation techniques, comparing results with Australia	Yes	Age of rehabilitation, soil penetrability, number of logs, litter and vegetation measures (three and five parameter, resp.)	Increase in species richness (non-statistical test) and change in composition (PCoA)	Ecological	Majer [62]
Restoration (mining)	Evaluate the efficacy of rehabilitation procedures in mining sites on facilitating ant recolonization and compare it with other tropical regions and climatic zones	Yes	Age of restoration, soil penetrability, litter depth, percentage of litter, grass, and herb cover, and vegetation (several parameters measured)	Species richness increased in early ages but slowed in late ages and was smaller than control site (non-statistical test). Distinct species composition in sites at early ages, intermediate ages, and control sites (ordination analyses)	Ecological	Majer [63]
Restoration (mining)	Investigate the community structure changes of different rehabilitation techniques	Yes	Rehabilitation technique	Change in species richness (non-statistical test) and composition (cluster analysis)	Ecological	Pereira et al. [64]
Road	Test the hypothesis that dirt roads are favourable landing sites for <i>Atta laevigata</i> founding queens. Analyze the importance of litter cover as a proximate cue in nest-site selection	Potential	Presence of dirt roads	The number of colonization attempts in roads was 5 to 10 times greater than that in the adjacent vegetation ($P < 0.001$)	Environmental	Vasconcelos et al. [65]

TABLE 1: Continued.

Disturbance	Aim	Indication	Environmental parameters	Effects on ant community	Indicator type	Reference
Seasonality	Investigate ant diversity and species composition on an island	Yes	Seasonality	Change in species richness and composition with seasonality (non-statistical test)*	Environmental	Schmidt et al. [66]
Succession	Examine whether secondary forests of the Brazilian Atlantic Forest act as refugia for forest-adapted species	Yes (implicit)	Age of succession and soil type	Richness ($P < 0.001$) and composition ($P < 0.004$) of ant assemblages in secondary forests have recovered slowly and have not approached conditions typical to old-growth forests	Environmental	Bihn et al. [67]
Succession	Examine bait preferences of litter ants along a successional gradient of forest	Potential	Age of succession	Preference of ants for the type of bait changed along the successional gradient ($F = 5.52$, $P = 0.02$). In young successional stages, N baits attracted more ants than CHO baits, whereas in late successional stages, CHO baits attracted more ants	Environmental	Bihn et al. [68]
Succession	Investigate how functional diversity profile changed in a successional gradient	Potential	Age of succession	Increased diversity and change in functional groups (non-statistical test)	Environmental	Bihn et al. [69]
Succession	Verify patterns in the structure of ant communities along a successional gradient	Potential	Age of succession	Increased diversity and equitability (non-statistical test)	Environmental	Castro et al. [70]
Succession	Compare ant diversity among sites in different successional stages	Potential	Age of succession	Higher diversity in intermediary stage and change in composition (non-statistical test)	Environmental	Leal et al. [71]
Succession	Compare the diversity and composition of tree-dwelling ants in different successional stages of a seasonal deciduous forest	Potential	Age of succession	Increase in species abundance ($F = 9.26$, $P = 0.003$) and change in species composition (PCA analysis)	Environmental	Neves et al. [72]
Succession	Compare the ant species diversity related to successional stage and seasonality	Yes	Age of succession, tree richness and density	Change in species composition (DCA deterrent correspondence analysis, $P < 0.001$)	Ecological	Neves et al. [73]
Succession	Evaluate the long-term effect of fire on ant species richness	Potential	Presence of fire 15 years before	Change in species composition (cluster analyses-Euclidean distance)	Environmental	Santos et al. [74]
Succession	Assess the changes in species richness and composition between relatively pristine habitat and along a forest regeneration gradient	Yes	Age of succession	Increase in species richness (sample-based accumulation curves) and distinct species composition between pristine area and areas at regeneration (ANOSIM, $R = 0.79$, $P < 0.001$)*	Environmental	Silva et al. [75]
Succession	Compare the structure of the ground ant communities in areas at different levels of restoration	Yes	Age of succession	Increase in species richness ($F = 5.1$, $P = 0.01$) and decrease in abundance ($F = 8.1$, $P < 0.001$), change in species composition (ordination analysis)	Environmental	Vasconcelos [76]

TABLE 1: Continued.

Disturbance	Aim	Indication	Environmental parameters	Effects on ant community	Indicator type	Reference
Succession	Determine experimentally the effects of selective logging on ground-living ants	Yes	Logging age, canopy cover, litter depth, and understory density	Species richness, evenness, and abundance per plot did not vary among treatments ($P > 0.05$). Most of the species found in the control plots were also present in the logged plots	Ecological	Vasconcelos et al. [77]
Urbanization	Compare the thermal tolerances of leaf-cutter ants (<i>Atta sexdens</i>) from colonies inside and outside an urban area	Potential	Temperature	Urban ants support higher temperatures better than rural ones, which present higher rates of mortality ($\beta = 20.54.237$, $P = 0.02$)	Environmental	Angilletta et al. [78]
Vegetation type	Inventory ants	Yes	Habitat type	Change in species richness (non-statistical test)*	Environmental	Diehl et al. [79]
Vegetation type	Test how the diversity of one taxa can be a good surrogate of all diversity	Yes	Habitat type	Correlation with other taxa (Pearson correlation coefficients)	Biodiversity	Leal et al. [80]
Vegetation type	Compare ant diversity in three different forest stages (primary, reforestation, and secondary)	Potential	Habitat type	Change in diversity and exclusive species (non-statistical test)*	Environmental	Lopes et al. [81]
Vegetation type	Compare the ant fauna from forests and nearby patches of savanna (Cerrado) in the Brazilian Amazon. Assess whether there is a difference in the fauna between the ground and lower vegetation strata in both habitats	Potential	Habitat type	Forests host twice as many species as savanna (sample-based rarefaction curves). In both habitats, the ground hosted more species than vegetation ($P < 0.005$). Distinct species composition between forest and savanna and between ground and vegetation within the same habitat; ant species fidelity and specificity is given by IndVal (see Table 2)	Environmental	Vasconcelos and Vilhena [82]

* papers with sample-based accumulation curves.

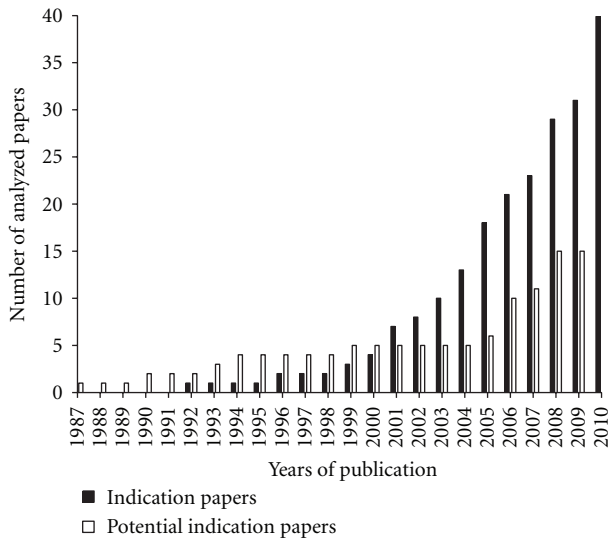


FIGURE 1: Trend of the number of analyzed papers regarding ants as indicators in Brazil. Indication papers—paper specifies (explicitly or implicitly) the intention of analyzing ants as indicators in the aim or introduction. Potential indication paper—the above criteria was not met, but the paper presents results that could potentially enable the use of ants as indicators.

hand collecting, pitfall traps, sweeping, Tretzel traps and Winkler's extractors. Among these methodologies, the most commonly used were baits (used in 26 studies), followed by hand collecting, pitfall traps and Winkler's extractors (used in 20 studies each), and Berlese extraction (used in five studies).

The majority of studies sampled ants at the soil surface (44), but some studies also considered the soil surface together with other habitats, including litter (10), vegetation (7), combination of the above (6). Some other studies did not sample ants at the soil surface, but only in the litter (11), vegetation (two), or in twigs (one), respectively.

The main impacts studied were succession (12), human land-use (11), restoration (6), and agriculture (5). Just a few papers (13) analyzed other environmental parameters besides disturbance (Table 1).

The parameters of the ant faunas that were most commonly related to the disturbance type were ant species richness or diversity indexes (42) and species composition (35) (Table 1). In these papers, if we considered only those that analyzed ant species diversity and composition rigorously (i.e., with statistical tests), the actual number of papers that analyzed ant species diversity decreased to 28, and those that analyzed ant species composition dropped to 22.

Regarding species composition, in 33 papers this parameter was sensitive to disturbance, although if we considered only those papers with statistical analyses, the number decreases to 21. Summarizing the papers that analyze species richness or diversity, the responses found were species richness or diversity increased with disturbance (1), decreased with disturbance (18), changed with disturbance (when there is any clear trend in the response of ants to disturbance) (11),

and not affected by disturbance (12). If we considered only papers that tested ant species richness or diversity statistically, the numbers changed to increase with disturbance (1), decrease with disturbance (11), change with disturbance (5), and not affected by disturbance (11).

By connecting the main responses found in the papers (ant species richness, diversity, or ant species composition) to the main methodologies used to sample ants, we can verify some trends (Figure 2). First, species composition was sensitive to disturbance in the majority of papers in which this parameter was tested, irrespective of the sampling methodology, namely, baits plus hand collecting, multiple sampling methods, or pitfall traps. Second, most papers that analyzed species richness or diversity showed that these metrics were also responsive to disturbance, although the sole use of baits or the Winkler did not show any trend, while only using pitfall traps revealed a positive response of ant species richness or diversity to disturbance. Nevertheless, when we considered only those papers with statistical tests (Figure 3) or without statistical tests (Figure 4), the trend for species composition remained the same, but for species richness the use of multiple methods to sample ants showed a higher number of responses to disturbance.

The ants were used as environmental indicators in the majority of studies (42 out of 55) but were also used as ecological indicators (10 papers) and as biodiversity indicators in only one paper. In 20 papers there was a species list, and; therefore, we could determine some of the ant species that served as indicators of certain habitats. The parameters used in the papers to define a species as an indicator were frequency of ant occurrence (11 papers), presence or absence of ant species (8 papers), and the indicator value (IndVal) (1 paper). Irrespective of the parameter used by the authors, 187 ant species were defined as indicators and linked to specific habitats (Table 2). The genera with higher numbers of indicator species were *Camponotus* (18), *Pseudomyrmex* (12), *Pachycondyla* (11), *Ectatomma* (9), *Gnamptogenys* (9), *Acromyrmex* (8), and *Cephalotes* (8). The sites with the most indicator species were forest (39 species), *Eucalyptus* (37), savanna (34), control or undisturbed sites (nonburnt) (29), primary forest (25), early succession sites (19), disturbed sites (15), secondary forest (14), intermediate succession sites (13), burnt sites, low human land-use-impacted sites and pasture (9), late succession (8), and strong human land-use-impacted sites (5).

4. Discussion

It has been possible to determine the history of research carried out in Brazil by searching for the use of ants as indicators over the last 25 years (Figure 1). From 1987 to 1991, there were only "Potential indication papers." In 1992 the first "Indication papers" were published, which increased in the following years and exceeded the "Potential indication papers" in 2001.

Regarding the idiom of the papers, it is interesting to observe that half of the papers are still published in Portuguese. In spite of the growing internationalization of Brazilian

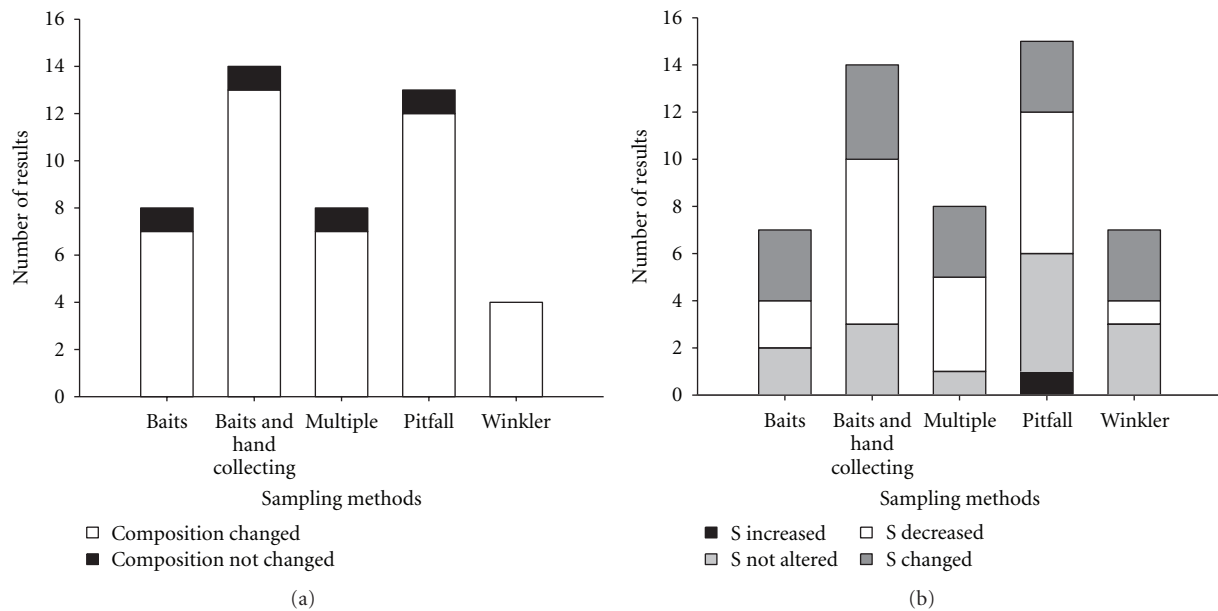


FIGURE 2: Papers that analyzed (a) ant species composition and/or (b) ant species richness/diversity with and without statistical tests and their responses to habitat disturbance through the use of different ant sampling methodologies. Composition changed—species composition altered by disturbance. Composition not changed—species composition not altered by disturbance. S increased—species richness or diversity increased with disturbance. S not altered—species richness or diversity not affected by disturbance. S decreased—species richness or diversity decreased with disturbance. S changed—species richness or diversity changed with disturbance when there is any clear trend in the response of ants to disturbance.

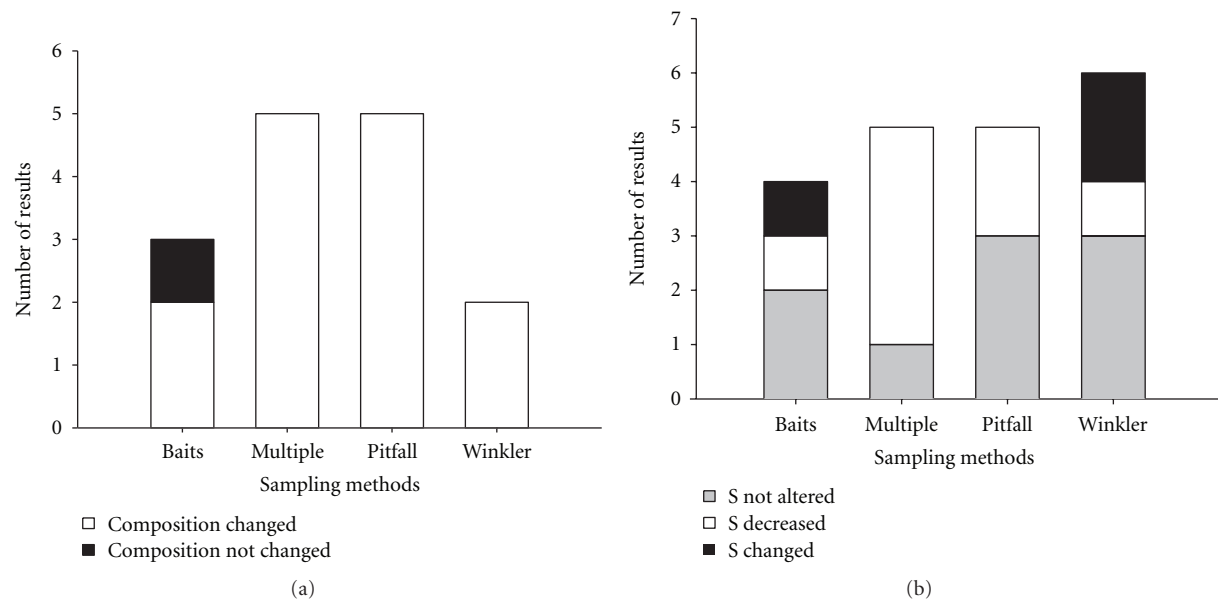


FIGURE 3: Papers that analyzed (a) ant species composition and/or (b) ant species richness/diversity with statistical tests and their responses to habitat disturbance through the use of different ant sampling methodologies. Composition changed—species composition altered by disturbance. Composition not changed—species composition not altered by disturbance. S increased—species richness or diversity increased with disturbance. S not altered—species richness or diversity not affected by disturbance. S decreased—species richness or diversity decreased with disturbance. S changed—species richness or diversity changed with disturbance when there is any clear trend in the response of ants to disturbance.

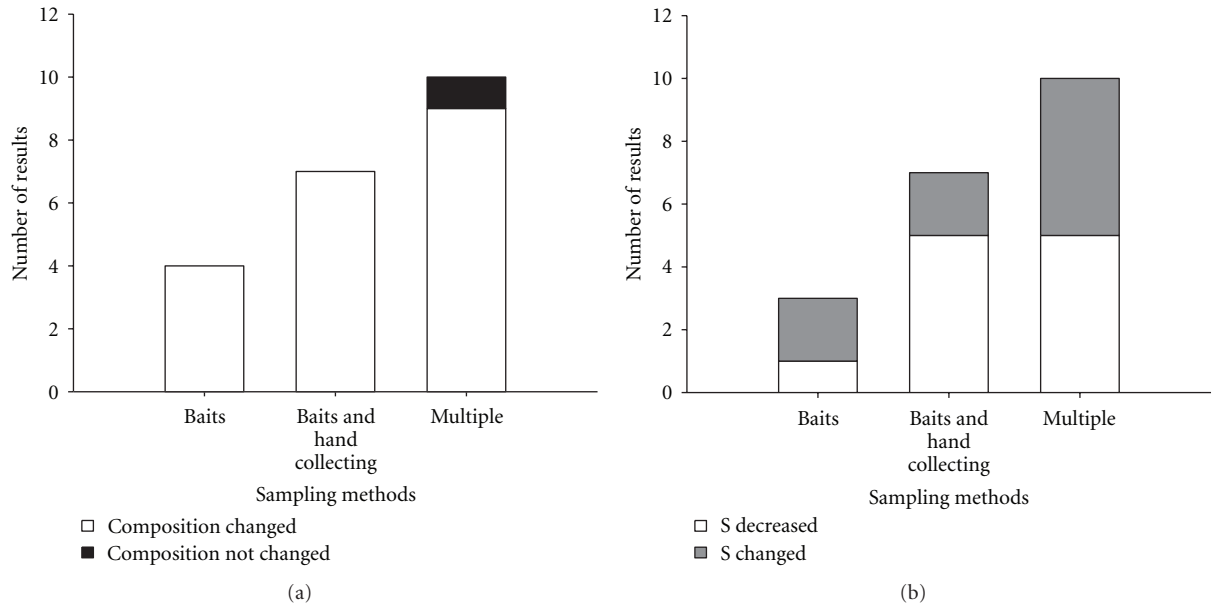


FIGURE 4: Papers that analyzed (a) ant species composition and/or (b) ant species richness/diversity without statistical tests and their responses to habitat disturbance through the use of different ant sampling methodologies. Composition changed—species composition altered by disturbance. Composition not changed—species composition not altered by disturbance. S increased—species richness or diversity increased with disturbance. S not altered—species richness or diversity not affected by disturbance. S decreased—species richness or diversity decreased with disturbance. S changed—species richness or diversity changed with disturbance when there is any clear trend in the response of ants to disturbance.

research [86, 87], many Brazilian studies that use ants as bio-indicators cannot have an international impact since they are in Portuguese. We determined at least two main reasons for this. The first is the “publish or perish” policy in Brazilian (and worldwide) science, which demands the publication of as many papers as possible in the shortest feasible time span, in which case publishing in Portuguese can be a way to speed up publication time. The second explanation may be that, due to problems with the style of writing of the papers, many international journals reject Brazilian papers. Despite these two issues, in this historical scenario, there is an improving and maturing of bioindication studies using ants, which is shown by the explicit use of the term “indication” in these papers. Furthermore, the increasing knowledge exchange with researchers from other countries reinforces the maturation of this area of research. Examples include Brazilian scientists that complete their Ph.D. studies abroad the possibility for doctorate students to undertake international exchange programs, and the internationalization of the Brazilian Symposium of Myrmecology.

However, it is important to clarify that although some authors explicitly used the term indicator in the introduction or in the aim of their papers (our criteria defined these papers as “Indication papers”), the authors did not always in reality use ants as indicators, either because they did not sample properly (i.e., sampling in just one habitat, without different levels of the disturbance/restoration and control sites) or because they did not analyze their results rigorously (i.e., did not include a satisfactory statistical analysis). Conversely, some authors did not use the term indicator in their papers,

but they did test the Potential use of ants as indicators, and were cautious in the above points.

The majority of articles that used ants as environmental indicators (sensu [7]) may be due to the fact that this is the simplest way to detect a change in the environmental state of the habitat but not necessarily the best one. The use of ecological indicators has the advantage of encompassing a broad response as they demonstrate the disturbance effect on the biota, not only for ants [6].

Moreover, the sampling of different environmental parameters and their correlation with the biota is essential, because their inclusion increases the predictive power of the study. If we recognize the environmental parameters that are most sensitive to disturbance and their effect on the biota, we may be able to more accurately monitor the effects of disturbance. Consequently, we may be able to choose the restoration effort according to the most appropriate or effective environmental parameters in order to promote the recovery of the biota [6, 7].

Regarding the number of ant sampling techniques used, although the majority of the papers used only one method, several studies (e.g., [52, 77, 88]) have highlighted the fact that ant communities show a pronounced vertical stratification, and ant faunas specific to each microhabitat may present specific ecological traits and distinct sensitivity to the same environmental impact [67, 89–91]; therefore, more than one sampling method must be considered [13]. On the other hand, the use of several sampling methods increases the financial costs and the time needed to collect, sort, and process the data [13]. Thus, since environmental monitoring

programs usually have short-term goals, it is desirable to balance the benefits and costs of using several types of sampling methods compared to using only one sampling method which could achieve similar reliable results (Figures 2(a) and 2(b)), compare multiple sampling and pitfall outcomes) about the patterns and aims under investigation.

The most used sampling method in the studies was attractive baits, which are more suitable for behavioural questions [92] and are useful for verifying the presence and population trends of invasive and keystone ant species [13]. However, this sampling method results in biased information about ant diversity (e.g., species richness and composition) because many ants have selective diets, and some ants can dominate the baits to the exclusion of a broad range of other ant species [92]. This notion concerning the use of baits in bioindication papers is confirmed in Figures 3(a) and 3(b), which shows that the sole use of baits revealed apparently unchanging species composition and no trend in species richness. Thus, Underwood and Fisher [13] recommend the use of pitfall traps and litter sampling (The Winkler and/or Berlese extractors) as effective ant sampling methods for monitoring goals related to the effect of habitat disturbance and transformation on ant diversity, which is corroborated in Figures 3(a), 3(b), 4(a), and 4(b).

Species richness and diversity and species composition are the parameters of ant communities most commonly analyzed in the papers. However, species richness and diversity should be used as an evaluative method with caution, since several studies have shown that these parameters were not affected by disturbance (Table 1), and only a narrow number of papers showed a trend in the response of ant species richness to disturbance (see Figures 3 and 4). This coarse relationship of species richness to disturbance is probably because ants are generalists, so the loss of some sensitive species to disturbance is compensated by the invasion of other opportunist species or more generalists. Moreover, in dynamic sites under frequent habitat transformation and disturbance, there is no change in species richness among sites at different restoration times, because perturbation events “reset” the ant community to the same stage [93].

In this way, as Hoffmann [94] has highlighted, the disturbance induced changes in species composition, but not necessarily in species richness. Moreover, the recovery of species composition takes longer than species richness [95] and has a strong relation to the vegetation structure [19, 64, 96–99], which changes with disturbance events. Thus, species composition should be a better parameter to evaluate the effect of disturbance on ant communities, even in areas with frequent perturbations, as described by Gollan et al. [93].

Using the same argument, the quantification of the relationship between each ant species and different disturbances (or level of disturbance) or habitats should be very useful, as it is important to decrease the time spent in indication studies. The general public and stakeholders need to know rapidly if the habitat is impacted or recovering, so recognizing which species can be associated positively or negatively with disturbance or restoration is a very desirable tool.

Several of the papers we analyzed described species occurring exclusively or more frequently in specific habitats

(Table 2), but we are concerned with the lack of rigour with which this has been carried out in most studies (exception in [82]), as there is no control about the specificity and fidelity of these ant species and few statistical analyses to validate the results. This lack of rigour may explain why there are some ant species with contradictory patterns of occurrence, such as species being present in disturbed *versus* undisturbed sites, such as *Acromyrmex balzani*, *Camponotus trapezoides*, *Dorymyrmex pyramicus*, *Ectatomma tuberculatum*, *Odontomachus haematodus*, and *Pseudomyrmex tenuis* (see Table 2). Moreover, these ant species might also be generalists, and the choice of better criteria should enable us to distinguish between inappropriate sampling design and truly generalist ant species. The use of the IndVal index [8], mentioned below, is one option to overcome this drawback.

The Indicator Value (IndVal) suggested by Dufrêne and Legendre [8] combines a measure of the habitat specificity of a species to a level of disturbance, or to a disturbance state, with its fidelity within that state. The random reallocation procedure of samples within sample groups can be used to test the significance of the IndVal measure for each species. The use of this method has increased (e.g., [100–105]) and has a number of advantages over other methods [6].

Some species seem to have more consistent responses to disturbance or specificity to some habitats, but this consistency is very difficult to assert due to the lack of rigour with which the ants were related to disturbance or habitats (presence or frequency of occurrence) and the lack of standardization regarding the level of disturbance in the papers. The habitats sampled in one paper may be defined as undisturbed, which may be different from the habitats studied in another paper that are defined as more degraded (or less) and should also be defined as an undisturbed habitat. In our paper (including Table 2), we used the definition of disturbed or undisturbed given by the original authors.

Thus, following the disturbance definition used by the authors, some species are present in disturbed habitats in more than one paper, and, therefore, could be indicators of disturbed habitats, such as *Atta sexdens rubropilosa*, *Camponotus crassus*, *Camponotus melanoticus*, *Camponotus novogranadensis*, *Odontomachus meinerti*, *Pachycondyla villosa*, *Pseudomyrmex termitarius*, and *Solenopsis saevissima*. In the same way, some species could be indicators of undisturbed habitats, such as *Labidus coecus*, *Pachycondyla arhuaca*, *Pachycondyla stigma*, and *Sericomyrmex bondari*. There are also some species that are indicators of specific habitats, such as indicators of forests (*Discothyrea sexarticulata*, *Ectatomma lugens*, *Labidus coecus*, and *Typhlomyrmex major*) and indicators of savannas (*Camponotus latangulus*, *Pheidole fimbriata*, and *Strumigenys perparva*).

One of the major mistakes related to the use of a taxon as an indicator is the personal motivation of the researchers. There are two ways of avoiding this mistake; several taxa should be rigorously tested *a priori* to select the best one [4] or studied *a posteriori* to validate the response of the indicator [7]. Very few studies have compared how different taxa, including ants, perform under different disturbances (see [89, 101, 106–109]).

[t!]

TABLE 2: Species of ants defined as indicators, indicating the parameter used by the authors (Parameter) when linking each ant species to each habitat type (Habitat) and the paper (Reference).

Ant species	Parameter	Habitat	Reference
<i>Acanthognathus brevicornis</i>	Frequency of occurrence	Secondary forest and area at early succession	Silva et al. [75]
<i>Acanthognathus ocellatus</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Acanthognathus rudis</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Acanthoponera mucronata</i>	Frequency of occurrence	Native forest remnant	Ilha et al. [48]
<i>Acromyrmex balzani</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	Presence/absence	Low human land-use-impacted sites	Delabie et al. [35]
	Presence/absence	Undisturbed sites—control site	Diehl et al. [58]
<i>Acromyrmex coronatus</i>	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]
	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Acromyrmex lobicornis</i>	Presence/absence	Undisturbed sites—control site	Diehl et al. [58]
<i>Acromyrmex lundii</i>	Frequency of occurrence	Secondary forest	Schmidt and Diehl [52]
<i>Acromyrmex niger</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Acromyrmex rugosus</i>	Frequency of occurrence	<i>Turnera ulmifolia</i> field	Santana-Reis and Santos [51]
<i>Acromyrmex striatus</i>	Presence/absence	Undisturbed sites—control site	Diehl et al. [58]
<i>Acromyrmex subterraneus</i>	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]
<i>Acromyrmex subterraneus brunneus</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Acromyrmex subterraneus subterraneus</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Acropyga decedens</i>	Frequency of occurrence	Pasture	Dias et al. [45]
<i>Amblyopone armigera</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
	Presence/absence	Savanna—cerrado sensu stricto	Marinho et al. [50]
	Frequency of occurrence	Secondary forest and area at early succession	Silva et al. [75]
<i>Amblyopone elongata</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Anochetus diegensis</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Anochetus mayri</i>	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
<i>Anochetus neglectus</i>	Frequency of occurrence	Pasture	Dias et al. [45]
<i>Anochetus targionii</i>	Frequency of occurrence	Pasture	Dias et al. [45]
<i>Apterostigma acre</i>	Frequency of occurrence	Forest fragment	Dias et al. [45]
<i>Apterostigma bolivianum</i>	Frequency of occurrence	Forest fragment	Dias et al. [45]
<i>Atta robusta</i>	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
<i>Atta sexdens rubropilosa</i>	Presence/absence	Area at early succession	Coelho et al. [60]
	Frequency of occurrence	Disturbed savanna	Ramos et al. [37]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Azteca alfari</i>	Presence/absence	Area at late succession stage—dry season	Neves et al. [73]
<i>Azteca muelleri</i>	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
<i>Basiceros disciger</i>	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]
<i>Blepharidatta brasiliensis</i>	Frequency of occurrence	Area at late succession stage	Vasconcelos [76]
<i>Brachymyrmex coactus</i>	Frequency of occurrence	Secondary forest and area at early succession	Silva et al. [75]
<i>Camponotus arboreus</i>	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
<i>Camponotus atriceps</i>	Presence/absence	Reforested area at intermediate succession stage	Coelho et al. [60]
<i>Camponotus bidens</i>	Presence/absence	Low human land-use-impacted sites	Delabie et al. [67]
<i>Camponotus burtoni</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Camponotus claviscapus</i>	Presence/absence	Undisturbed sites	Delabie et al. [35]
<i>Camponotus crassus</i>	Presence/absence	Burned restinga	Endringer et al. [38]
	Frequency of occurrence	Burnt site	Teixeira et al. [39]
	Frequency of occurrence	Disturbed sites	Diehl et al. [58]
	Frequency of occurrence	Secondary forest and forest edge	Leal et al. [71]

TABLE 2: Continued.

Ant species	Parameter	Habitat	Reference
	IndVal	Savanna—vegetation and ground stratum	Vasconcelos and Vilhena [82]
<i>Camponotus fastigatus</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Camponotus latangulus</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
	Presence/absence	Savanna—cerrado sensu stricto	Marinho et al. [50]
<i>Camponotus leydigi</i>	Frequency of occurrence	Area at early succession	Vasconcelos [76]
<i>Camponotus melanoticus</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	Frequency of occurrence	Pasture	Dias et al. [45]
	Presence/absence	Area at early succession	Coelho et al. [60]
<i>Camponotus novogranadensis</i>	Frequency of occurrence	Area at early succession	Vasconcelos [76]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	IndVal	Forest—vegetation and ground stratum	Vasconcelos and Vilhena [82]
	Frequency of occurrence	Disturbed savanna	Ramos et al. [37]
<i>Camponotus punctatus minutior</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Camponotus renggeri</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Camponotus rufipes</i>	Frequency of occurrence	Disturbed savanna	Ramos et al. [37]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]
<i>Camponotus sericeiventris</i>	Frequency of occurrence	Native forest remnant	Ilha et al. [48]
<i>Camponotus trapezoides</i>	Frequency of occurrence	Burnt site	Teixeira et al. [39]
	Frequency of occurrence	Forest fragment	Dias et al. [45]
	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Camponotus vitatus</i>	Presence/absence	Low human land-use-impacted sites	Delabie et al. [35]
<i>Camponotus westermanni</i>	Presence/absence	Strong human land-used-impacted sites	Delabie et al. [35]
<i>Cardiocondyla obscurior</i>	Presence/absence	Area at intermediate succession	Coelho et al. [60]
<i>Carebara urichi</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Cephalotes atratus</i>	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
	IndVal	Forest—vegetation stratum	Vasconcelos and Vilhena [82]
<i>Cephalotes grandinosus</i>	Presence/absence	Forest	Lopes et al. [81]
<i>Cephalotes minutus</i>	Presence/absence	Area at early succession—dry season	Neves et al. [73]
	Presence/absence	Low human land-use-impacted sites	Delabie et al. [35]
<i>Cephalotes pallidicephalus</i>	Presence/absence	Low human land-use-impacted sites	Delabie et al. [35]
<i>Cephalotes pavonii</i>	Frequency of occurrence	Burnt site	Teixeira et al. [39]
<i>Cephalotes pellans</i>	Presence/absence	Area at intermediate succession—wet season	Neves et al. [73]
<i>Cephalotes pusillus</i>	IndVal	Savanna—vegetation and ground stratum	Vasconcelos and Vilhena [82]
<i>Cephalotes simillimus</i>	IndVal	Savanna—vegetation stratum	Vasconcelos and Vilhena [82]
<i>Crematogaster brasiliensis</i>	IndVal	Forest—vegetation and ground stratum	Vasconcelos and Vilhena [82]
<i>Crematogaster erecta</i>	Presence/absence	Area at intermediate succession	Coelho et al. [60]
	IndVal	Savanna—vegetation and ground stratum	Vasconcelos and Vilhena [82]
<i>Crematogaster limata</i>	IndVal	Forest—vegetation and ground stratum	Vasconcelos and Vilhena [82]
<i>Crematogaster minutissima</i>	IndVal	Forest—ground stratum	Vasconcelos and Vilhena [82]
<i>Crematogaster nigropilosa</i>	Frequency of occurrence	Native forest remnant	Ilha et al. [48]

TABLE 2: Continued.

Ant species	Parameter	Habitat	Reference
<i>Crematogaster quadriformis</i>	IndVal	Savanna—ground stratum	Vasconcelos and Vilhena [82]
<i>Cyphomyrmex laevigatus</i>	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]
<i>Cyphomyrmex major</i>	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]
<i>Cyphomyrmex olitor</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Cyphomyrmex peltatus</i>	Frequency of occurrence	Disturbed savanna	Ramos et al. [37]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	Frequency of occurrence	Forest fragments	Dias et al. [45]
<i>Cyphomyrmex plaumanni</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Cyphomyrmex salvini</i>	Frequency of occurrence	Area at early succession	Vasconcelos [76]
	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
<i>Cyphomyrmex transversus</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Discothyrea sexarticulata</i>	Frequency of occurrence	Forest fragment	Dias et al. [45]
	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Dolichoderus attelabooides</i>	IndVal	Forest—vegetation stratum	Vasconcelos and Vilhena [82]
<i>Dolichoderus bispinosus</i>	IndVal	Forest—vegetation stratum	Vasconcelos and Vilhena [82]
<i>Dolichoderus schulzi</i>	Presence/absence	Undisturbed sites	Delabie et al. [35]
<i>Dolichoderus voraginosus</i>	Presence/absence	Area at early succession—dry season	Neves et al. [73]
<i>Dorymyrmex guianensis</i>	IndVal	Savanna—ground stratum	Vasconcelos and Vilhena [82]
<i>Dorymyrmex pyramicus</i>	Frequency of occurrence	Burnt site	Teixeira et al. [39]
	Presence/absence	Undisturbed sites	Delabie et al. [35]
<i>Dorymyrmex thoracicus</i>	IndVal	Savanna—ground stratum	Vasconcelos and Vilhena [82]
<i>Eciton quadriglume</i>	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]
<i>Ectatomma brunneum</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	Frequency of occurrence	Area at early succession	Braga et al. [54]
	Presence/absence	Low human land-use-impacted sites	Delabie et al. [35]
<i>Ectatomma edentatum</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Ectatomma lugens</i>	Frequency of occurrence	Area at late succession stage	Vasconcelos [76]
	IndVal	Forest—ground stratum	Vasconcelos and Vilhena [82]
<i>Ectatomma muticum</i>	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
<i>Ectatomma opaciventre</i>	IndVal	Savanna—ground stratum	Vasconcelos and Vilhena [82]
<i>Ectatomma permagnum</i>	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
	Frequency of occurrence	<i>Eucalyptus</i> forestry	Braga et al. [54]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Ectatomma planidens</i>	Frequency of occurrence	Disturbed savanna	Ramos et al. [37]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Ectatomma quadridens</i>	Frequency of occurrence	Area at early succession	Vasconcelos [76]
<i>Ectatomma tuberculatum</i>	Frequency of occurrence	Area at early succession	Silva et al. [75]
	Presence/absence	Burned restinga	Endringer et al. [38]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	Frequency of occurrence	Area at late succession stage	Braga et al. [54]
<i>Forelius maranhoensis</i>	IndVal	Savanna—ground stratum	Vasconcelos and Vilhena [82]
	Frequency of occurrence	Secondary forest and forest edge	Leal et al. [71]
<i>Gnamptogenys acuminata</i>	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]

TABLE 2: Continued.

Ant species	Parameter	Habitat	Reference
<i>Gnamptogenys continua</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Gnamptogenys horni</i>	Frequency of occurrence	Area at late succession stage	Vasconcelos [76]
<i>Gnamptogenys mediatrix</i>	Frequency of occurrence	Forest fragment	Dias et al. [45]
<i>Gnamptogenys moelleri</i>	Frequency of occurrence	Pasture	Dias et al. [45]
	Frequency of occurrence	Secondary forest and area at early succession	Schmidt and Diehl [52]
<i>Gnamptogenys reichenspergeri</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Gnamptogenys striatula</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	IndVal	Forest—ground stratum	Vasconcelos and Vilhena [82]
<i>Gnamptogenys sulcata</i>	Presence/absence	Area at early succession—wet season	Neves et al. [73]
<i>Gnamptogenys tortuolosa</i>	Frequency of occurrence	Intermediate disturbed area	Vasconcelos [76]
<i>Heteroponera flava</i>	Frequency of occurrence	Forest fragment	Dias et al. [45]
<i>Heteroponera microps</i>	Frequency of occurrence	Disturbed habitat (<i>Eucalyptus</i>)	Ilha et al. [48]
<i>Hylomyrma balzani</i>	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]
<i>Hylomyrma reitteri</i>	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]
<i>Hypoconerops foeda</i>	Frequency of occurrence	Native forest remnant	Ilha et al. [48]
<i>Hypoconerops foreli</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Hypoconerops opacior</i>	Frequency of occurrence	Disturbed habitat (<i>Eucalyptus</i>)	Ilha et al. [48]
<i>Labidus coecus</i>	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]
	Presence/absence	Undisturbed sites	Delabie et al. [35]
<i>Labidus praedator</i>	Frequency of occurrence	Disturbed savanna	Ramos et al. [37]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	Frequency of occurrence	Secondary forest	Schmidt and Diehl [52]
<i>Leptogenys pusilla</i>	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
<i>Leptothorax asper</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Leptothorax spininodis</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Linepithema humile</i>	Frequency of occurrence	Burnt site	Teixeira et al. [39]
	Frequency of occurrence	Disturbed savanna	Ramos et al. [37]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]
<i>Megalomyrmex goeldii</i>	Frequency of occurrence	Area at early succession	Silva et al. [75]
<i>Mycetagoicus cerradensis</i>	Frequency of occurrence	Disturbed savanna	Ramos et al. [37]
<i>Mycetarotes paralelus</i>	Presence/absence	Area revegetated with native species	Pereira et al. [64]
<i>Mycetophylax conformis</i>	Presence/absence	Strong human land-used-impacted sites	Delabie et al. [35]
<i>Myrmicocrypta foreli</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Neivamyrmex orthonotus</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Nesomyrmex spininodis</i>	Presence/absence	Strong human land-used-impacted sites	Delabie et al. [35]
<i>Octostruma balzani</i>	Frequency of occurrence	Area at intermediate succession	Braga et al. [54]
<i>Octostruma jheringhi</i>	Frequency of occurrence	Forest fragment	Dias et al. [45]
	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Odontomachus affinis</i>	Frequency of occurrence	Secondary forest	Silva et al. [75]
<i>Odontomachus bauri</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Odontomachus brunneus</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Odontomachus caelatus</i>	Frequency of occurrence	Area at late succession stage	Vasconcelos [76]
<i>Odontomachus chelifer</i>	Frequency of occurrence	Pasture	Braga et al. [54]
	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
	Frequency of occurrence	Secondary forest and area at early succession	Schmidt and Diehl [52]
	Frequency of occurrence	Secondary forest and area at early succession	Silva et al. [75]

TABLE 2: Continued.

Ant species	Parameter	Habitat	Reference
<i>Odontomachus haematodus</i>	Frequency of occurrence	Area at intermediate succession	Braga et al. [54]
	Presence/absence	Burned restinga	Endringer et al. [38]
	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
	IndVal	Forest—ground stratum	Vasconcelos and Vilhena [82]
<i>Odontomachus meinerti</i>	Frequency of occurrence	Disturbed savanna	Ramos et al. [37]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Oxyepoecus plaumanni</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Oxyepoecus rastratus</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Pachycondyla apicalis</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Pachycondyla arhuaca</i>	Frequency of occurrence	Area at late succession stage	Braga et al. [54]
	Presence/absence	Primary restinga	Endringer et al. [38]
<i>Pachycondyla bucki</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Pachycondyla crassinoda</i>	IndVal	Forest—ground stratum	Vasconcelos and Vilhena [82]
<i>Pachycondyla ferruginea</i>	Frequency of occurrence	Secondary forest and area at early succession	Silva et al. [75]
<i>Pachycondyla gilberti</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Pachycondyla harpax</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	IndVal	Forest—ground stratum	Vasconcelos and Vilhena [82]
	Presence/absence	Low human land-use-impacted sites	Delabie et al. [35]
<i>Pachycondyla obscuricornis</i>	Frequency of occurrence	<i>Eucalyptus</i> (reforestation)	Lapola and Fowler [49]
<i>Pachycondyla stigma</i>	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
	Frequency of occurrence	Primary forest	Braga et al. [54]
<i>Pachycondyla striata</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
	Presence/absence	Savanna—cerrado sensu stricto	Marinho et al. [50]
	Frequency of occurrence	Secondary forest and area at early succession	Schmidt and Diehl [52]
	Frequency of occurrence	Secondary forest and area at early succession	Silva et al. [75]
<i>Pachycondyla villosa</i>	Presence/absence	Burned restinga	Endringer et al. [38]
	Frequency of occurrence	Disturbed savanna	Ramos et al. [37]
<i>Paratrechina longicornis</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	Presence/absence	Undisturbed sites	Delabie et al. [35]
<i>Pheidole diligens</i>	Presence/absence	Area at intermediate succession	Coelho et al. [60]
<i>Pheidole embolopyx</i>	Frequency of occurrence	Area at late succession stage	Vasconcelos [76]
<i>Pheidole exigua</i>	IndVal	Forest—ground stratum	Vasconcelos and Vilhena [82]
<i>Pheidole fimbriata</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
	Presence/absence	Savanna—cerrado sensu stricto	Marinho et al. [50]
<i>Pheidole fracticeps</i>	IndVal	Forest—ground stratum	Vasconcelos and Vilhena [82]
<i>Pheidole radoszkowskii</i>	Presence/absence	Low human land-use-impacted sites	Delabie et al. [35]
<i>Pheidole scalaris</i>	Presence/absence	Area at early succession—wet season	Neves et al. [73]
<i>Pogonomyrmex abdominalis</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Pogonomyrmex naegelii</i>	Presence/absence	Area at intermediate succession	Coelho et al. [60]
<i>Prionopelta punctulata</i>	Frequency of occurrence	Secondary forest and area at early succession	Silva et al. [75]
<i>Pseudomyrmex elongatus</i>	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
<i>Pseudomyrmex filiformis</i>	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
<i>Pseudomyrmex flavidulus</i>	IndVal	Savanna—vegetation stratum	Vasconcelos and Vilhena [82]

TABLE 2: Continued.

Ant species	Parameter	Habitat	Reference
<i>Pseudomyrmex gracilis</i>	Presence/absence	Area at intermediate succession	Coelho et al. [60]
	IndVal	Savanna—vegetation stratum	Vasconcelos and Vilhena [82]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Pseudomyrmex kuenckeli</i>	Presence/absence	Undisturbed sites	Delabie et al. [35]
<i>Pseudomyrmex oculatus</i>	Presence/absence	Area at intermediate succession	Coelho et al. [60]
	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	IndVal	Forest—vegetation stratum	Vasconcelos and Vilhena [82]
<i>Pseudomyrmex schuppi</i>	Presence/absence	Area at intermediate succession	Coelho et al. [60]
<i>Pseudomyrmex sericeus</i>	Presence/absence	Undisturbed sites	Delabie et al. [35]
<i>Pseudomyrmex simplex</i>	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Pseudomyrmex spiculus</i>	Presence/absence	Undisturbed sites	Delabie et al. [35]
<i>Pseudomyrmex tenuis</i>	Frequency of occurrence	Area at early succession	Vasconcelos [76]
	IndVal	Forest—vegetation and ground stratum	Vasconcelos and Vilhena [82]
	Presence/absence	Strong human land-use-impacted sites	Delabie et al. [35]
	Frequency of occurrence	Area at intermediate succession	Braga et al. [54]
	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
<i>Pseudomyrmex termitarius</i>	Presence/absence	Area at early succession—dry season	Neves et al. [73]
	Frequency of occurrence	Pasture	Braga et al. [54]
	IndVal	Savanna—vegetation stratum	Vasconcelos and Vilhena [82]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Pyramica appretiata</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Pyramica denticulata</i>	Frequency of occurrence	Area at early succession	Silva et al. [75]
<i>Pyramica lygatrix</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Pyramica rugithorax</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Pyramica schulzi</i>	Presence/absence	Strong human land-use-impacted sites	Delabie et al. [35]
<i>Pyramica subdentata</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
	Frequency of occurrence	Secondary forest and area at early succession	Silva et al. [75]
<i>Pyramica zeteki</i>	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Sericomyrmex bondari</i>	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
	Presence/absence	Low human land-use-impacted sites	Delabie et al. [35]
<i>Simopelta curvata</i>	Frequency of occurrence	Pasture (edge)	Dias et al. [45]
<i>Solenopsis geminata</i>	Frequency of occurrence	Area at early succession	Vasconcelos [76]
	Frequency of occurrence	<i>Caesalpinia echinata</i> forest	Santana-Reis and Santos [51]
<i>Solenopsis saevissima</i>	Frequency of occurrence	Disturbed sites	Ilha et al. [48]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
<i>Solenopsis substituta</i>	Frequency of occurrence	Burnt site	Teixeira et al. [39]
	Presence/absence	<i>Eucalyptus</i> forestry	Marinho et al. [50]
	IndVal	Savanna—ground stratum	Vasconcelos and Vilhena [82]
<i>Sphinctomyrmex stali</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Stegomyrmex vizzotoi</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Strumigenys denticulata</i>	Frequency of occurrence	Intermediate disturbed area	Vasconcelos [76]
<i>Strumigenys elongata</i>	Frequency of occurrence	Area at early succession	Silva et al. [75]
	Frequency of occurrence	Preserved savanna	Ramos et al. [37]

TABLE 2: Continued.

Ant species	Parameter	Habitat	Reference
<i>Strumigenys perparva</i>	Presence/absence	Savanna—cerrado sensu stricto	Marinho et al. [50]
	Frequency of occurrence	Preserved savanna	Ramos et al. [37]
<i>Tapinoma melanocephalum</i>	Frequency of occurrence	Disturbed habitat (<i>Eucalyptus</i>)	Ilha et al. [48]
	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]
<i>Trachymyrmex cornetzi</i>	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
<i>Trachymyrmex fuscus</i>	Frequency of occurrence	Pasture (edge)	Dias et al. [45]
<i>Trachymyrmex zeteki</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Typhlomyrmex major</i>	Frequency of occurrence	Forest fragments	Lapola and Fowler [49]
	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Typhlomyrmex pusillus</i>	Frequency of occurrence	Primary forest	Silva et al. [75]
<i>Wasmannia auropunctata</i>	Presence/absence	Area at intermediate succession	Coelho et al. [60]
	Frequency of occurrence	Control site (nonburnt)	Teixeira et al. [39]
<i>Wasmannia rochai</i>	Presence/absence	Area at early succession	Coelho et al. [60]

The majority of studies end at the seventh step of the “Procedural steps in bioindicator studies” according to McGeoch [7], which is “Based on the nature of the relationship, either accept or reject the species, higher level taxon or assemblage as an indicator,” and just investigate the nature of the relationship between the disturbance and the indicator. To validate the organism as a suitable indicator, we must move to step eight (Establish the robustness of the indicator by developing and testing appropriate hypotheses under different conditions)—establish the robustness of the indicator by testing the same relationship in other areas or at different times (to validate the indicator) [6, 14, 103].

We would like to flag some issues to improve and validate the use of ants as indicators in environmental monitoring programs, including consideration of robust criteria for the validation of ants as indicators, sampling in different seasons and under different disturbances with comparable methodologies, collecting ants with different sampling methodologies in order to recognize that the responses of different ant life styles could be different for the same disturbance, and evaluation of different environmental parameters (biotic and abiotic) to correlate with the ants’ response along the disturbance/restoration gradients. The search for indicator ant species should be with analyses that consider their fidelity and specificity to the habitats (e.g., “IndVal” index), in order to more quickly achieve monitoring goals. Finally, evaluating the functional loss of ant species in disturbed habitats will improve predictions about the functional implication of the disturbance.

Moreover, incorporating new approaches that efficiently simplify the study may help to decrease the problems related to time spent identifying ant species, as suggested by Groc et al. [85]. In this study, the authors introduced a new method based on mixed-level taxonomic sufficiency, highly focused on higher-taxon surrogacy. Under this method, only ant species pre established as “indicator taxa” must be taxonomically identified to species level, while other species may be identified to higher (and easier to identify) levels, such as genera. By using this mixed-level approach, the authors

argue that a considerable improvement in cost effectiveness can be achieved, mainly by reducing the necessity for well-trained taxonomists to be involved in the study. This is highly desirable in monitoring programs, where time and budget are key limiting factors.

Also, species which have been identified as possible indicators because they occur in specific habitats or conditions still require validation for reliable use as bioindicators, and their presence or frequency in specific conditions can generate testable hypothesis about their relationship with these habitats and conditions, which in turn can validate the use of these species as bioindicators.

In conclusion, we point out that the use of ants as indicators in Brazil has been improving each year. Ants are a useful tool not only because they are sensitive to environmental changes, as related in the papers we reviewed but also because they are keystone species in several ecological processes and, therefore, provide reliable inferences about the ecological and functional implications of disturbances.

We should continue to study ants in Brazil, with proper *a priori* hypothesis tests and sampling designs, statistical analysis and standardized methods, in order to reach the same widespread acceptance of ants as indicators that is common in Australia, as well as to improve our understanding of ant dynamics for predictive frameworks. Moreover, we need to build an effective bridge between our accumulated knowledge (almost 25 years of research) of ants as bioindicators and monitoring programs developed to examine natural resources and areas.

Acknowledgments

This study resulted from the research project: CRA 270/07 “Utilização de formigas como bioindicadoras de impacto ambiental e de sua recuperação em Cerrado e em Mata Atlântica.” The authors are grateful to Jacques H. C. Delabie for encouraging the elaboration of this paper, to Jonathan D. Majer for his kind attention in providing several papers and to

Patty Ramirez for her valuable suggestions in the English expression. The authors received grants and funding from the FAPEMIG, CAPES, and CNPq.

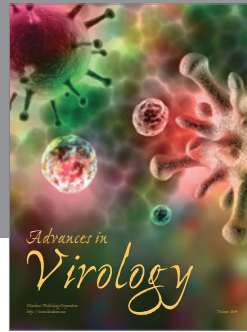
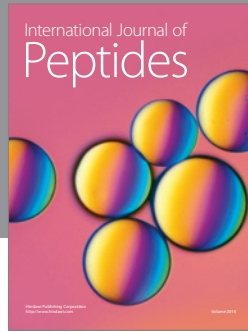
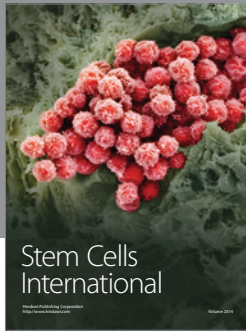
References

- [1] E. O. Wilson, "On the future of conservation biology: editorial," *Conservation Biology*, vol. 14, no. 1, pp. 1–3, 2000.
- [2] K. S. Bawa, W. J. Kress, N. M. Nadkarni et al., "Tropical ecosystems into the 21st century," *Science*, vol. 306, no. 5694, pp. 227–228, 2004.
- [3] J. K. A. Benhin, "Agriculture and deforestation in the tropics: a critical theoretical and empirical review," *Ambio*, vol. 35, no. 1, pp. 9–16, 2006.
- [4] G. J. Niemi and M. E. McDonald, "Application of ecological indicators," *Annual Review of Ecology, Evolution, and Systematics*, vol. 35, pp. 89–111, 2004.
- [5] P. J. Goodsell, A. J. Underwood, and M. G. Chapman, "Evidence necessary for taxa to be reliable indicators of environmental conditions or impacts," *Marine Pollution Bulletin*, vol. 58, no. 3, pp. 323–331, 2009.
- [6] T. A. Gardner, *Monitoring Forest Biodiversity: Improving Conservation through Ecologically-Responsible Management*, Earthscan, London, UK, 2010.
- [7] M. A. McGeoch, "The selection, testing and application of terrestrial insects as bioindicators," *Biological Reviews of the Cambridge Philosophical Society*, vol. 73, no. 2, pp. 181–201, 1998.
- [8] M. Dufrêne and P. Legendre, "Species assemblages and indicator species: the need for a flexible asymmetrical approach," *Ecological Monographs*, vol. 67, no. 3, pp. 345–366, 1997.
- [9] J. Hilty and A. Merenlender, "Faunal indicator taxa selection for monitoring ecosystem health," *Biological Conservation*, vol. 92, no. 2, pp. 185–197, 2000.
- [10] P. J. Folgarait, "Ant biodiversity and its relationship to ecosystem functioning: a review," *Biodiversity and Conservation*, vol. 7, no. 9, pp. 1221–1244, 1998.
- [11] L. Lach, C. L. Parr, and K. L. Abbott, *Ant Ecology*, Oxford University Press, Oxford, UK, 2010.
- [12] D. Agosti, J. D. Majer, L. E. Alonso, and R. Schultz, *Ants: Standard Methods for Measuring and Monitoring Biodiversity*, Smithsonian Institution Press, Washington, DC, USA, 2000.
- [13] E. C. Underwood and B. L. Fisher, "The role of ants in conservation monitoring: if, when, and how," *Biological Conservation*, vol. 132, no. 2, pp. 166–182, 2006.
- [14] S. M. Philpott, I. Perfecto, I. Armbrrecht, and C. L. Parr, "Ant diversity and function in disturbed and changing habitats," in *Ant Ecology*, L. Lach, C. L. Parr, and K. L. Abbott, Eds., pp. 137–156, Oxford University Press, Oxford, UK, 2010.
- [15] J. D. Majer, "Ants: bio-indicators of minesite rehabilitation, land-use, and land conservation," *Environmental Management*, vol. 7, no. 4, pp. 375–383, 1983.
- [16] B. D. Hoffmann and A. N. Andersen, "Responses of ants to disturbance in Australia, with particular reference to functional groups," *Austral Ecology*, vol. 28, no. 4, pp. 444–464, 2003.
- [17] A. N. Andersen and J. D. Majer, "Ants show the way Down Under: invertebrate as bioindicators in land management," *Frontiers in Ecology and the Environment*, vol. 2, pp. 291–298, 2004.
- [18] A. N. Andersen, A. Fisher, B. D. Hoffmann, J. L. Read, and R. Richards, "Use of terrestrial invertebrates for biodiversity monitoring in Australian rangelands, with particular reference to ants," *Austral Ecology*, vol. 29, no. 1, pp. 87–92, 2004.
- [19] J. D. Majer, K. E. C. Brennan, and M. L. Moir, "Invertebrates and the restoration of a forest ecosystem: 30 years of research following bauxite mining in Western Australia," *Restoration Ecology*, vol. 15, no. 4, pp. S104–S115, 2007.
- [20] C. Gómez, D. Casellas, J. Oliveras, and J. M. Bas, "Structure of ground-foraging ant assemblages in relation to land-use change in the northwestern Mediterranean region," *Biodiversity and Conservation*, vol. 12, no. 10, pp. 2135–2146, 2003.
- [21] H. van Hamburg, A. N. Andersen, W. J. Meyer, and H. G. Robertson, "Ant community development on rehabilitated ash dams in the South African highveld," *Restoration Ecology*, vol. 12, no. 4, pp. 552–558, 2004.
- [22] L. Ottonetti, L. Tucci, and G. Santini, "Recolonization patterns of ants in a rehabilitated lignite mine in Central Italy: potential for the use of Mediterranean ants as indicators of restoration processes," *Restoration Ecology*, vol. 14, no. 1, pp. 60–66, 2006.
- [23] K. C. Fagan, R. F. Pywell, J. M. Bullock, and R. H. Marrs, "Are ants useful indicators of restoration success in temperate grasslands?" *Restoration Ecology*, vol. 18, no. 3, pp. 373–379, 2010.
- [24] C. Castracani, D. A. Grasso, A. Fanfani, and A. Mori, "The ant fauna of Castelporziano Presidential Reserve (Rome, Italy) as a model for the analysis of ant community structure in relation to environmental variation in Mediterranean ecosystems," *Journal of Insect Conservation*, vol. 14, no. 6, pp. 585–594, 2010.
- [25] J. R. Verdú, C. Numa, and O. Hernández-Cuba, "The influence of landscape structure on ants and dung beetles diversity in a Mediterranean savanna-Forest ecosystem," *Ecological Indicators*, vol. 11, no. 3, pp. 831–839, 2011.
- [26] R. R. Silva and C. R. F. Brandão, "Formigas (Hymenoptera: Formicidae) como indicadores da qualidade ambiental e da biodiversidade de outros invertebrados terrestres," *Biotemas*, vol. 12, pp. 55–73, 1999.
- [27] J. M. Queiroz, F. S. Almeida, and M. P. S. Pereira, "Conservação da biodiversidade e o papel das formigas (Hymenoptera: Formicidae) em agroecossistemas," *Floresta e Ambiente*, vol. 13, pp. 37–45, 2006.
- [28] D. Baretta, Á. L. Mafra, J. C. P. Santos, C. V. T. Do Amarante, and I. Bertol, "Multivariate analysis of soil fauna under different soil tillage and crop management systems," *Pesquisa Agropecuária Brasileira*, vol. 41, no. 11, pp. 1675–1679, 2006.
- [29] A. O. Merlim, J. G. M. Guerra, R. M. Junqueira, and A. M. Aquino, "Soil macrofauna in cover crops of figs grown under organic management," *Scientia Agricola*, vol. 62, pp. 57–61, 2005.
- [30] L. R. S. Lacau, R. Zanetti, J. H. C. Delabie et al., "Respostas das guildas de formigas (Hymenoptera: Formicidae) a práticas silviculturais em plantio de eucaliptos," *Agrotropica*, vol. 20, pp. 61–72, 2008.
- [31] L. A. P. L. Nunes, J. A. Araújo Filho, and R. I. Q. Meneses, "Recolonização da fauna edáfica em áreas de caatinga submetidas a queimadas," *Caatinga*, vol. 21, pp. 214–220, 2008.
- [32] L. S. Ramos, C. G. S. Marinho, R. Zanetti, J. H. C. Delabie, and M. N. Schlindwein, "Impact of formicid granulated baits on non-target ants in eucalyptus plantations according to two forms of application," *Neotropical Entomology*, vol. 32, no. 2, pp. 231–237, 2003.
- [33] A. F. Silva, B. Meireles, J. Da Silva Rosa, M. W. De Oliveira, M. S. De Castro Morini, and A. F. De Oliveira, "Evaluation of the level of metals in *Camponotus rufipes* (Hymenoptera:

- Formicidae) collected in different environments,” *Sociobiology*, vol. 47, no. 2, pp. 293–304, 2006.
- [34] K. S. Carvalho, A. L. B. de Souza, M. S. Pereira, C. P. Sampaio, and J. H. C. Delabie, “Comunidade de formigas epígeas no Ecótono Mata de Cipó, domínio da Mata Atlântica, BA, Brasil,” *Acta Biológica Leopoldensia*, vol. 26, pp. 249–257, 2004.
- [35] J. H. C. Delabie, V. R. L. D. M. Paim, I. C. Do Nascimento, S. Campiolo, and C. D. S. F. Mariano, “Ants as biological indicators of human impact in mangroves of the southeastern coast of Bahia, Brazil,” *Neotropical Entomology*, vol. 35, no. 5, pp. 602–615, 2006.
- [36] N. L. Hites, M. A. N. Mourão, F. O. Araújo, M. V. C. Melo, J. C. De Biseau, and Y. Quinet, “Diversity of the ground-dwelling ant fauna (Hymenoptera: Formicidae) of a moist, montane forest of the semi-arid Brazilian ”Nordeste”,” *Revista de Biologia Tropical*, vol. 53, no. 1-2, pp. 165–173, 2005.
- [37] L. D. Ramos, R. Z. B. Filho, J. H. C. Delabie et al., “Ant communities (Hymenoptera: Formicidae) of the leaf-litter in cerrado “stricto sensu” areas in Minas Gerais, Brazil,” *Lundiana*, vol. 4, no. 2, pp. 95–102, 2003.
- [38] F. B. Endringer, I. A. Santos, M. Da Cunha Teixeira, and J. H. Schoederer, “Ant species richness in sand dune environments following burning (Hymenoptera: Formicidae),” *Sociobiology*, vol. 51, no. 2, pp. 415–423, 2008.
- [39] M. C. Teixeira, J. H. Schoederer, J. T. Nascimento, and J. N. C. Louzada, “Response of ant communities to sand dune vegetation burning in Brazil (Hymenoptera: Formicidae),” *Sociobiology*, vol. 45, no. 3, pp. 631–641, 2005.
- [40] K. S. Carvalho and H. L. Vasconcelos, “Forest fragmentation in central Amazonia and its effects on litter-dwelling ants,” *Biological Conservation*, vol. 91, no. 2-3, pp. 151–157, 1999.
- [41] J. P. Gomes, L. Iannuzzi, and I. R. Leal, “Resposta da comunidade de formigas aos atributos dos fragmentos e da vegetação em uma paisagem da floresta Atlântica nordestina,” *Neotropical Entomology*, vol. 39, no. 6, pp. 898–905, 2010.
- [42] M. S. Santos, J. N. C. Louzada, N. Dias, R. Zanetti, J. H. C. Delabie, and I. C. Nascimento, “Litter ants richness (Hymenoptera, Formicidae) in remnants of a semi-deciduous forest in the Atlantic rain forest, Alto do Rio Grande region, Minas Gerais, Brazil,” *Iheringia - Serie Zoologia*, vol. 96, no. 1, pp. 95–101, 2006.
- [43] R. C. Fonseca and E. Diehl, “Riqueza de formigas (Hymenoptera, Formicidae) epigéicas em povoamentos de Eucalyptus spp. (Myrtaceae) de diferentes idades no Rio Grande do Sul,” *Revista Brasileira de Entomologia*, vol. 48, pp. 95–100, 2004.
- [44] A. G. Castro and M. V. B. Queiroz, “Estrutura e organização de uma comunidade de formigas em agro-ecossistemas neotropical,” *Anais da Sociedade Entomológica do Brasil*, vol. 16, pp. 363–375, 1987.
- [45] N. S. Dias, R. Zanetti, M. S. Santos, J. Louzada, and J. Delabie, “Interaction between forest fragments and adjacent coffee and pasture agroecosystems: responses of the ant communities (Hymenoptera, Formicidae),” *Iheringia - Serie Zoologia*, vol. 98, no. 1, pp. 136–142, 2008.
- [46] E. Diehl, D. F. Florencio, F. A. Schmidt, and L. V. A. Menzel, “Riqueza e composição das comunidades de formigas e de térmitas na floresta nacional de São Francisco de Paula (FLONA-SFP), RS,” *Acta Biológica Leopoldensia*, vol. 27, pp. 99–106, 2005.
- [47] J. B. V. Gomes, A. C. Barreto, M. M. Michereff Filho et al., “Relationship among soil attributes and ant activity in restinga soils,” *Revista Brasileira de Ciencia do Solo*, vol. 34, no. 1, pp. 67–78, 2010.
- [48] C. Ilha, J. A. Lutinski, D. V. M. Pereira, and F. R. M. Garcia, “Riqueza de formigas (Hymenoptera: Formicidae) da Bacia da Sanga Caramuru, município de Chapecó-SC,” *Biotemas*, vol. 22, pp. 95–105, 2009.
- [49] D. M. Lapola and H. G. Fowler, “Questioning the implementation of habitat corridors: a case study in interior São Paulo using ants as bioindicators,” *Brazilian Journal of Biology*, vol. 68, no. 1, pp. 11–20, 2008.
- [50] C. G. S. Marinho, R. Zanetti, J. H. C. Delabie, M. N. Schindwein, and L. D. S. Ramos, “Ant (hymenoptera: formicidae) diversity in eucalyptus (myrtaceae) plantations and cerrado litter in Minas Gerais, Brazil,” *Neotropical Entomology*, vol. 31, no. 2, pp. 187–195, 2002.
- [51] V. P. G. Santana-Reis and G. M. M. Santos, “Influência da estrutura do habitat em comunidades de formigas (Hymenoptera - Formicidae) em Feira de Santana, Bahia, Brasil,” *Sientibus*, vol. 1, pp. 66–70, 2001.
- [52] F. A. Schmidt and E. Diehl, “What is the effect of soil use on ant communities?” *Neotropical Entomology*, vol. 37, no. 4, pp. 381–388, 2008.
- [53] A. A. Tavares, P. C. Bispo, and A. C. Zanzini, “Effect of collect time on communities of epigeaic ants (Hymenoptera: Formicidae) in areas of Eucalyptus cloeziana and cerrado,” *Neotropical Entomology*, vol. 37, no. 2, pp. 126–130, 2008.
- [54] D. L. Braga, J. N. C. Louzada, R. Zanetti, and J. Delabie, “Rapid evaluation of ant diversity in land use systems in Southern Bahia, Brazil,” *Neotropical Entomology*, vol. 39, no. 4, pp. 464–469, 2010.
- [55] J. D. Majer and J. H. C. Delabie, “Comparison of the ant communities of annually inundated and terra firme forests at Trombetas in the Brazilian Amazon,” *Insectes Sociaux*, vol. 41, no. 4, pp. 343–359, 1994.
- [56] K. A. B. Kalif, C. Azevedo-Ramos, P. Moutinho, and S. A. O. Malcher, “The effect of logging on the ground-foraging ant community in eastern Amazonia,” *Studies on Neotropical Fauna and Environment*, vol. 36, no. 3, pp. 215–219, 2001.
- [57] Y. J. Barros, V. de Freitas Melo, K. D. Sautter et al., “Soil quality indicators in lead mining and metalurgy area. II - mesofauna and plants,” *Revista Brasileira de Ciencia do Solo*, vol. 34, no. 4, pp. 1413–1426, 2010.
- [58] E. Diehl, C. E. Sanhudo, and E. Diehl-Fleig, “Ground-dwelling ant fauna of sites with high levels of copper,” *Brazilian Journal of Biology*, vol. 64, no. 1, pp. 33–39, 2004.
- [59] M. P. Pais and E. M. Varanda, “Arthropod recolonization in the restoration of a semideciduous forest in southeastern Brazil,” *Neotropical Entomology*, vol. 39, no. 2, pp. 198–206, 2010.
- [60] M. S. Coelho, G. W. Fernandes, J. C. Santos, and J. H. C. Delabie, “Ants (Hymenoptera: Formicidae) as bioindicators of land restoration in a brazilian atlantic forest fragment,” *Sociobiology*, vol. 54, no. 1, pp. 51–63, 2009.
- [61] C. B. Costa, S. P. Ribeiro, and P. T. A. Castro, “Ants as bioindicators of natural succession in savanna and riparian vegetation impacted by dredging in the Jequitinhonha River Basin, Brazil,” *Restoration Ecology*, vol. 18, no. 1, pp. 148–157, 2010.
- [62] J. D. Majer, “Ant recolonisation of rehabilitated bauxite mines of Pocos de Caldas, Brazil,” *Journal of Tropical Ecology*, vol. 8, no. 1, pp. 97–108, 1992.
- [63] J. D. Majer, “Ant recolonization of rehabilitated bauxite mines at Trombetas, Pará, Brazil,” *Journal of Tropical Ecology*, vol. 12, no. 2, pp. 257–273, 1996.
- [64] M. P. D. S. Pereira, J. M. Queiroz, R. Valcarcel, and A. J. Mayhé-Nunes, “Ant fauna as a tool for the monitoring of

- a rehabilitated sand mine at Ilha da Madeira, Itaguaí, RJ," *Ciencia Florestal*, vol. 17, no. 3, pp. 197–204, 2007.
- [65] H. L. Vasconcelos, E. H. M. Vieira-Neto, F. M. Mundim, and E. M. Bruna, "Roads alter the colonization dynamics of a keystone herbivore in neotropical savannas," *Biotropica*, vol. 38, no. 5, pp. 661–665, 2006.
- [66] K. Schmidt, R. Corbetta, and A. J. A. Camargo, "Formigas (Hymenoptera: Formicidae) da Ilha João da Cunha, SC: composição e diversidade," *Biotemas*, vol. 18, pp. 57–71, 2005.
- [67] J. H. Bihn, M. Verhaagh, M. Brändle, and R. Brandl, "Do secondary forests act as refuges for old growth forest animals? Recovery of ant diversity in the Atlantic forest of Brazil," *Biological Conservation*, vol. 141, no. 3, pp. 733–743, 2008.
- [68] J. H. Bihn, M. Verhaagh, and R. Brandl, "Ecological stoichiometry along a gradient of forest succession: bait preferences of litter ants," *Biotropica*, vol. 40, no. 5, pp. 597–599, 2008.
- [69] J. H. Bihn, G. Gebauer, and R. Brandl, "Loss of functional diversity of ant assemblages in secondary tropical forests," *Ecology*, vol. 91, no. 3, pp. 782–792, 2010.
- [70] A. G. Castro, M. V. B. Queiroz, and L. M. Araújo, "O papel do distúrbio na estrutura de comunidades de formigas (Hymenoptera, Formicidae)," *Revista Brasileira de Entomologia*, vol. 34, pp. 201–213, 1990.
- [71] I. R. Leal, S. O. Ferreira, and A. V. L. Freitas, "Diversidade de formigas de solo em um gradiente sucessional de Mata Atlântica, ES, Brasil," *Biotemas*, vol. 6, pp. 42–53, 1993.
- [72] F. S. Neves, R. F. Braga, and B. G. Madeira, "Diversidade de formigas arborícolas em três estágios sucessionais de uma floresta estacional decidual no norte de Minas Gerais," *Unimontes Científica*, vol. 8, pp. 59–68, 2006.
- [73] F. S. Neves, R. F. Braga, M. M. Do Espírito Santo, J. H. C. Delabie, G. W. Fernandes, and G. A. Sánchez-Azofeifa, "Diversity of arboreal ants in a Brazilian tropical dry forest: effects of seasonality and successional stage," *Sociobiology*, vol. 56, no. 1, pp. 177–194, 2010.
- [74] J. C. Santos, J. H. C. Delabie, and G. W. Fernandes, "A 15-year post evaluation of the fire effects on ant community in an area of Amazonian forest," *Revista Brasileira de Entomologia*, vol. 52, no. 1, pp. 82–87, 2008.
- [75] R. R. Silva, R. S. Machado Feitosa, and F. Eberhardt, "Reduced ant diversity along a habitat regeneration gradient in the southern Brazilian Atlantic Forest," *Forest Ecology and Management*, vol. 240, no. 1–3, pp. 61–69, 2007.
- [76] H. L. Vasconcelos, "Effects of forest disturbance on the structure of ground-foraging ant communities in central Amazonia," *Biodiversity and Conservation*, vol. 8, no. 3, pp. 409–420, 1999.
- [77] H. L. Vasconcelos, J. M. S. Vilhena, and G. J. A. Caliri, "Responses of ants to selective logging of a central Amazonian forest," *Journal of Applied Ecology*, vol. 37, no. 3, pp. 508–514, 2000.
- [78] M. J. Angilletta, R. S. Wilson, A. C. Niehaus, M. W. Sears, C. A. Navas, and P. L. Ribeiro, "Urban physiology: city ants possess high heat tolerance," *PLoS One*, vol. 2, no. 2, article no. e258, 2007.
- [79] E. Diehl, F. Sacchett, and E. Z. Albuquerque, "Riqueza de formigas de solo na praia da Pedreira, Parque Estadual de Itapuã, Viamão, RS, Brasil," *Revista Brasileira de Entomologia*, vol. 49, pp. 552–556, 2005.
- [80] I. R. Leal, A. G. D. Bieber, M. Tabarelli, and A. N. Andersen, "Biodiversity surrogacy: indicator taxa as predictors of total species richness in Brazilian Atlantic forest and Caatinga," *Biodiversity and Conservation*, vol. 19, no. 12, pp. 3347–3360, 2010.
- [81] D. T. Lopes, J. Lopes, I. C. do Nascimento, and J. H. Delabie, "Epigeic ants diversity (Hymenoptera, Formicidae) in three environments in Mata dos Godoy State Park, Londrina, State of Paraná, Brazil," *Iheringia - Serie Zoologia*, vol. 100, no. 1, pp. 84–90, 2010.
- [82] H. L. Vasconcelos and J. M. S. Vilhena, "Species turnover and vertical partitioning of ant assemblages in the Brazilian Amazon: a comparison of forests and savannas," *Biotropica*, vol. 38, no. 1, pp. 100–106, 2006.
- [83] R. R. Silva and R. Silvestre, "Riqueza da fauna de formigas (Hymenoptera: Formicidae) que habita as camadas superficiais do solo em Seara, Santa Catarina," *Papéis Avulsos de Zoologia*, vol. 44, pp. 1–11, 2004.
- [84] R. Silvestre and R. R. Silva, "Guildas de formigas da estação ecológica Jataí, Luiz Antônio – SP – sugestões para a aplicação do modelo de guildas como bio-indicadores ambientais," *Biotemas*, vol. 14, pp. 37–69, 2001.
- [85] S. Groc, J. H. C. Delabie, J. T. Longino et al., "A new method based on taxonomic sufficiency to simplify studies on Neotropical ant assemblages," *Biological Conservation*, vol. 143, no. 11, pp. 2832–2839, 2010.
- [86] C. A. Joly, R. R. Rodrigues, J. P. Metzger et al., "Biodiversity conservation research, training, and policy in São Paulo," *Science*, vol. 328, no. 5984, pp. 1358–1359, 2010.
- [87] A. Petherick, "High hopes for Brazilian science," *Nature*, vol. 465, no. 7299, pp. 674–675, 2010.
- [88] K. T. R. Wilkie, A. L. Mertl, and J. F. A. Traniello, "Biodiversity below ground: probing the subterranean ant fauna of Amazonia," *Naturwissenschaften*, vol. 94, no. 9, pp. 725–731, 2007.
- [89] J. H. Lawton, D. E. Bignell, B. Bolton et al., "Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest," *Nature*, vol. 391, no. 6662, pp. 72–76, 1998.
- [90] C. R. Ribas, R. R. C. Solar, R. B. F. Campos, F. A. Schmidt, C. L. Valentim, and J. H. Schoederer, "Can ants be used as indicators of environmental impacts caused by arsenic?" *Journal of Insect Conservation*. In press.
- [91] C. R. Ribas, F. A. Schmidt, R. R. C. Solar, R. B. F. Campos, C. L. Valentim, and J. H. Schoederer, "Ants as indicators of the success of rehabilitation efforts in deposits of gold mining tailings," *Restoration Ecology*. In press.
- [92] B. T. Bestelmeyer, D. Agosti, L. E. Alonso et al., "Field techniques for the study of ground dwelling ants. An overview, description, and evaluation," in *Ants: Standard Methods for Measuring and Monitoring Biodiversity*, D. Agosti, J. D. Majer, L. E. Alonso, and T. R. Schultz, Eds., pp. 122–144, Smithsonian Institution Press, London, UK, 2000.
- [93] J. R. Gollan, L. L. D. Bruyn, N. Reid, D. Smith, and L. Wilkie, "Can ants be used as ecological indicators of restoration progress in dynamic environments? A case study in a revegetated riparian zone," *Ecological Indicators*, vol. 11, no. 6, pp. 1517–1525, 2011.
- [94] B. D. Hoffmann, "Using ants for rangeland monitoring: global patterns in the responses of ant communities to grazing," *Ecological Indicators*, vol. 10, no. 2, pp. 105–111, 2010.
- [95] R. R. Dunn, "Recovery of faunal communities during tropical forest regeneration," *Conservation Biology*, vol. 18, no. 2, pp. 302–309, 2004.
- [96] J. D. Majer, J. E. Day, E. D. Kabay, and W. S. Perriman, "Recolonization by ants in bauxite mines rehabilitated by a number of different methods," *Journal of Applied Ecology*, vol. 21, no. 1, pp. 255–257, 1984.

- [97] J. D. Majer and O. G. Nichols, "Long-term recolonization patterns of ants in Western Australian rehabilitated bauxite mines with reference to their use as indicators of restoration success," *Journal of Applied Ecology*, vol. 35, no. 1, pp. 161–182, 1998.
- [98] O. G. Nichols and F. M. Nichols, "Long-term trends in faunal recolonization after bauxite mining in the Jarrah forest of Southwestern Australia," *Restoration Ecology*, vol. 11, no. 3, pp. 261–272, 2003.
- [99] D. C. Cardoso, T. G. Sobrinho, and J. H. Schoederer, "Ant community composition and its relationship with phytophysiognomies in a Brazilian Restinga," *Insectes Sociaux*, vol. 57, no. 3, pp. 293–301, 2010.
- [100] M. A. McGeoch, B. J. Van Rensburg, and A. Botes, "The verification and application of bioindicators: a case study of dung beetles in a savanna ecosystem," *Journal of Applied Ecology*, vol. 39, no. 4, pp. 661–672, 2002.
- [101] A. Nakamura, C. P. Catterall, A. P. N. House, R. L. Kitching, and C. J. Burwell, "The use of ants and other soil and litter arthropods as bio-indicators of the impacts of rainforest clearing and subsequent land use," *Journal of Insect Conservation*, vol. 11, no. 2, pp. 177–186, 2007.
- [102] G. R. Pohl, D. W. Langor, and J. R. Spence, "Rove beetles and ground beetles (Coleoptera: Staphylinidae, Carabidae) as indicators of harvest and regeneration practices in western Canadian foothills forests," *Biological Conservation*, vol. 137, no. 2, pp. 294–307, 2007.
- [103] R. A. da Mata, M. McGeoch, and R. Tidon, "Drosophilid assemblages as a bioindicator system of human disturbance in the Brazilian Savanna," *Biodiversity and Conservation*, vol. 17, no. 12, pp. 2899–2916, 2008.
- [104] T. A. Gardner, J. Barlow, I. S. Araujo et al., "The cost-effectiveness of biodiversity surveys in tropical forests," *Ecology Letters*, vol. 11, no. 2, pp. 139–150, 2008.
- [105] G. F. Smith, T. Gittings, M. Wilson et al., "Identifying practical indicators of biodiversity for stand-level management of plantation forests," *Biodiversity and Conservation*, vol. 17, no. 5, pp. 991–1015, 2008.
- [106] Y. Basset, J. F. Mavoungou, J. B. Mikissa et al., "Discriminatory power of different arthropod data sets for the biological monitoring of anthropogenic disturbance in tropical forests," *Biodiversity and Conservation*, vol. 13, no. 4, pp. 709–732, 2004.
- [107] Y. Basset, O. Missa, A. Alonso et al., "Changes in arthropod assemblages along a wide gradient of disturbance in gabon," *Conservation Biology*, vol. 22, no. 6, pp. 1552–1563, 2008.
- [108] S. M. Philpott, W. J. Arendt, I. Armbrecht et al., "Biodiversity loss in Latin American coffee landscapes: review of the evidence on ants, birds, and trees," *Conservation Biology*, vol. 22, no. 5, pp. 1093–1105, 2008.
- [109] M. Kessler, S. Abrahamczyk, M. Bos et al., "Alpha and beta diversity of plants and animals along a tropical land-use gradient," *Ecological Applications*, vol. 19, no. 8, pp. 2142–2156, 2009.



Hindawi

Submit your manuscripts at
<http://www.hindawi.com>

