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Deadly trap or sweet home? The case of discarded containers as novelty microhabitats for ants

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ABSTRACT

The presence of anthropogenic waste in the environment is one of the most pervasive pollution problems affecting wildlife around the world. Among different types of rubbish, beverage containers represent an ecological trap for invertebrates. However, it also may serve as a nest site. In the present study, we aim to assess if ants can exploit discarded containers as nesting sites, the intensity of mortality of ant workers foraging discarded containers, and ant preferences toward particular features of containers. The study was conducted in September 2018 in 10 woodland areas in the city of Wrocław, Poland. In total, 4.4% of 939 collected containers were used as nest sites by four ant species. Additionally, we found 698 dead workers, representatives of at least 11 species, in 10.3% of investigated containers. Most frequently, ants inhabited brown plastic and glass bottles, and an increase in neck diameter of containers decreased the possibility of nest occurrence. Dead workers were marginally significantly more often found in colourless glass bottles when compared to brown ones and were more frequent in sweet drink and vodka bottles than in beer bottles. Additionally, larger capacity increased the frequency of occurrence of dead ants. Although ants use anthropogenic waste as nest sites, it predominantly appears as a threat for foraging ant workers, most probably attracted by the smell of fermenting beverages or decomposing carcasses of previously trapped animals. Thus, to protect species inhabiting human-disturbed habitats, we suggest developing tools helping to prevent the accumulation of waste in urban woodlands.

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1. Introduction

Human alteration of the environment has led to the global loss of biodiversity, and insects are considered as one of the most vulnerable to such changes (Butchart et al., 2010; Bidau, 2018; Sánchez-Bayo and Wyckhuys, 2019; Cardoso et al., 2020). Recent studies show a drastic decline of 75% flying insect biomass in 63 nature protection areas in Germany over the last 27 years (Hallmann et al., 2017) and arthropod biomass losses between 78% and 98% over a 36 years-long period in rainforests of Puerto Rico (Lister and Garcia, 2018). Moreover, a global analysis of reports focused on the decline of entomofauna estimates that 40% of them are threatened with extinction and may disappear over the next few decades (Sánchez-Bayo and Wyckhuys, 2019). However, there are also documented cases of insects capable of adapting and using highly human-altered habitats, and even increase their abundance and/or diversity in local refuges (Eversham et al., 1996; Baranová et al., 2015; Heneberg et al., 2016). In agricultural and forest areas, quarries or waste dump sites can constitute habitats suitable for flies and soil-dwelling invertebrates such as harvestmen, beetles or orthopteroids (Heneberg and Řezáč, 2014; Baranová et al., 2015; Heneberg et al., 2016; De Smedt and Van de Poel, 2017; Oboňa et al., 2018). It is also well known that urban areas provide refuges for rare and/or threatened species and are essential for the conservation of some invertebrates (Jones and Leather, 2012; Dyderski et al., 2017). Also, different green zones in human-disturbed habitats, such as woodlands, parks, green infrastructure in housing estates, wastelands, etc. are favourable for different groups of invertebrates (Uno et al., 2010; Dylewski et al., 2019).

Ants, because of their high species diversity and abundance, and occupation of a large variety of niches, are commonly used as a model in biomonitoring and ecological studies (Hölldobler and Wilson, 1990; Andersen and Majer, 2004; Underwood and Fisher, 2006). They are also an example of animals with a broad spectrum of potential nesting sites. For example, they use soil, leaf litter, tree trunk, or small twigs as a material for nest construction (for more details, see Hölldobler and Wilson, 1990). During the selection of nesting sites, ants can show specific preferences towards the size of the entrance, or darkness and internal height of the cavity (Franks et al., 2003). The durability of nests is very variable within species. In some, a fixed nest location is chosen by a queen after her nuptial flight. By contrast, other species manifest high flexibility. The colony can move to a new location due to environmental changes (e.g., food resources decline) or destruction of currently occupied nests (e.g., Foitzik and Heinze, 1998).

Some species demonstrate high plasticity and can build their nests in snail shells, hollow twigs, acorns, in bird nests on the ground, and also in human-made, artificial sites (Philpott and Foster, 2005; Offenberg, 2014; Jimenez-Soto and Philpott, 2015; Maziarz et al., 2018). Urban areas and green zones, like parks and woodlands, play an essential role in the maintenance of their populations (Pacheco and Vasconcelos, 2007; Ślipiński et al., 2012). A recent study documented a high density of *Myrmica rubra* in sites abundant in anthropogenic waste, which was used as a resource for artificial nesting sites (Michlewicz and Tryjanowski, 2017). In areas used by people to discard waste, nests were located exclusively inside clothes, tires, jars, cans, bottles, etc.

In recent years, the amount of waste in the environment has increased dramatically, especially in and around urban areas (Thompson et al., 2009; Kaza et al., 2018). Much of it, e.g. bottles and cans, constitute a deadly ecological trap for small animals, mainly mammals and invertebrates (Benedict and Billeter, 2004; Kolenda et al., 2015; Poeta et al., 2015; Moates, 2018; Lavers et al., 2019). Hitherto, ants were listed as victims of such traps in suburban forests and abandoned buildings (Kolenda et al., 2015; Najbar et al., 2018). Although, our principal and ongoing project targets studies on anthropogenic waste, with particular focus on bottles and cans, and its impact on the mortality of entomofauna, here we specifically investigate if there are ant species manifesting preference towards nesting in such waste to determine whether it can become an ecological trap for them. Thus, the present study aims to assess: (i) species richness of ants establishing their nests in discarded containers; (ii) ant preferences toward containers which they choose for nests; (iii) species richness and intensity of mortality of ant workers foraging in discarded containers; (iv) features of containers that pose the major threat for ant workers. We assume that containers could impact ants in two ways: as alternative nesting sites and ecological traps. However, the latter and negative role should be predominant. We also hypothesise that containers with dark colouration, which to some extend can resemble conditions provided by natural habitats, would be chosen as nesting sites more often than containers with other colouration.

2. Materials and methods

2.1. Material collection

The study was conducted in September 2018 in the city of Wrocław, south-western Poland. Ten woodlands varying between 16 and 139 ha and located mainly in river valleys were selected. Most of the sampling sites were dominated by oak-hornbeam and riparian habitats. However, some were strongly impacted by human activity. We sampled 100 uncapped, discarded containers (bottles or cans) at each site, fewer only when 100 items were not obtainable. Containers were collected by two investigators (K. Kolenda and N. Kuśmierek) in a 10-m-wide buffer along paths starting at the entrance to each site. If ants were using selected waste as a nesting site, it was left in situ. For species determination, we collected only a few workers from each colony. Collected specimens were preserved in 75% ethanol. The remaining collected containers were transported to the laboratory for further analyses. In search of remains of dead ants, the contents of these containers was poured into plastic trays. All dead specimens were counted. If the number of specimens was impossible to estimate due to body fragmentation or decomposition, the number was noted based on available body fragments and classified to the lowest possible

Table 1
The variables used for the container description in analyses of the relationships between effect of container features on the occurrence of ant nest and mortality of ant workers.

Variable	Abbrev.	Variable type/unit	Values
Capacity	CAP	Numeric (ml)	75-5000, mean = 595, SD = 404
Opening diameter	DIA	Numeric (mm)	10-43, mean = 18, SD = 5
Material	MAT	Categorical	“Glass” or “Plastic” or “Aluminium”
Presence of neck	NECK	Categorical	“Yes” or “No”
Colour	COL	Categorical	“Brown” or “Green” or “Colourless”
Original content	CON	Categorical	“Water” or “Beer” or “Vodka” or “Sweet”

level. We documented the following traits of all investigated containers, including those used as nesting sites: capacity (CAP), opening diameter (DIA), material (MAT), presence of neck (NECK), colour (COL), and original content (CON).

Due to (i) small sample size of some classes and (ii) overlapping of some variables (e.g., COL nested in MAT), we used only selected variables and values of categorical variables for statistical analyses (Table 1). The main factor included for the data analyses (for ant nests and dead ant workers) was material used in container production (“Plastic” or “Glass” or “Aluminium”), and the size of the subclass (>50).

2.2. Statistical analyses

Both, the preferences of ants towards categorical variables (features) of containers chosen as a nesting sites, and the differences in the frequency of dead ant workers across container category, were tested using Chi-squared. In cases where sample size <5, we used Fisher’s exact test. Bonferroni correction was used to eliminate type II error due to multiple tests. Additionally, a similar analysis was performed to compare proportions of containers without dead ants with a proportion of containers in which we found the highest number of dead ants (minimum 5 per container). For assessing the effect of a given feature of containers on the presence of ant nests or dead workers, the appropriate subclasses were selected (Table A1). In the case of original contents (CON), factor level differed between materials; in some cases the sample size was very small or even zero for a given category. For example, “vodka” (including other high alcohol drinks such as whiskey, bourbon, etc.) were not noted in plastic containers. Therefore, sweet beverages, water, and beer were considered in the analysis of plastic containers, while sweet drinks, beer, and vodka were included in the analysis of glass containers.

As many subclass sizes were small (N < 10), a multivariate pattern of nest presence/absence could not be analysed with the use of a full six-variable model. Instead, a combination of two numerical variables (DIA and CAP) and a single categorical variable were applied (Table A2). To recognize the relationships between presence/absence patterns (both for ant nests and dead ant workers) and multiple container features, the generalized linear model (GLZ) was applied with binomial error distribution and logit link function. Differences in the mean number of dead ant workers between those found in bottles and cans were compared using the Mann-Whitney *U* test. Statistical analyses were carried out using Statistica 12 software (StatSoft, Inc. 2014).

3. Results

3.1. Nests in bottles and cans

Forty-one (4.4%) of 939 collected containers were used as artificial nest sites by four ant species: *Myrmica rubra* (26 nests), *M. ruginodis* (7), *Lasius niger* (7), and *Temnothorax crassispinus* (1) (Fig. 1). The latter one was found in colourless bottle of vodka (200 ml, 18 mm hole diameter), and its nest was partially located in a shell of *Cepaea nemoralis*.

The nests were found in 0–16.7% of considered container categories, and most of the assessed features did not affect the frequency of nests (Table 2, Fig. 2). However, in the case of bottles, the presence of a nest was, in general, significantly related to bottle colouration. Brown plastic and glass bottles were inhabited the most frequently. Within the class of glass bottles, the

Fig. 1. Examples of containers used by ants as nest site: A – glass bottle with the partially built-up entrance, B – plastic bottle.

Table 2
Number and percentages of containers with and without ant nests, and statistical significance of the difference in relation to container feature.

	Present		Absent		P in Test Chi-squared (C) or Fisher exact test (F)
	N	%	N	%	
Material					
Aluminium	4	2.7	142	97.3	0.53 (F)
Glass	27	4.5	579	95.5	
Plastic	10	5.4	176	94.6	
Presence of neck					
Yes	26	4.6	540	95.4	0.87 (C)
No	11	4.9	215	95.1	
Bottle colour					
Colourless	10	2.8	346	97.2	<0.001 (F)
Brown	23	9.7	213	90.3	
Green	0	0.0	176	100.0	
Plastic bottle colour					
Colourless	5	3.4	142	96.6	0.24 (F)
Brown	1	16.7	5	83.3	
Green	0	0.0	10	100.0	
Glass bottle colour					
Colourless	5	2.4	204	97.6	<0.001 (F)
Brown	22	9.6	208	90.4	
Green	0	0	166	100.0	
Original content in plastic containers					
Sweet drink	4	6.1	62	93.9	0.08 (F)
Water	1	1.4	72	98.6	
Beer	1	16.7	5	83.3	
Original content in glass containers					
Sweet drink	1	2.6	37	97.4	0.83 (F)
Beer	22	5.4	389	94.6	
Vodka	4	3.9	98	96.1	

frequency of nests in brown bottles (9.6%) was significantly higher than in colourless (2.4%) and green (0.0%) ones ($P = 0.002$ and $P < 0.001$ in Fisher's exact test, respectively). The frequency of nests in colourless bottles was marginally significantly higher than in green bottles ($P = 0.07$ in Fisher's exact test). The pattern found in plastic bottles was similar. However the level of statistical significance was lower, presumably due to smaller sizes within each subclass.

In multivariate logistic regressions of nest occurrence on the MAT, NECK, COL, and CON effect (together with DIA and CAP), statistically significant effects were found in the cases of MAT and NECK (Table A3). In both models, an increase in NECK diameter decreased the possibility of nest occurrence. When MAT was considered, the nests were located significantly more frequently in plastic containers, and significantly less frequently in containers made of aluminium, when compared to glass containers in both cases (Table A4). The model for the COL effect was assessed as unreliable (Table A3).

3.2. Dead workers in containers

Dead ant workers, members of three subfamilies, were found in 97 (10.3% of all) containers (Table 3). Nineteen of them contained corpses of more than one taxon. In total, at least 698 ants died in collected containers (mean $7.2 \pm SD = 16.5$ per container with detected ant workers, range 1–107). Ant carcasses were found in 86 bottles (10.9% of all bottles; mean $7.02 \pm SD = 11.6$) and 11 cans (7.5%; mean $8.54 \pm SD = 16.2$), and there was no significant difference in the mean number of dead ants between types of containers (Mann-Whitney *U* test, $U = 498.5$, $p = 0.64$). At the subfamily level, the most numerous was Formicinae (4 species, 359 carcasses) followed by Myrmicinae (6 species, 290 carcasses) and Dolichoderinae (2 specimens of 1 species) (Table 3). Due to the advanced decomposition stage of 49 individuals, their determination to the subfamily level was impossible.

Dead ant workers were found in 0%–23.7% of considered container categories, and none of container features affected their frequency (Table 4, Fig. 3). A marginal statistical effect was found in glass bottle colour ($P = 0.06$), where the dead ants occurred more frequently in colourless bottles than brown bottles. A second marginal significant effect ($P = 0.03$) occurred in the case of CON analysis. Dead ants were found greater than two-fold more frequently in sweet drink bottles and vodka bottles than in beer bottles. The comparison of the frequency of empty containers with those with the highest number of dead workers ($N > 5$) did not reveal any significant relationship (Table 4).

Logistic regression of occurrence of dead workers in containers on the MAT, NECK, COL, and CON, combined with DIA and CAP, showed a statistically significant and positive effect of CAP (where larger CAP increased the frequency of occurrence of dead ants; Table A5). Marginally significant relationships between the presence of dead ant and COL ($P = 0.055$) occurred due to a weak positive effect ($OR = 1.6$, $P = 0.02$) of colourless containers and marginally negative significant effect ($P = 0.08$) of

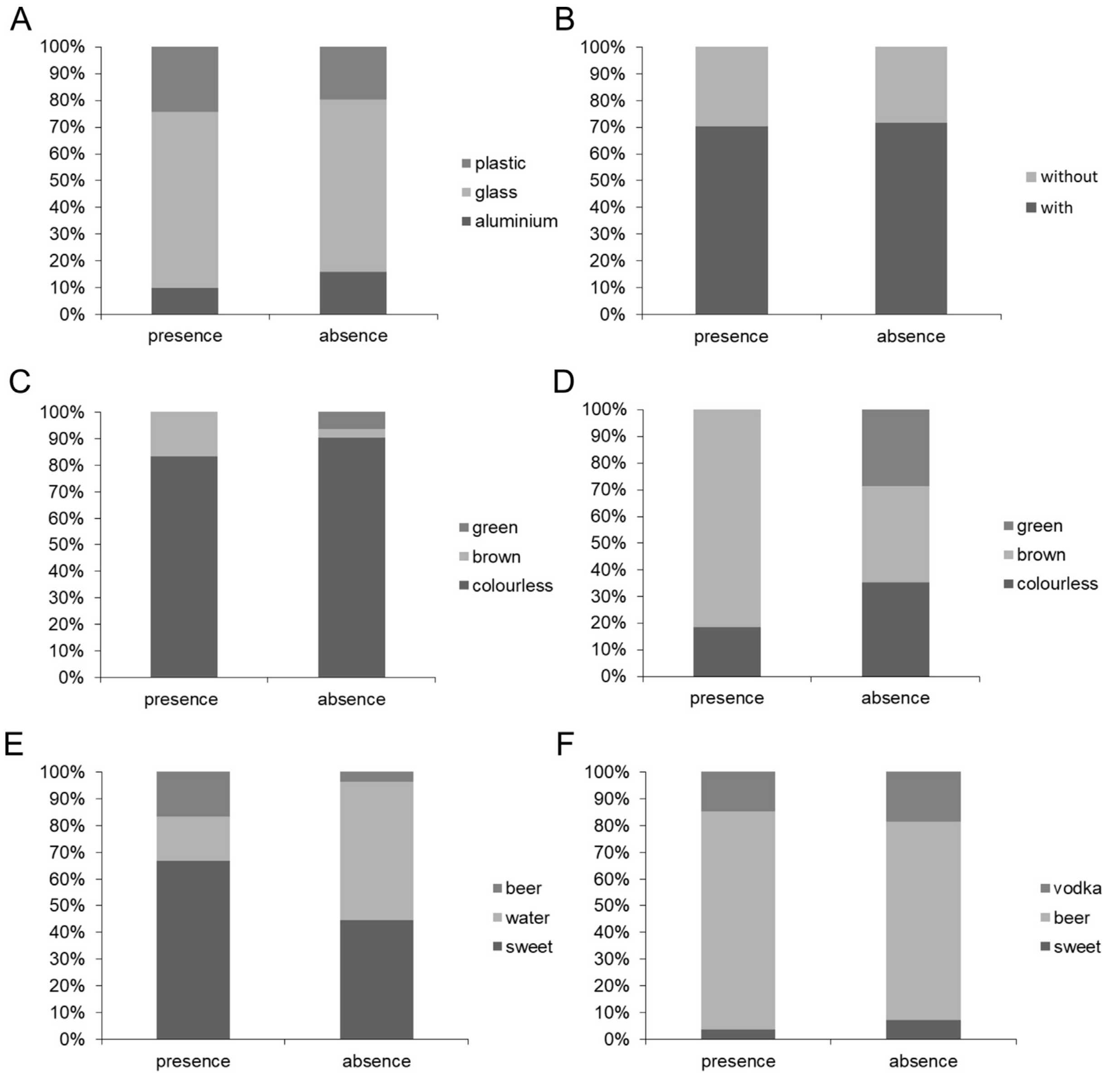

Fig. 2. Percentage share of presence/absence of ant nest in particular container feature: A – material, B – neck, C – plastic bottle colour, D – glass bottle colour, E – plastic bottle content, F – glass bottle content.

brown colour (OR = 0.8) (Table A6). Also, a marginal significant relationship between the presence of dead ants and CON (P = 0.06) resulted from a positive effect (OR = 3.2, P = 0.019) of sweet contents (Table A7).

4. Discussion

Our study is the very first confirmation of usage of discarded containers as alternative nesting sites by at least four ant species. However, those four species are also listed among the most prone to suffer from containers as traps. Thus, we suppose that other species characterised by similar biology and body size may also use human-made products as nesting sites. The only exception in our study is *Formica* spp. – a common container victim. Despite the abundance of its workers in containers, we excluded the possibility of choosing bottles or cans as nesting sites. This assumption is due to the distinct nesting preferences of *Formica* spp. Which usually establish colonies in big, self-constructed, and dome-shaped mounds (Robinson, 2004).

Our results contribute to a better understanding of the impact of progressive degradation of natural environments on insects and highlight the ecological flexibility of some species. The vast majority of studies focused on investigating the impact of environmental pollution (at a different scale) on insects show a negative correlation (e.g. Khaliq et al., 2014).

Table 3
Species list of ant dead workers found in discarded containers.

Subfamily	Species	No of individuals	No of containers
Dolichoderinae	*Dolichoderus quadripunctatus* (Linnaeus, 1771)	2	2
Formicinae	*Formica rufa* Linnaeus, 1761	93	3
	Formica sp.	126	7
	Lasius brunneus (Latreille, 1798)	1	1
	Lasius fuliginosus (Latreille, 1798)	2	1
	Lasius niger (Linnaeus, 1758)	10	7
	Lasius sp.	125	12
Myrmicinae	*Myrmica rubra* (Linnaeus, 1758)	82	24
	Myrmica ruginodis Nylander, 1846	108	26
	Myrmica rugulosa (Nylander, 1849)	2	1
	Myrmica scabrinodis Nylander, 1846	1	1
	Myrmica sp.	42	17
	Solenopsis fugax (Latreille, 1798)	1	1
	Temnothorax crassispinus (Karavaiev, 1926)	46	5
	Temnothorax sp.	7	2
	Undetermined	1	1
Undetermined		49	8

Table 4
Number and percentages of containers with and without dead ant workers, and statistical significance of the difference in relation to container feature.[1] – analyses of containers with dead workers regardless their number,[2] – analyses of containers with the highest number of dead workers (minimum 5 per container).

	Present				Absent			P in Test Chi-squared or Fisher exact test (F):
	All containers		With >5 dead workers					
	N	%	N	%	N	%[1]	%[2]	
Material								
Aluminium	11	7.5	2	1.5	135	92.5	98.5	0.45 (C)[1]
Glass	67	11.1	12	2.2	539	88.9	97.8	0.75 (F)[2]
Plastic	19	10.2	5	2.9	167	89.8	97.1	
Presence of neck								
Yes	30	5.6	10	1.9	506	94.4	98.1	0.11 (C)[1]
No	9	4.3	7	3.4	200	95.7	96.6	0.28 (C)[2]
Colour								
Colourless	21	6.3	6	1.9	310	93.7	98.1	0.11 (C)[1]
Brown	6	2.7	7	3.1	218	97.3	96.9	0.61 (F)[2]
Green	11	6.6	3	1.9	156	93.4	98.1	
Plastic bottle colour								
Colourless	15	10.2	Too small sample sizes		132	89.8	–	0.37 (F)
Brown	0	0.0			6	100.0	–	
Green	2	20.0			8	80.0	–	
Glass bottle colour								
Colourless	31	14.8	4	2.2	178	85.2	97.8	0.06 (C)[1]
Brown	18	7.8	7	3.2	212	92.2	96.8	0.30 (F)[2]
Green	18	10.8	1	0.7	148	89.2	99.3	
Original content in plastic containers								
Sweet drink	8	12.1	Too small sample sizes		58	87.9	–	1.00 (F)
Water	9	12.3			64	87.7	–	
Beer	0	0.0			6	100.0	–	
Original content in glass containers								
Sweet drink	9	23.7	1	3.3	29	76.3	96.7	0.03 (C)[1]
Beer	43	10.5	10	2.6	368	89.5	97.4	0.24 (F)[2]
Vodka	9	23.7	0	0.0	93	91.2	100	

However, here we present examples of ants being able to adapt end exploit disturbed habitats. So far, similar results have been revealed in beetles, isopods, hymenopterans, spiders, and other soil macrofauna, of which higher diversity inhabits waste dumps in contrast to surrounding habitats (Baranová et al., 2015).

Our results revealed that in some cases, containers can be used as nesting sites by at least four ant species. It is worth mentioning that in examined samples of nests, the internal walls of bottles and cans were usually covered with soil, and the entrance was partially blocked up with the only a small hole remaining (Fig. 1A). It is unclear whether the presence of soil inside those containers was a factor stimulating ants to establish nests inside them, or if soil accumulation was an effect of worker activity. We assume that soil can provide more stable microclimatic conditions inside containers. Three of the species found here: *Myrmica rubra*, *M. ruginodis*, and *Lasius niger*, when found in the natural environment, nest in soil, usually under

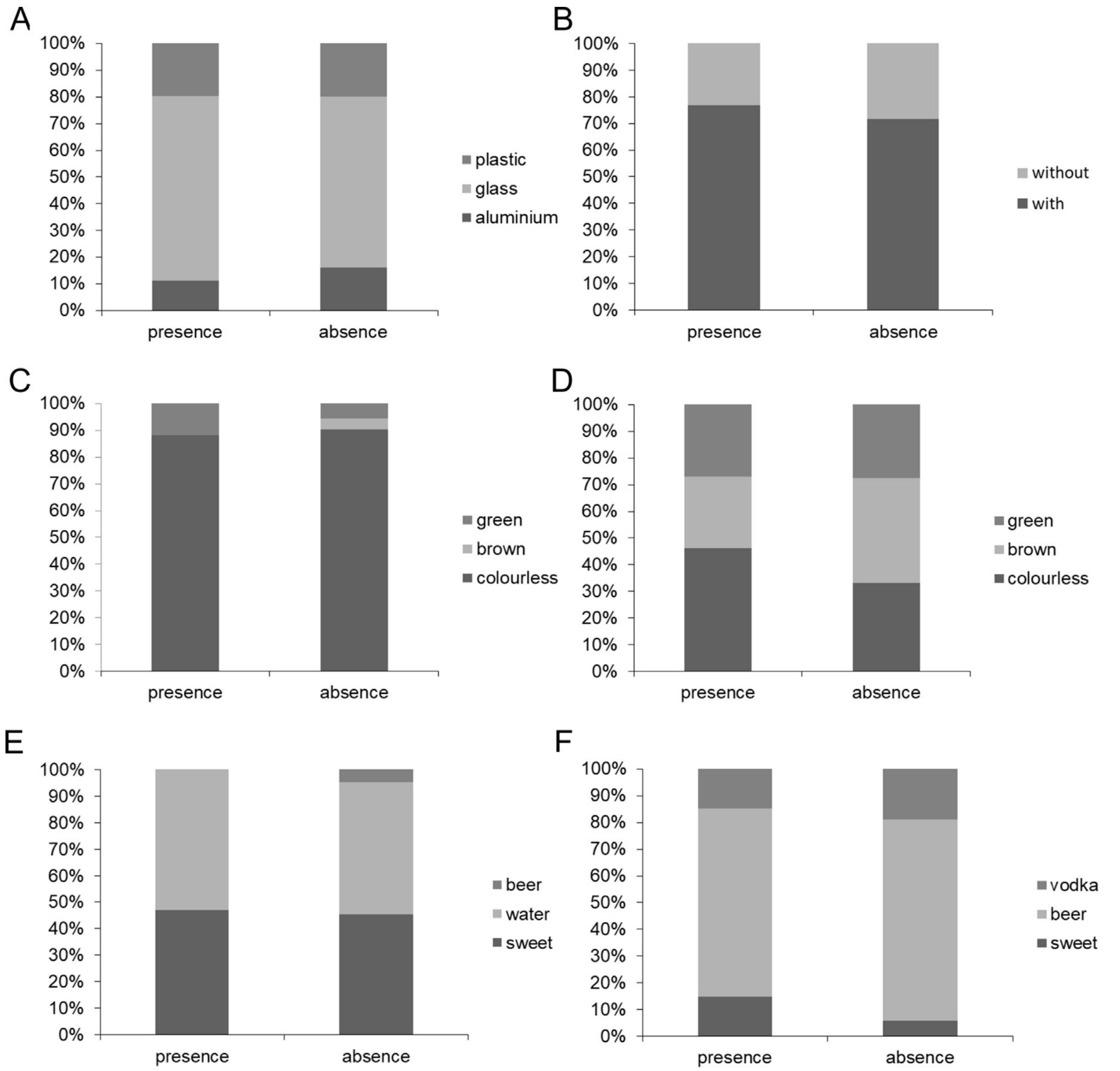

Fig. 3. Percentage share of presence/absence of dead ant workers in particular container feature: A – material, B – neck, C – plastic bottle colour, D – glass bottle colour, E – plastic bottle content, F – glass bottle content.

rocks or rooting branches (Czechowski et al., 2012). Therefore, we assume that the significant predominance of brown colouration of containers used as nests suggests that they prefer containers resembling their natural nesting sites. It cannot be excluded that choice of containers where soil covers the walls or brown colours is driven by protection against UV transmission, especially considering that brown is one of the best colours for blocking light (Lennersten, 1995). This requires further studies.

The only nest of *Temnothorax crassispinus* was found in a colourless bottle, but it also was partially located in a shell of *Cepaea nemoralis*. Acorn ants, in their natural environment, are commonly found inside shells or acorns (Seifert et al., 2013). Thus, we assume that the presence of the shell inside the bottle strongly contributed to choosing this container as a nesting site. In this case, the container played a dual role. It trapped and caused the death of a snail and therefore provided conditions suitable for *T. crassispinus*. However, we don't know if the abundance of shells inside containers is higher than in undisturbed localities and if the frequency of nests of acorn ants inside them differ between those habitats. This subject requires further investigation. However, this case shows that discarded containers may become a nest indirectly. During collecting of study material, we commonly found containers with acorns, probably collected by rodents, or empty snail shells, and numerous papers reveal that both acorns and shells are exploited by some invertebrates as shelters (Karlik et al., 2016; Bogusch et al., 2019).

Based on available data, among these four taxa nesting in containers, only *Temnothorax crassispinus* does not move its colony into deeper layers of soil to overwinter (Herbers, 1989; Herbers and Johnson, 2007; Mitrus, 2013). Probably this behavior allows the species to preserve good nesting sites and respond quickly to warm temperatures in spring to access resources faster than species overwintering underground (Mitrus, 2013). However, it is unknown if containers provide conditions promoting them as overwintering shelters for *Temnothorax*. Additionally, we were not able to verify if *Myrmica* spp. and *Lasius* spp. relocate their colonies from containers to soil during colder seasons. If they do, it should be checked if colonies reuse the same containers next season. A study on the phenology of those taxa will allow the determination of when, if at all, containers are not exploited by ants. This information should enable estimating when waste removal is least harmful to invertebrate biodiversity.

Our study also revealed a ‘dark side’ to discarded containers. Around 10% of them turned out to be an ecological trap for ants. Interestingly, the containers with dead ant bodies usually had damp walls, which could hinder escape. Often, we located a single carcass per bottle, and rarely did the number exceeded several or a dozen individuals. The highest numbers per container were noted within *Formica* spp. This observation could be explained by possible proximity of nests or secretion of alarm pheromones by trapped workers, which attracted more workers involved in rescue (Kleineidam et al., 2017).

We hypothesise that the main attractant luring foragers to enter containers is the smell of decomposing animal carcasses and/or fermenting beverages. It could explain the prevalence of predatory and omnivorous ant species among trapped specimens. *Myrmica* spp. appear to be most vulnerable to being trapped by containers, and we assume that it is due to their predatory nature, and the fact that they forage mainly on the ground surface and nest in soil (Czechowski et al., 2012). The same explanation could be applied to *Lasius niger* and undetermined *Lasius* sp., as all belong to the *Lasius niger-platythorax* complex (Czechowski et al., 2012). Most interesting are records of arboreal species nesting and foraging almost exclusively or predominantly above ground level, i.e., *Dolichoderus quadripunctatus*, *Lasius brunneus,* and *L. fuliginosus*. The main diet component for both *Lasius* species is honeydew (Czechowski et al., 2012). Thus, sweet, and fermenting beverages could attract those species. *Dolichoderus quadripunctatus* is considered to be predatory species foraging almost exclusively on trees. However, there are records of this species feeding on honeydew (Czechowski et al., 2019). Therefore, containers could possibly attract workers of this species as well. *Temnothorax crassispinus* is the most common acorn ant species in Poland. Its colonies are relatively small (100–200 workers) and tend to temporarily divide into smaller units during summer (Czechowski et al., 2012). Three of the investigated containers had more than 10 dead *Temnothorax* workers inside, that could suggest that they were chosen as temporary nesting sites and caused the death of at least some of their inhabitants. As we mentioned before, containers can threaten acorn ants in a dual way. One is by attracting foraging workers to the smell of rotting carcasses or fermenting beverages. The second one, which is a threat for the whole colony, is by providing potentially attractive nesting sites in the form of acorns, stored in containers by small mammals, or empty shells of previously trapped snails.

Myrmecofauna of Wrocław is poorly known. Hence, it is difficult to estimate a percentage of ant species threatened by wasted containers. However, results published in the last two decades reveal that Wroclaw green areas host uncommon ant species (Borowiec and Borowiec, 2013; Borowiec and Salata, 2018). The city provides habitats suitable especially for more thermophilic species. For example, the very first Polish record of *Colobopsis truncata* comes from the old park of the city (Borowiec, 2007). Acorn and slender ants of Wrocław are also rich in rare taxa (Borowiec, 2009), e.g., *Temnothorax clypeatus*, *T. corticalis,* and *Leptothorax gredleri*. Thus, empty bottles and cans containing fermenting beverages can pose a dangerous threat to those species. A study of ant species diversity performed in Warsaw, Poland revealed the occurrence of 27 species, of which 19 were detected in urban woodlands (Ślipiński et al., 2012). All ant taxa recorded in our study were also found in Warsaw. It could imply that several urban ant species are exposed to threats arising from the presence of discarded containers. However, to assess the number of ant species that are truly threatened by discarded containers, further research should focus on the comparison of ant species that nest (or die) in discarded rubbish with other species nesting in nearby clean habitats. Additional studies should be supplemented by an inventory of ants nesting or foraging below discarded containers, which can provide attractive niches for rare epigeic taxa (e.g. *Ponera* spp.).

Our research concerned ant species and their possible interaction with discarded bottles and cans. The generic conclusions correspond with similar studies on other hymenopterans. Sandilyan (2014), during an 8-h observation, found more than 800 dead bees *Melipona irridipennis* in a single dustbin filled with disposable paper cups containing leftovers of sweet drinks. While Chandrasekaran et al. (2011), during a 30 day long study, recorded a mass death of 25000 honey bees lured by sugar filling disposed cups thrown into bins near five coffee bars in India.

5. Conclusions

Despite the increase of articles addressing research on urban ants, there is still little known about their adaptive potential in littered habitats, and there are no practical recommendations for the conservation of biodiversity of urban green areas (Santos, 2016; Michlewicz and Tryjanowski, 2017). Our study revealed that epigeic ant species can use empty bottles and cans as alternative nesting sites. Containers can provide conditions suitable for colonies directly or indirectly. We now understand all cases when ants directly use the interior of bottles as nesting sites. As an example of an indirect way, we define a situation when ants inhabit shells or acorns located in containers. However, these results require further studies. It is still unknown whether containers are used as temporary or permanent nesting sites, and if ants use them to overwinter. It is also unknown whether ants recolonize the same containers after overwintering in the soil. In any case, our results confirmed that some ant species exploit waste as an alternative nesting site (see also Michlewicz and Tryjanowski, 2017).

Additionally, our results showed that containers appear as a threat for foraging ant workers probably attracted by the smell of fermenting beverages or decomposing carcasses of animals previously trapped in bottles and cans. We suppose that the deadly effects of this ecological trap overweigh the positive effects of a new niche for nest sites. We are aware that further research is required to confirm this thesis. We suggest that developing tools helping to prevent the accumulation of waste in urban woodlands (such as raising of public awareness, recycling programs, cleaning activities involving citizens, placing more bins in the entrance to woodlands, etc.) could contribute to ant and terrestrial invertebrates conservation in human-disturbed habitats.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2020.e01064.

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