Bottled & canned – Anthropogenic debris as an understudied ecological trap for small animals

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Bottled & canned – Anthropogenic debris as an understudied ecological trap for small animals

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HIGHLIGHTS

- Invertebrates and small vertebrates are negatively affected by discarded containers
- 56% of beverage containers collected in urban woodlands contained dead animals
- The most common functional groups were predators, phytophages, and saprophages
- Container capacity and material were positively associated with the number of dead animals
- Mortality in containers can seriously affect animal populations worldwide

GRAPHICAL ABSTRACT

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ABSTRACT

Nowadays, littering is one of the biggest challenges that environmental conservation is facing. Although beverage containers, such as bottles and cans, belong to the most common threats in this context, their effect on animals has been poorly studied. The aim of this study was to assess the diversity and mortality level of the animal taxa entering discarded containers and to investigate which container features influence the number and functional composition of the trapped animals. The study was conducted in 10 urban woodlands in the city of Wrocław, Poland. In total, 939 open containers were collected. In 56% of them, a total number of 10,162 dead individuals (10,139 invertebrates and 23 vertebrates) was found. The most common amongst them were insects (orders: Coleoptera, Diptera, Hymenoptera), malacostracans (Isopoda), arachnids (Opiliones, Sarcoptiformes) and gastropods (Stylommatophora). The number of dead animals was affected positively by the container capacity and was significantly higher in glass and plastic bottles when compared to aluminium cans. At the same time, the presence of a neck negatively affected the number of dead animals. Container capacity was also positively correlated with the abundance of the most common functional groups: predators, phytophages and saprophages. Moreover, colourless and green, but not brown, containers were a

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significant predictor for the abundance of the latter two groups. Our study revealed that discarded containers constitute an ecological trap for many groups of animals. There is an urgent need to reduce the amount of rubbish in the environment by, for example, the implementation of regional and international regulations addressing the problem of littering, or organising repeated clean-up and educational activities.

1. Introduction

Human impact on the environment leads to drastic and rapid changes or even loss of habitats. When human impacts occur more rapidly than behavioural adaptation of animals, e.g. habitat selection decision, previous responses may become maladaptive, i.e. they may create an 'evolutionary trap' (Schlaepfer et al., 2002; Robertson et al., 2013). Evolutionary traps have an impact on various animal taxa and may cause shrinking of populations or even their collapse (Robertson et al., 2013; Robertson and Blumstein, 2019). A specific type of evolutionary trap is an ecological trap. This term refers to a habitat, which is apparently attractive but – when occupied – causes a decrease in animal fitness (Schlaepfer et al., 2002; Battin, 2004). Emergence of such traps is mostly linked to alterations in the environment (e.g. landscape modification). Bears, for example, prefer regions rich in food resources (especially berries). Meanwhile, these areas are densely populated by people. Foraging in such regions causes human-induced mortality and consequently leads to reduced population survival (Lamb et al., 2017). Another scenario involves appearance of a new element in the environment that mimics a natural component of an ecosystem (Schlaepfer et al., 2002). In this case, the original behavior is induced, and results in reduced survival. Some insects laying eggs in water, such as mayflies or beetles, may serve as an example of this scenario. Misled by a specific light polarization, they try to oviposit on asphalt roads, oil stains, or car bodies mistaking them for the surface of water (Horváth et al., 2009).

Mass emergence of anthropogenic debris in the environment in the last decades has resulted in many animals failing to recognize the threat and to consider discarded waste as a natural part of their habitats. Some of the many examples of this are birds that use plastic items as nest material or turtles that mistake plastic bags for food (Jagiello et al., 2019; Blettler and Mitchell, 2021; Petry et al., 2021), consequently, these animals may get entangled in the debris and die from starvation.

One of the most common litter items is beverage containers (Ryan et al., 2019; Roman et al., 2020). Their mass production began in the middle of the 20th century (Bellis, 2019) and the problem of illegal dumping of this waste soon turned out to be a threat to small mammals (Morris and Harper, 1965). Another problematic example is the so called 'stubbie', a 370 ml brown beer bottle which resembles a huge carapace of females of the jewel beetle *Julodimorpha bakewelli* (Gwynne and Rentz, 1983). The deceived males try to copulate with the bottle, which leads to their complete exhaustion, and makes them easy prey to ants, or causes them to dry up in the sun. Occasionally, discarded containers may also be confused with prey (Carson, 2013). Disposable beverage containers, such as bottles or cans, are also considered a convenient microhabitat for the development and spread of *Aedes aegypti*, the mosquito that is a major vector of dengue fever (Mazine et al., 1996).

Although discarded containers are widely acknowledged as a significant environmental problem, their direct effect on animals has been poorly studied. Most research has focused on small mammal mortality inside containers (Benedict and Billeter, 2004; Hamed and Laughlin, 2015; Moates, 2018; Torre et al., 2019) with only a few researchers additionally mentioning invertebrates and salamanders (e.g. Benedict and Billeter, 2004). Some reports also indicate empty bottles or cans can act as traps for lizards or crabs (Davenport et al., 2001; Lavers et al., 2020). The most recent study based on online media data, i.e. pictures and film clips shared on information portals or on social media, revealed the broad impact of various containers (bottles, cans, jars, cups) not only on small animals (e.g. invertebrates, shrews, mice) but also on medium- and large-sized animals like monitor lizards, deer, coyotes, wolfs and bears (Kolenda et al., 2021a). However, other studies suggest that invertebrates are the most affected group (Skłodowski and Podściański, 2004; Kolenda et al., 2015; Poeta et al., 2015; Romiti et al., 2021). Kolenda et al. (2015) and Poeta et al. (2015) revealed that invertebrates (mostly beetles and molluscs, respectively) were trapped in >40% of the collected containers. At the same time, remains of small mammals were found in up to 5% of containers (Benedict and Billeter, 2004; Hamed and Laughlin, 2015; Kolenda et al., 2018; Moates, 2018). Moreover, this specific threat appears to be more harmful in the terrestrial than the aquatic environment (Kolenda et al., 2021a). In the latter case, the discarded containers more often served as a shelter for macroinvertebrates (Czarnecka et al., 2009); however, due to a low sample size, such a conclusion should be treated with caution.

Although the problem of animal mortality in discarded containers seems to be common wherever the waste appears – including coastal sand dunes, deserts, forests of which many are legally protected (Poeta et al., 2015; Kolenda et al., 2021a) – special attention should be paid to habitats that are highly penetrated by humans and at the same time often inhabited by a considerable diversity of animals, such as urban green areas and municipal woodlands. They are considered hotspots for local diversity (Croci et al., 2008), and may became a refuge for threatened species (Ives et al., 2016; De Andrade et al., 2019). Furthermore, urban woodlands provide many ecosystem services (Livesley et al., 2016). Since they provide recreational areas for city inhabitants and have numerous social benefits. These forests contrast with the so called 'concrete deserts' of some city quarters, performing a valuable role in increasing the aesthetic value of cities, helping to reduce stress and improve physical health of city inhabitants (Brockerhoff et al., 2017). However, human activity causes high pressure on woodlands and littering became one of the most common problems (Referowska-Chodak, 2019).

In this study, we examined invertebrates and small vertebrates that got trapped in containers discarded in urban forests of a Central European city. We hypothesized that containers are an ecological trap for numerous animal groups, mainly arthropods and, to a smaller extent, vertebrates. We predicted that death in the containers could be caused by difficulties with getting out of them due to wet and slippery walls, with animals drowning in liquid gathered inside or by sudden change in weather conditions, e.g. high temperatures caused by the direct exposition to sunlight. Additionally, we assumed that some taxa may explore these artificial habitats for different purposes, for example, we found that many ant workers die in the discarded containers. However, some ant species take advantage of discarded containers and build nests inside them (Kolenda et al., 2020). Moreover, we found that mortality of spiders in containers is surprisingly low and that these animals may live in discarded beverage containers, utilizing them as hunting, hiding or breeding sites (Kolenda et al., 2021b). In the present work, we summarize data on the whole animal assemblages that entered discarded containers. We present the diversity of the trapped taxa, analyse their richness and functional composition. Furthermore, we hypothesize that container features have a strong influence on the number and composition of the trapped animals.

2. Material and methods

2.1. Study area and material collection

The study was conducted in the city of Wrocław (51.10° N, 17.03° E), which is situated in the lowlands (107–143 m a. s. l.) of southwestern Poland. The city area is 293 km^2, with a population size of ca. 644,000 people. The characteristic feature of this city is the abundance of riparian areas with the Odra river, four smaller tributaries, numerous channels and flooded areas. Approximately 12.5% of the city area is covered by forest habitats, of which most are situated alongside rivers (Jaworek-Jakubska et al., 2020).

Ten woodlands with the area varying between 16 and 139 ha were selected for this study (Table A1). Opened, discarded containers were collected in September 2018 by two investigators in a 10-m buffer along paths, starting from the entrance to each forest. If possible, approximately 100 containers per forest were sampled. We selected forests with a similar vegetation type to avoid too many variables, and assumed that the heterogeneity of habitats was low. Apart from bottles and cans that contained ant nests (see Kolenda et al., 2020 for details), all the containers were secured against spillage and transported to the laboratory. Then, the contents of each container were emptied onto a plastic tray. We noted the occurrence of: a) living animals (presence vs. absence; however, only selected groups such as spiders and several insect larvae were collected for further identification), b) dead animals (all animal remains were collected, counted and identified), c) other signs of the animal occurrence in containers (e.g. cocoons, moults, nests, stored seeds). We identified the invertebrates to the lowest possible taxonomic level and the animals ascribed at least to a family (in some cases also single individuals at an order level) were assigned to functional groups, according to González-Césped et al., 2021 with some adaptations to the local fauna (see Table A2 for details).

2.2. Statistical analyses

Estimated taxonomical richness (Chao2) of dead animals was computed with the use of the "SpadeR" R-package (Chao et al., 2016). Spearman's correlation coefficient was used to compare the number of animal orders, whose representatives were found dead in containers, with the total number of orders per class that occur in Poland. For this analysis: (i) only-marine orders were excluded, (ii) the Oligochaeta and Hirudinea subclasses from Clitellata were counted as separate orders.

The effect of container features on the i) number of dead animals, ii) number of families and iii) number of dead individuals from the most numerous functional groups (saprophages, phytophages and predators) was assessed with the use of generalized linear models (GLM) with the Poisson error frequency distribution and log link function. Due to a small sample size in some combinations of categorical subclasses and strong redundancy between the material and type of container (e.g. metal – cans, plastic – bottles) only single categorical variables, i.e. each of four variables: material (MAT), neck presence (NECK), colour (COL), content (CON) and two numerical variables (capacity – CAP and opening diameter – DIA) were considered when building the models (Table A3). The best models were selected with the use of the "MuMIn" R-package (Bartoń, 2016) and their Goodness-Of-Fit was assessed by the generalized, likelihood-ratio based R-squared. We define best subset of models according to the Akaike Information Criterion (AIC). A subset of the best models was selected with the use of all possible models and it includes all the models for which ΔAIC<2 (the difference between the AIC of the best model and the AIC for each of the other models). If a subset of such best models included more than one model, these models were averaged with the revised formula from Burnham and Anderson (2004, eq. 4) as explained in the "MuMIn" package.

The significance of coefficients of each model was assessed with the aid of estimated statistical significance (P) and 95% confidence intervals (CI). In the case of averaged models, the number of best models (N models) containing a specific predictor was given, as well as the relative variable importance (RVI) of the estimated predictors.

3. Results

3.1. Overview of the taxonomic and functional groups of animals found in the containers

A total of 939 containers were collected, including 792 bottles, 146 cans and one cardboard box. Living animals were found in 348 (37.1%) containers. The most common were spiders (163 individuals in 130 [13.8%] containers; details in Kolenda et al., 2021b), followed by flies (larvae and pupal cases in 67 [7.1%] containers where pupal cases prove that the animal has completed its life cycle in the container; for full list of taxa see Table A4) and ants (nested in 41 [4.4%] containers; details in Kolenda et al., 2020). We also found pupal cases of Lepidoptera in 11 (1.2%) containers.

A total of 10,162 dead animals were found in 528 (56.2%) containers (full list in Table A2). The mean number (± SD) of specimens was 19.2 ± 65.9 (median = 3) per positive containers (i.e. those with at least one animal), and 10.8 ± 50.3 (median = 1) for all collected containers. The highest number of dead animals in a single container was 735. Animal remains represented 12 classes from four phyla: Annelida, Arthropoda, Mollusca and Chordata. Most of them (96.5%) were identified at least to the order level. We noted 29 orders and 99 families, while the expected numbers according to richness estimator Chao2 were 33 (95%CI: 30–55) and 155 (95%CI: 120–246), respectively. There were 4297 larvae of Coleoptera, Dermaptera, Diptera, Hemiptera and Poduromorpha, and one nymph of Hemiptera, other invertebrates were represented by adult or juvenile specimens. Amongst vertebrates, only the legless lizard *Anguis fragilis* was juvenile, the remaining individuals (mammals and amphibian) were adult.

Invertebrates ($N = 10{,}139$, 56.1% containers with at least one specimen) were found more often than vertebrates ($N = 23$, 1.7%) (Fig. 1A–B). The most common (at least 100 dead individuals found in at least 3% containers) were three insect orders: Coleoptera, Diptera, Hymenoptera, two arachnid orders: Opiliones and Sarcoptiformes, one isopod order: Malacostraca and one mollusc order: Stylommatophora (Fig. 1C, 2A). We found a strong positive correlation between the number of orders whose representatives were found in containers and the total number of orders per class that occur in Poland ($r = 0.9023, p = 0.0001$; Fig. 2D). Amongst individuals identified to a species level ($N = 3425$), 127 (3.7%) belonged to seven species that are protected by Polish law and 236 (6.9%) belonged to eight species are included in the Red list of threatened animals in Poland (Table A5).

A total of 8864 individuals were grouped to eight functional groups. The most numerous in individuals and most frequently found in the samples were saprophages, followed by phytophages and predators. These groups definitely dominated over parasitoids, micophages, pollinators, saproxylics and filter feeders, constituting 97.8% of animals (Fig. 2B).

3.2. Containers as a direct and an indirect trap

We found that discarded containers may be used by animals for different purposes (Fig. 3). In some cases, we also distinguished direct and indirect utilization of containers. We defined 'direct' as a situation when animals use containers (e.g. as storage sites by rodents) or their original content (e.g. flies feeding on juice leftovers). 'Indirect' mode of using rubbish refers to a situation when an animal is lured in by the presence of other animals or their remains, e.g. some spiders that hunt on animals in the containers, or ants nesting in empty snail shells. However, it should be noted that in many cases, it is hard to judge what was the exact cause of an animal entering a container, and accidental entry while exploring the area cannot be excluded.

3.3. Effect of the container features on the abundance and diversity of dead animals

The GLM models revealed that the number of dead animals was affected positively by the container capacity, and negatively by the presence of a neck, the latter factor seems to limit some animals from moving inside. At the same time, the number of animals per container was significantly higher in glass and plastic containers (bottles) when compared to those made of aluminium (cans). Conversely, the effect of container capacity on the number of animals in glass and plastic container was weaker than in aluminium cans (there are negative interactions), and the effect of the neck's

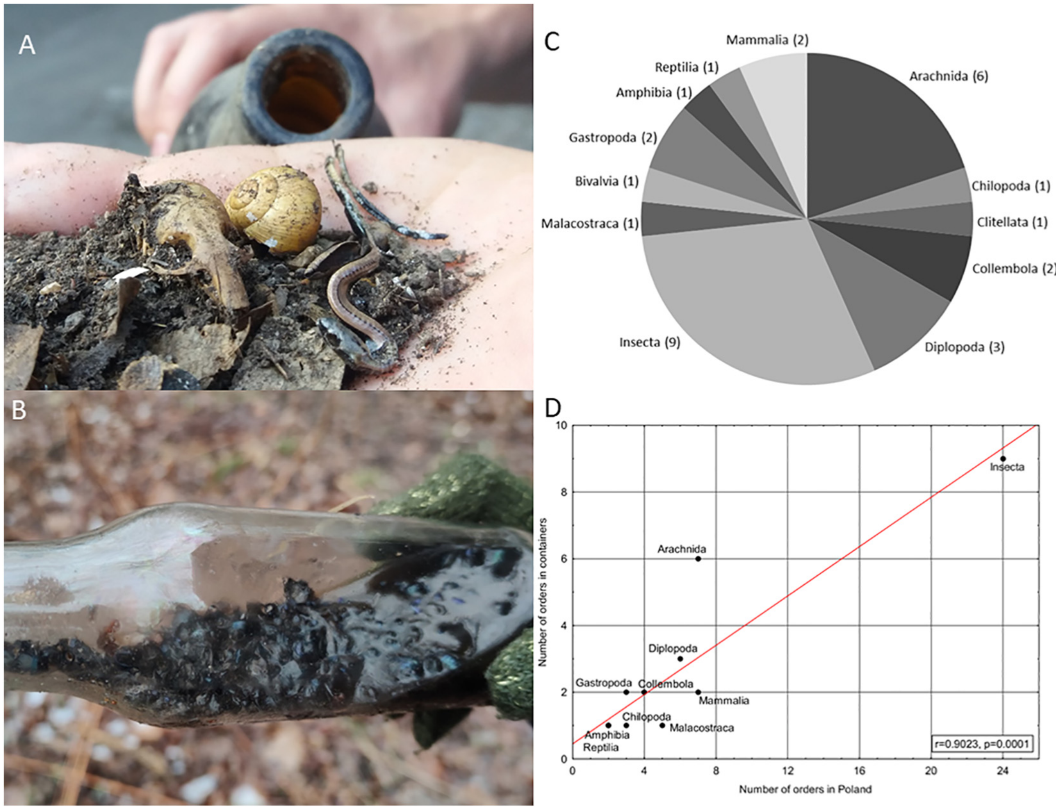

Fig. 1. A – remains of a grove snail *Cepaea nemoralis*, a slow worm *Anguis fragilis* and a bank vole *Myodes glareolus* collected from a beer bottle (photo by N. Kuśmierek); B – mass remains of dor beetle *Anoplotrupes stercorosus* in a glass bottle (photo by K. Kolenda); C – number of orders within the class of animals trapped in discarded containers; D – correlation between the number of orders per class whose representatives were found dead in containers and the total number of orders in each class that occur in Poland.

presence was the strongest in glass bottles. Only one model was selected according to AIC and it explained 90% of variability in dead animal abundance (Tables 1, A6).

A similar pattern was observed when analysing the effects of container features on the number of families per container. However, the effect of the neck's presence was much weaker and the significance of the predictors much smaller than in the previous case. Three models that were considered equally good (ΔAIC <1.5), explained only 10% of the variability in the family number per sample (Tables 1, A6).

The occurrence of functional groups in containers was also explained by some container characteristics. The number of individuals from each of the analysed groups (phytophages, predators or saprophages) was positively affected by the container capacity. The impact of other features differed, however, depending on the analysed functional group. The colour was a significant predictor for the number of phytophages and saprophages, with a positive effect of colourless and green bottles, when compared to those made of brown glass. However, we did not record any effect of colour on the number of predators. Moreover, the percentage of the variability in the number of animals from the guilds explained by the best models differed strongly, being equal to 10% in phytophages, ca. 51% in predators and ca. 91% in saprophages (see Table A6 for details regarding particular groups). It indicates that the number of animals representing the analysed functional groups is variously affected by the characteristics of studied containers and – for some groups, especially the phytophages – appears to be much more random in relation to the container features (Tables 1, A6).

4. Discussion

Our data indicate that there is a huge variety of small organisms that are prone to getting trapped in discarded bottles and cans. The correlation analysis revealed that the diversity of animals dying in containers is proportional to their general diversity in Poland. On this basis, we assume that discarded containers are a universal threat to animal biodiversity. The bottles and cans littering the municipal forests cause death or affect in some other ways the biology of almost the whole set of small terrestrial (and aquatic to a significantly smaller extent) animals. However, the total number and diversity of dead animals is certainly underestimated. This is confirmed by the results of the Chao2 estimator, which revealed that many families remain undetected. Moreover, taxa without highly chitinised cuticles or strongly calcified shells rapidly decompose, which could result in an almost complete lack of various major litter dwelling groups, such as the collembolans. Some of invertebrates could also be hunted by predators, e.g. spiders (Kolenda et al., 2021b). Low mortality rate of such groups as spiders or collembolans may be also explained by their ability to walk on the surface of liquids (Bush and Hu, 2006). Incomplete skeletons of small mammals and amphibian may suggest that carcasses are taken out of the containers by scavengers; however, the opposite scenario cannot be excluded, as well. We also do not know the real exposure time of containers, since we have captured a single moment of their long-lasting presence in forest litter. Such factors as circadian activity or phenology were also not considered; however, they may prove important in the case of some groups (Kolenda et al., 2021b). Thus, the mortality rate in discarded containers and the extent to which they are used by animals are probably much higher than what we have found (see also Benedict and Billeter, 2004). For these reasons, and the fact that 30 to 50% of bottles discarded in the environment are closed (capped; Brannon and Bargelt, 2013, Romiti et al., 2021), estimations of annual mortality of particular taxa can be biased (Skłodowski and Podściański, 2004; Moates, 2018). Importantly, we also do not know the exact taxa composition and population size of species that live in the studied areas, thus the effect of containers on the surrounding population is difficult to assess. However, Davenport et al. (2001) and Lavers et al. (2020) suggested that containers may contribute to the shrinking of island populations of lizards and crabs, respectively. The real influence on animal population should be considered mainly as a synergistic effect of various factors

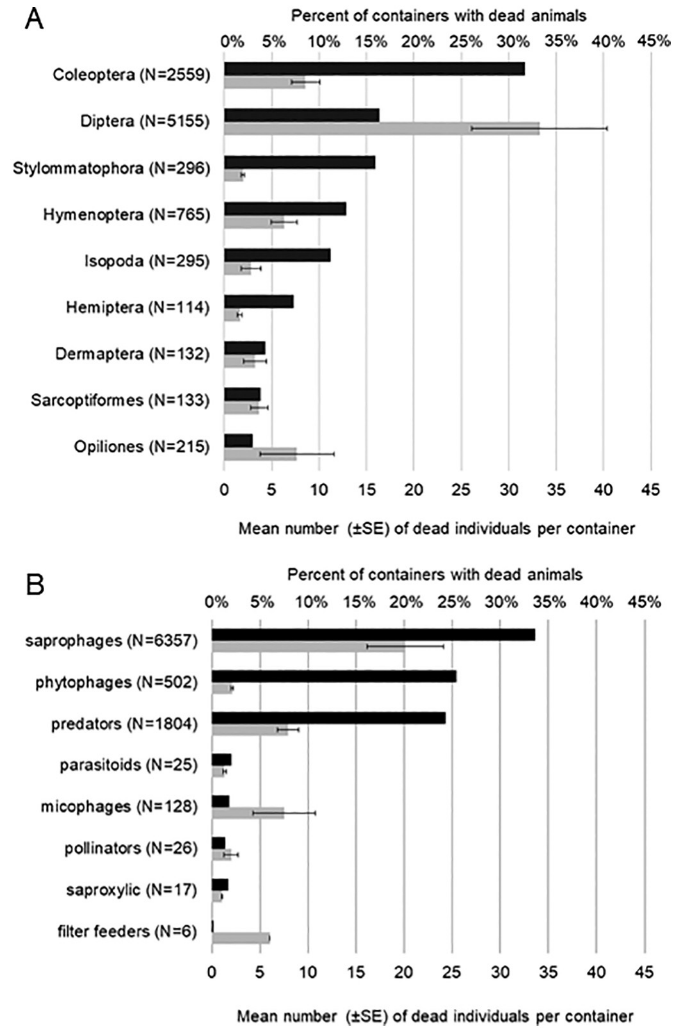

Fig. 2. A – the percent of containers with dead animals according to the most common orders (black bars) and the mean number of individuals per container* (grey bars); B – the percent of containers with dead animals grouped according to functional groups (black bars) and the mean number of individuals per container* (grey bars). *Only containers with at least one individual from a particular order or functional group were included.

that occur together with littering in urbanised habitats (isolation, habitat fragmentation, noise and artificial light pollution, etc.; Gomes et al., 2011, Shannon et al., 2016, Ditmer et al., 2021).

4.1. When a small ecosystem becomes an ecological trap

Our study confirmed that containers left in the environment entice many animals and have ecological consequences, such as death of adults and a reduction of the reproduction rate (death of larvae due to unsuitable abiotic conditions for their development). They may also increase the risk of predation, as we have already suggested in the analysis of spiders living in containers (Kolenda et al., 2021b). Thus, they can be considered as true ecological traps that decrease the fitness of animals in different ways (see Robertson et al., 2013 for other consequences of different ecological traps).

Although the exact sequence of containers colonization is almost completely unknown (but see Didier, 2004; Skłodowski and Podściański, 2004), we can distinguish some general patterns (see also Fig. 3). Representatives of some functional groups, such as microphages or saproxylic animals may enter the container randomly, probably while penetrating the area. However, most animals seem to be directly or indirectly lured in. Containers which have been recently dumped and still have some leftover drink, lure in the first colonisers, especially the phytophages. A small entrance and dark colour of containers may resemble a burrow for some animals, which could enter them while seeking shelter (e.g. snails, beetles, rodents). For the same reason, animals may choose containers as a nesting site (e.g. ants, Kolenda et al., 2020). Wet and warm site, partially filled with water, is a suitable breeding place for flies (this study) or mosquitoes (Juarez et al., 2020). Some chemicals secreted by the trapped animals may serve as kairomones and lure in their predators, e.g. carabids. In the case of social insects such as ants, secreted pheromones attract more individuals which may try to rescue the entrapped insects (Turza and Miler, 2021), whereas decaying corpses become a "bait" for two functional groups that mainly die in containers. The first of these are saprophages (such as flies or beetles), for which the carcasses are a food source and a place for reproduction (especially for necrophages). The second group are predators, like soricids, carabids or spiders, which are apex predators in such microecosystems (Skłodowski and Podściański, 2004). A constant influx of allochthonous organic matter and a lack of primary producers in containers resembles a heterotrophic ecosystem, similar to those in caves or on the seabed (Gage, 2003; Ramirez-Llodra et al., 2010). In summary, discarded containers may become a small, separate microsystem with its own history and numerous, different factors that shape it, i.e. colonization sequence and patterns or composition of surrounding communities.

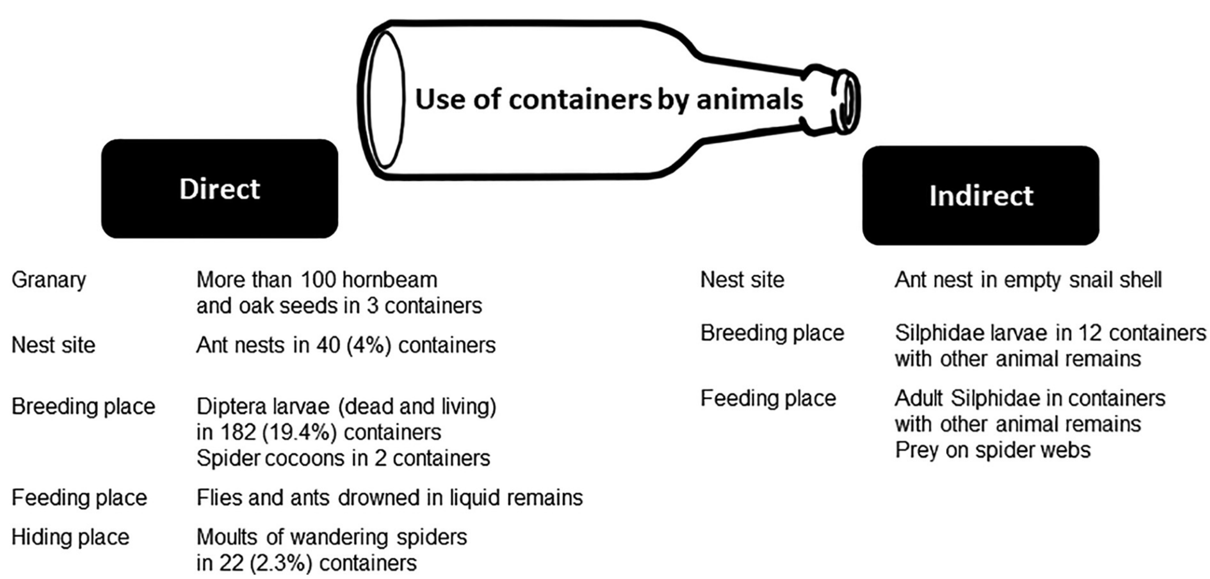

Fig. 3. Diverse ways of use of discarded containers by invertebrates and small vertebrates, with indication of direct and indirect utilization.

Table 1
The relationships between: i) total number of dead animals per container, ii) number of families per container, iii) number of dead individuals from the most numerous functional groups (saprophages, phytophages and predators) per container and six predictors (container features): four categorical predictors – material (MAT), presence of a neck (NECK), colour (COL) and original content (CON), and two numeric predictors – capacity (CAP) and opening diameter (DIA). The generalized linear model with the best subset selection was applied. The models ii) and iii) – averaged best models (see Table A6 for details).

		RVI	No. of models	Predictor level	Coefficient	SE	CI-Min	CI-Max	*Z*-value	*p*
Number of all individuals	(Intercept)				−1.850	0.379	−2.633	−1.144	−4.881	0
	CAP		1		0.009	0.001	0.007	0.010	11.546	0
	MAT		1	MAT = "glass"	2.719	0.395	1.978	3.529	6.888	0
				MAT = "plastic"	2.927	0.383	2.212	3.716	7.644	0
	CAP × MAT		1	MAT = "glass"	−0.008	0.001	−0.010	−0.006	−9.993	0
				MAT = "plastic"	−0.008	0.001	−0.010	−0.007	−10.656	0
	NECK		1		−0.937	0.317	−1.581	−0.338	−2.959	0.003
	CAP × NECK		1		0	0	0	0.001	2.367	0.018
	MAT × NECK		1	MAT = "glass"	1.919	0.262	1.427	2.456	7.324	0
				MAT = "plastic"						
Number of families	(Intercept)				−1.600	0.670	−2.915	−0.284		0.017
	CAP	1	3		0.004	0.001	0.001	0.006		0.006
	MAT	1	3	MAT = "glass"	1.440	0.677	0.112	2.767		0.034
				MAT = "plastic"	1.387	0.680	0.053	2.721		0.042
	CAP × MAT	1	3	MAT = "glass"	−0.003	0.001	−0.005	0		0.058
				MAT = "plastic"	−0.003	0.001	−0.006	−0.001		0.015
	NECK	0.25	1		0.095	0.121	−0.143	0.332		0.435
	DIA	0.24	1		−0.005	0.007	−0.017	0.008		0.475
Number of individuals from functional groups	PHYTOPHAGES									
	(Intercept)				−1.354	0.237	−1.820	−0.888		0
	CAP	1	3		0.001	0	0	0.001		0
	MAT	1	3	MAT = "plastic"	−0.501	0.247	−0.985	−0.016		0.043
	CAP × MAT	0.21	1	MAT = "plastic"	0	0	−0.001	0.001		0.870
	COL	1	3	COL = "colourless"	0.517	0.132	0.259	0.776		0
				COL = "green"	0.489	0.134	0.226	0.752		0
	NECK	1	3		−0.081	0.248	−0.569	0.406		0.743
	CAP × NECK	1	3		0.001	0	0	0.001		0.027
	MAT × NECK	0.21	1	MAT = "plastic"	−0.050	0.464	−0.961	0.862		0.915
	PREDATORS									
	(Intercept)				−0.400	0.196	−0.785	−0.014		0.042
	CAP	1	3		0.001	0	0	0.002		0.001
	MAT	1	3	MAT = "plastic"	0.142	0.212	−0.274	0.557		0.505
	CAP × MAT	0.52	2	MAT = "plastic"	0	0	−0.001	0		0.194
	NECK	1	3		0.295	0.207	−0.110	0.701		0.153
	CAP × NECK	0.68	2		0.001	0	0	0.001		0.038
	MAT × NECK	1	3		−2.556	0.628	−3.790	−1.323		0
	SAPROPHAGES									
	(Intercept)				−0.003	0.154	−0.305	0.299		0.984
	CAP	1	2		0.001	0	0	0.001		0.004
	MAT	1	2	MAT = "plastic"	0.085	0.172	−0.252	0.423		0.619
	CAP × MAT	0.5	1	MAT = "plastic"	0	0	−0.001	0		0.159
	COL	1	2	COL = "colourless"	0.184	0.039	0.108	0.259		0
				COL = "green"	0.596	0.035	0.527	0.665		0
	NECK	1	2		1.1	0.153	0.799	1.401		0
	CAP × NECK	1	2		0.001	0	0	0.001		0.005
	MAT × NECK	1	2	MAT = "plastic"	−1.847	0.353	−2.541	−1.154		0

4.2. Preferences toward container features

Without a comparative study of species that live in littered areas, we cannot precisely determine if the dominance of selected taxa in containers results from their high abundance in the environment, or specific container features, or the content that attracts them toward the new microhabitat. We assume that containers act similarly to pitfall traps that are used to collect ground-dwelling invertebrates (Brown and Matthews, 2016). Sampling efficiency in such traps depends on the material from which they were made (Luff, 1975), their colour (Buchholz et al., 2010), size (Luff, 1975), entrance size (Work et al., 2002), preservation fluid (Knapp and Růžička, 2012), use of bait (Knapp et al., 2016), vegetation structure around traps (Topping and Sunderland, 1992) or sampling intervals (Schirmel et al., 2010). All these variables can also influence container "efficiency". Previous studies revealed that pitfall traps provide an incomplete species list of epigeic fauna (Knapp et al., 2020), even if sampled extensively (Żmihorski et al., 2013). We suppose that similar patterns may be expected for the containers. Indeed, we found that some features, especially capacity, presence of a neck and material influence the abundance and diversity of taxa in containers. However, these results should be treated with caution. As we mentioned above, we do not know the real "operation time" of containers and the sequence of entering of particular functional groups into them, but we suppose that this may significantly affect the number of dead animals in a container, independently from its characteristics.

Spatial orientation of the container opening in relation to the ground is also important. Containers pointing upwards act as the most efficient trap at least for small mammals. Some authors found that a bottle at an angle of 15° or more becomes a trap with no way out (Benedict and Billeter, 2004; Hamed and Laughlin, 2015), this was also confirmed by Morris and Harper (1965). This factor has, however, never been tested in relation to invertebrates. Although we agree that it can significantly influence the number of causalities, we did not consider it in our study. According to our field observations, the position of many containers changes in time, probably due to wind, trampling by larger animals and activity of predators. We suggest testing the effect of container position on animal entrapment only in experimental conditions.

4.3. Implications for conservation and citizen science

In light of our findings, there is an urgent need to limit the number of discarded containers in the environment. Unlike the other threats that affect the wildlife, such as artificial and polarized light (Horváth et al., 2009; Lao et al., 2020), elimination of containers seems easy to achieve. Nonetheless, a drastic increase in the quantity of waste in the environment has been observed (Jakiel et al., 2019). Broad scale education and clean-up activities should contribute to a decrease of the litter amount, and in consequence of animal mortality. Indeed, Skłodowski and Podściański (2004) found that on regularly cleaned paths in the Tatra National Park (S Poland), the number of dead animals in the containers was small, because leftover liquid did not have time to ferment. Although extensive clean-up actions may result in less discarded litter (Haarr et al., 2020), they should be managed by local authorities and follow detailed planning and criteria to avoid habitat destruction (e.g. by excessive trampling) (Battisti et al., 2020; Haarr et al., 2020). Engaging communities in such activities is associated with raising their environmental awareness (Wyles et al., 2017). However, without a strict law and regulations at local, national and global levels, bottom-up pro-environmental initiatives are unable to stop this problem. So far, numerous general and detailed recommendations have been proposed including limitation of consumption, improvement in waste collection systems or giving priority to recycling (Prata et al., 2019). Although studies show that some of them, like container deposit legislation, reduce the number of beverage containers in the environment (Schuyler et al., 2018), such regulations have not yet been implemented in many countries. Additionally, in local human communities, installation of more rubbish bins might contribute to reduced littering (Bator et al., 2011). These bins should be emptied regularly and, to avoid accumulation of rubbish in biodiversity rich areas, we suggest placing them at the entrances and not within such places.

Our research proves that data obtained from discarded containers have a scientific value and provide important faunistic and distributional data. Although we found mostly common species, invasive as well as rare and protected species were also noted. It should be noted that containers do not offer a full list of small animals that inhabit a particular habitat but may fill the gap where scientific data are limited or may serve as a surrogate for faunistic studies, especially when habitats from which rubbish was collected are highly endangered or host extremely small populations of vulnerable species (Rodríguez-estrella and Moreno, 2006). Moreover, the huge advantage of searching discarded containers is the fact that it is a quick and cheap method that does not require special equipment, thus can be done by amateur-naturalists or volunteers during clean-up activities. In the latter case, collecting animal remains from containers can be a part of educational programmes (e.g. Kolenda et al., 2015; Brannon et al., 2017) or they can be simply delivered to scientists within a citizen-science approach.

5. Conclusions

In this research, we confirmed that discarded containers constitute an ecological trap for many groups of animals, including rare and legally protected species. This is another argument for the urgent implementation of systemic changes that reduce the amount of rubbish in the environment. Broad-scale volunteer clean-up actions may additionally accelerate this process and at the same time provide data on animal distribution.

Our results have broad implications for the future studies on the relationship between animals and rubbish. The use of DNA metabarcoding could help in a more effective estimation of the exact taxonomic richness of animals entering containers, especially those that are represented solely by juvenile specimens or remain in trace amounts that do not allow for a precise identification. The assessment of the mortality rate of particular taxa should also go beyond the already studied places, i.e. roadsides (Benedict and Billeter, 2004; Brannon and Bargelt, 2013; Hamed and Laughlin, 2015; Moates, 2018) and beaches (Poeta et al., 2015; Lavers et al., 2020; Romiti et al., 2021), especially as data from deserts, meadows or rivers suggest that the impact of discarded containers is similar (Kolenda et al., 2021a). A whole-season monitoring could also provide more data on possible overwintering or reproductive success of selected groups inside containers. Finally, comparison of taxonomic richness and abundance of a particular animal group, between individuals that died in containers with those living in the surrounding area, could reveal to what extent containers affect the population of terrestrial invertebrates.

CRediT authorship contribution statement

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Natalia Kuśmierek: Conceptualization, Methodology, Investigation, Writing – Review & Editing.
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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

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