

1                   **Application of crime theory in urban ecology, evolution and planning:**  
2                   **factors influencing the disappearance of field equipment**

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20 **Abstract**

21 1. Research in urban ecology and evolution relies on the use of deployable scientific equipment. If left  
22 unattended in the field, it may be prone to vandalism and theft, especially in the urban space. We empirically  
23 applied crime theory, specifically the Routine Activity Theory (RAT), to predict disappearance rates of  
24 scientific equipment in an on-going urban ecology research project.

25  
26 2. First, we tested a routinely applied method of equipment protection - labelling - and tested whether  
27 equipment disappearance varied with label information content and message tone. Second, we tested whether  
28 equipment attributes (price, mass, volume, colour and type of installation) and environmental variables (human  
29 presence, tree cover, distance to paths and distance to roads) covaried with the disappearance of two types of  
30 field equipment, and whether patterns of disappearance changed over time spent in the urban space (novelty  
31 effect).

32  
33 3. The disappearance of 474 nestboxes and 141 frassboxes was followed over four years and two field seasons,  
34 respectively. By using a crime theory framework, we successfully predicted that nestboxes were less likely to  
35 disappear than frassboxes. In contrast to an earlier study, we did not find any association between label type  
36 and disappearance rates. Instead, we identified environmental variables that covaried with equipment  
37 disappearance: for both types of scientific equipment, there was an interaction between human presence and  
38 tree cover. Thus, in highly-frequented places, people were more likely to remove scientific equipment if they  
39 were less seen (e.g. in areas with high tree cover). Moreover, we detected an interaction between distance to  
40 roads and paths for frassboxes but not nestboxes, revealing that equipment properties may interact with  
41 environmental setting. Importantly, frassbox disappearance decreased over time in both study seasons,  
42 confirming the important role of novelty for scientific equipment disappearance rates.

43  
44 4. We encourage other researchers, site-managers and stakeholders working in cities and other frequently  
45 visited areas to apply the RAT framework, as it is an easily applicable and inexpensive way to gain insight into  
46 patterns of equipment disappearance in the public space, thereby strengthening the potential for informed  
47 project planning and as a result, safer, and more effective studies.

48

49 **Key words:**

50 crime prevention, crime theory, equipment protection, field equipment, labelling, socio-eco-evo, urban

51 ecology, urbanisation

52 **INTRODUCTION**

53 Urban areas currently occupy about 3% of the Earth's land and are home to more than half of the human  
54 population; both numbers are expected to increase over time (Seto et al., 2012, United Nations et al., 2019). In  
55 line with this growth, urban ecology and evolution emerged in the past decades as blooming fields of research  
56 worldwide (Rivkin et al., 2019, James & Douglas, 2014, Szulkin et al., 2020). Knowledge gained from these  
57 studies can ultimately allow us to build more sustainable cities, and guarantee a more harmonious coexistence  
58 of humans and other biological life in the urban space (Douglas et al., 2010). As such, both the scientific  
59 community and land managers working in the urban space need carefully planned data collection protocols to  
60 work efficiently.

61 Field studies are the cornerstone staple for the collection of biological data. To achieve reliable and  
62 repeatable results, scientists must apply efficient data collecting protocols that rely on the use of field  
63 equipment, and the same holds true for site managers and land-planners. Deployable equipment is used to gain  
64 information on biological processes across a wide-range of habitat types: from green areas – including natural  
65 reserves and national parks – to urbanised neighbourhoods (e.g. Munshi-South & Kharchenko, 2010, Sprau et  
66 al., 2017, Corsini et al., 2022). Such equipment may vary in terms of costs, quality and scope (Perkin et al.,  
67 2014, Zárbynická et al., 2016), but for the purpose of urban data collection, it is often left outdoors. Human  
68 response may vary widely – from indifference and inoffensive curiosity to worse case scenarios, equipment  
69 theft and / or vandalism. The latter risk is likely to be amplified in urban areas due to increased densities of  
70 humans (Corsini et al., 2019; see Table S1 in Supporting Information). The loss of equipment is usually  
71 irreparably translated into data loss or, more generally, failure in achieving research aims or site management-  
72 objectives (Meek et al., 2018). It can also threaten the target species of the study: for example, the removal of  
73 nestboxes with eggs or nestlings inside (personal obs.) will inevitably lead to the death of these individuals.

74

75 **Preventing the disappearance of field equipment**

76 Steps taken to minimise the loss of scientific equipment in the field are regularly considered and may include:  
77 securing items with chains, locks or boxes (Fiehler et al., 2007, Meek et al., 2012), hiding and camouflaging  
78 (Jackson & Hutchison, 1985), placing the items in hard-to-reach places, avoiding the set up in highly-  
79 frequented areas, (Rovero & Marshall, 2009, Gil-Sánchez et al., 2011) or shortening deployment periods  
80 (Meek et al., 2018). Some of these practices can significantly undermine the quality of obtained results: for

81 example, Meek et al. demonstrated that placing camera traps at three meters height to avoid their potential  
82 theft may significantly reduce the detection rates of mammals (Meek et al., 2016). Attaching labels with  
83 pictograms and messages to inform city dwellers about the study is another avenue to minimise equipment loss  
84 (Clarín et al., 2014). Clarín et al. (2014) have shown the effectiveness of phrasing and verbal tone used on the  
85 scientific equipment labels to prevent vandalism and theft events: 60 identical equipment dummies –  
86 consecutively distributed for a week in four urban parks in Munich, Germany – were assigned with one out of  
87 three types of labels differing in tone (*neutral, personal or threatening*). The authors found conclusive evidence  
88 that the *personal* label, which was written in a kind tone and accompanied by a picture of a juvenile squirrel,  
89 revealed to be the most effective in reducing the overall number of vandalism and theft events in the unattended  
90 equipment. Although methods applied by Clarín et al. (2014) paved the way for investigating a new and  
91 pertinent approach to reducing the disappearance of scientific equipment – focused on the verbal aspect of  
92 labelling – the study was not set in the context of a real-life study (thus bringing greater liberty in modulating  
93 treatment effects, such as label tone), nor did it investigate other important drivers of disappearance, which  
94 include:

- 95 ● **environmental variables** – the characteristic of the immediate environment next to the scientific item  
96 of interest – such as human presence, distance to paths or roads, tree cover (Fig. 1) – or, more generally,  
97 – the wider spectrum of habitat types pertaining to the spatially heterogeneous urban mosaic.
- 98 ● **equipment attributes** – the intrinsic properties of an item, such as approximate value, mass, volume,  
99 colour or type of installation (Fig. 1 & Box 1).
- 100 ● **temporal aspects of equipment disappearance**, and specifically – the effect of passers-by  
101 habituation with the items (further referred to as *novelty*) on disappearance probability (Dinnin, 2009)

102  
103 According to the quite distinct field of crime theory (Cohen & Felson, 1979, Felson & Clarke, 1998), (Felson  
104 & Clarke, 1998) all drivers outlined above can play a crucial role in the probability of object disappearance  
105 when driven by theft. Therefore, in this study, the following research questions were addressed:

- 106 1. **Extrinsic factors.** Do environmental variables affect the dynamics of deployable field equipment  
107 disappearance in urban areas?
- 108 2. **Intrinsic factors.** Are some types of deployable field equipment more prone to disappearance?

109 3. **Novelty.** Does novelty, (measured as the period the equipment spent in a certain area), play a role in  
110 the item's disappearance over time?

111

112 Based on crime theory (and specifically Routine Activity Theory (acronym RAT)) and VIVA theory embedded  
113 within RAT; see Fig. 1 and full details in Methods; Miró, 2014), we predicted that external factors may  
114 considerably affect the dynamics of deployable scientific equipment disappearance by providing more or less  
115 suitable settings for its removal (Fig. 1). Likewise, some intrinsic properties of the equipment may simplify  
116 and encourage or, conversely, impede and discourage its removal (Fig. 1, Box 1). As part of these intrinsic  
117 factors, verbal cues in labelling (such as language and tone in labelling) may play a role in the disappearance  
118 of scientific equipment, as readily investigated by Clarin et al. (2014). Lastly, we also predicted a decrease in  
119 scientific equipment disappearance over time, which can be potentially explained by visitors' habituation to  
120 the equipment presence itself in the studied areas, leading to further reduction in removal rates (Dinnin, 2009).

121

### 122 **Labelling and Routine Activity Theory Implementation**

123 Based on Clarin's et al. (2014) work, we conducted a follow-up study in the city of Warsaw, Poland, a capital  
124 city of c 1.76 million inhabitants in Central Eastern Europe (Statistics Poland, n.d.). We implemented the  
125 method of equipment labelling while setting up study sites for a long-term research project on the ecology and  
126 evolution of two urban birds: the great tit (*Parus major*) and the blue tit (*Cyanistes caeruleus*) (Szulkin et al.,  
127 2020, Corsini et al., 2021, Corsini et al., 2022). We monitored the disappearance of two types of equipment  
128 deployed in the field (Fig. 3, Box 1): specifically, nestboxes, where hole-nesting passerines rear their young,  
129 and frassboxes, i.e. collectors of caterpillars' faeces – an important field-method commonly used to quantify  
130 the total biomass of natural-food resources available to tits in the environment whilst feeding young (Perrins,  
131 1991).

132 Crime theory set out in the RAT-VIVA framework allowed us to formulate concise and testable  
133 predictions about the role of distinct external variables characterising the urban space on the dynamics of  
134 scientific equipment disappearance (Fig. 1). Moreover, we also implemented VIVA to compare the attributes  
135 of both types of equipment in order to predict which of these were more prone to disappear (Box 1). To the  
136 best of our knowledge, it is the first time that the Routine Activity Theory was empirically tested in the context  
137 of urban ecology and evolution research.

## 138 MATERIALS AND METHODS

139

140 In this study, we refer to all cases of equipment removal by passers-by with the neutral word *disappearance*,  
141 which includes both theft or removal for other purposes.

142 To infer patterns of disappearance of scientific equipment in the urban space, we detail below (1) the  
143 RAT-VIVA framework derived from crime theory (Cohen & Felson, 1979, Felson & Clarke, 1998), (2)  
144 study sites and equipment, (3) drivers of equipment disappearance, and (4) statistical methods.

145

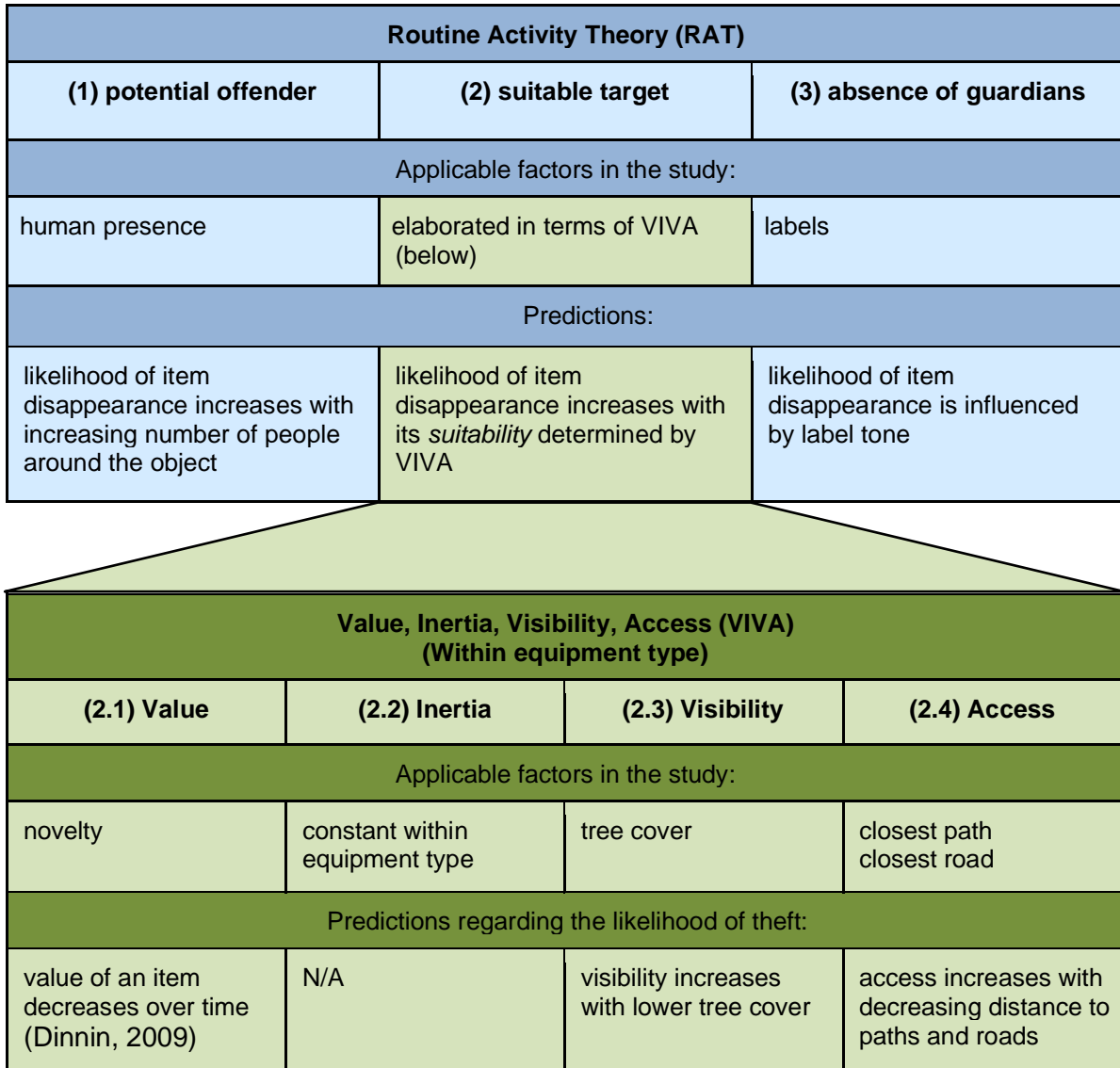
### 146 1. Crime theory-based RAT-VIVA framework and resulting predictions for the selective 147 disappearance of scientific equipment

148 To better understand the dynamics of equipment disappearance, we took an interdisciplinary approach  
149 and applied theory from criminal studies to our research. Tools developed in this field often focus on the issue  
150 of infringement of private property and, as such, provide a useful framework for this study. Cohen and Felson  
151 (1979) formulated the Routine Activity Theory (RAT): one of the most influential theoretical constructs in the  
152 field of criminology (Fig. 1). Put succinctly, instead of focusing on the figure of the criminal and the  
153 psychological, biological or social factors that motivate the criminal act, RAT studies crime as an *event* (Miró,  
154 2014). The theory highlights crime's relation to space and time, and emphasizes its ecological nature and the  
155 implications thereof. Cohen and Felson (1979) specified three essential elements needed for a criminal event  
156 to occur and to explain it: (1) a potential offender with the capacity to commit a crime; (2) a suitable target or  
157 victim; (3) the absence of guardians capable of protecting targets and victims (Fig. 1).

158 An important aspect of the Routine Activity Theory in terms of identifying the causes of scientific  
159 equipment disappearance relates to the *suitable target* concept ((2); Fig. 1). The probability of an item  
160 becoming a target is influenced by four attributes: Value, Inertia, Visibility, and Access (acronym VIVA; Fig.  
161 1; Box 1) – described from the point of view of the offender (Cohen & Felson, 1979, Felson & Clarke, 1998,  
162 Miró, 2014). All of these four attributes are predicted to translate into object disappearance:

- 163 ● **Value**, real or symbolic, from the perspective of the offender;
- 164 ● **Inertia**, referring to size, weight, and shape, or to other physical aspects of the good;
- 165 ● **Visibility** of target to the offender;
- 166 ● **Access**, referring to object positioning in space.

167 **Figure 1.** Graphical representation of the RAT-VIVA framework, including predictions on the effect of  
 168 external factors on the scientific equipment disappearance. The definition of a guardian (3) is not limited to a  
 169 person, it is a concept: „the physical or symbolic presence of an individual (or group of individuals) that acts  
 170 either intentionally or unintentionally to deter a potential criminal event” (Hollis et al., 2011). Therefore we  
 171 treat labels as potential guardians (analogous to the use of “watching eyes” imagery in studies inferring theft  
 172 reduction and other socially negative behaviours (Dear et al., 2019)).



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**Box 1.** (A) VIVA comparison of nestbox and frassbox attributes determining their disappearance susceptibility. (B) Translation from qualitative to quantitative predictors of disappearance of scientific equipment. The monetary value of a nestbox and of a frassbox can be approximated by eye, as the latter is made from a single sheet of paper (see Methods and Fig. 3)

Descriptive comparison of nestboxes and frassboxes in terms of VIVA

(A)	Value	Inertia	Visibility	Access
<b>Applicable factors</b>	<i>Price</i>	<i>Mass and volume</i>	<i>Colour</i>	<i>Installation type</i>
<b>Nestbox</b>	c. 26,00 €	Mass = 3,6 kg Volume = c. 8000 cm <sup>3</sup>	Brown, blending with trees	Hung 214-325 cm above the ground
<b>Frassbox</b>	c. 0,03 €	Mass = 0,015 kg Volume = 930 cm <sup>3</sup>	Paper-white, highly contrasting with its surrounding	Fixed to the ground with a nail
<b>Predictions</b>	An item with higher price is more valuable	A lighter and smaller item is easier to carry	An eye-catching item is more visible	An object that is easier to reach is more accessible

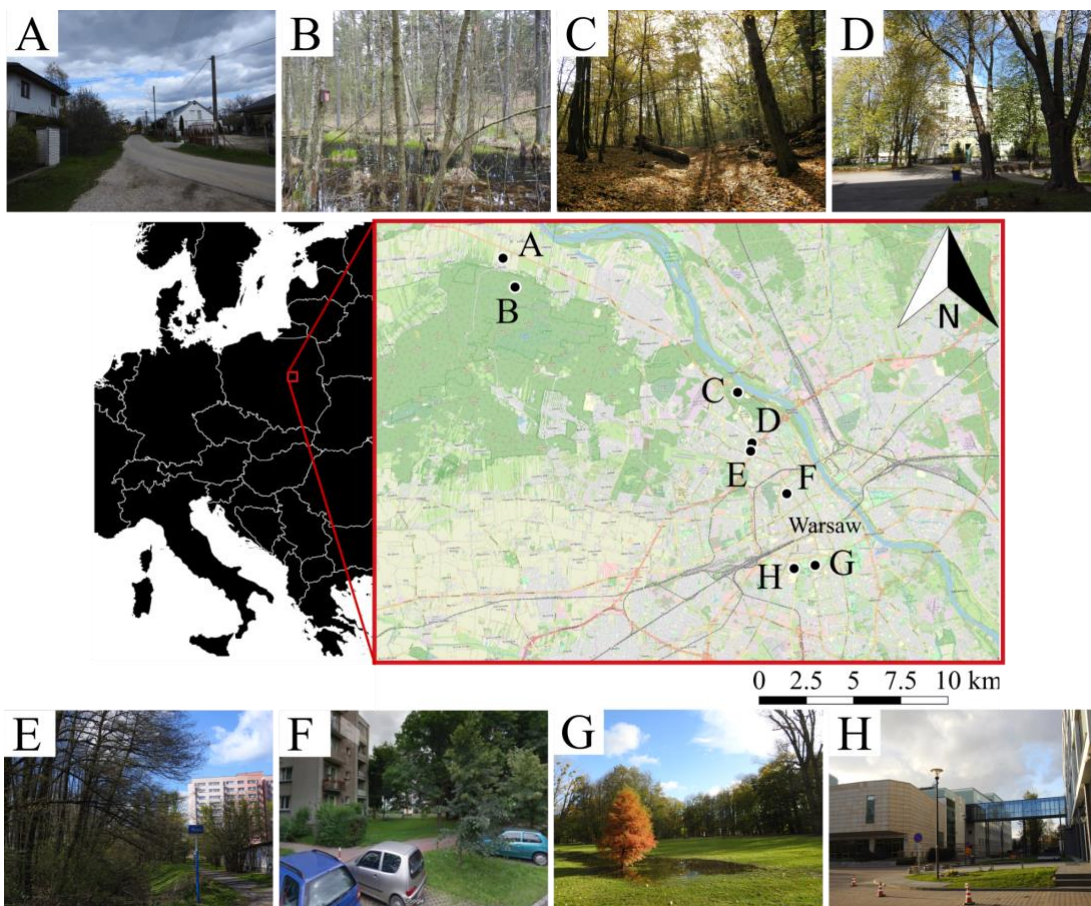
Predictions formulated under the VIVA framework can be further translated into quantitative predictions of nestbox and frassbox susceptibility to disappearance in the urban space:

(B)	Value	Inertia	Visibility	Access	Total of suitable target points	Predictions under the RAT-VIVA framework
<b>Nestbox</b>	1	0	0	0	<b>1</b>	A frassbox is a more suitable target for disappearance than a nestbox
<b>Frassbox</b>	0	1	1	1	<b>3</b>	

189 **2. Field Data**

190 **2.1 Study sites**

191 We used field data collected as part of a long-term project addressing the impact of urbanisation on the biology  
192 of two wild passerines in Warsaw, Poland (Fig. 2). Poland is a democratic, post-communist country in Central  
193 Eastern Europe and its capital city, Warsaw, hosts *c.* 1,76 million people, making it the largest city of the  
194 country (Statistics Poland, 2018) and the 11<sup>th</sup> largest city in the European Union (*Eurostat / Regions and Cities*  
195 *Illustrated (RCI)*, 2017). The project started in 2016 and currently consists of eight study sites that include:  
196 (A) a suburban village *c.* 20 km from Warsaw, (B) a national park, (C) an urban forest, two (D and F) residential  
197 areas, (E) an urban woodland, (G) an urban park and (H) a university campus (Figure 2). Wherever possible,  
198 nestboxes are set out in a 50 m grid (for more information on the study sites please see Table S1, S2 & Text  
199 S1; these are also detailed in Corsini et al., 2019, Corsini et al., 2022, Szulkin et al., 2020).



200  
201 **Figure 2.** Map of study sites located in the Warsaw gradient of urbanisation, Poland. These include: a suburban  
202 village (A), a national park (B), an urban forest (C), two residential areas (D and F), an urban woodland (E),  
203 an urban park (G) and a university campus (H).

204

205 **2.2 Scientific equipment in the field**

206 In this study, we compared the disappearance of two types of scientific equipment: nestboxes, used as breeding  
207 cavities in the project, and frassboxes - used in a two-year study to quantify caterpillar abundance in a gradient  
208 of urbanisation, assessed by collecting frass (e.g., caterpillar faeces; Fischbacher et al., 1998) from frassboxes  
209 across the urban matrix (Stadnicki et al., in prep).

210 Schwegler woodcrete nestboxes (Schorndorf, Germany; type 1B; Fig. 3 A & Fig. S1) are brown with  
211 pinkish doors, measure W 17 x H 26 x D 18 cm and weigh *c.* 3,6 kg. They are hung on metal grips, which are  
212 fixed to trees, and distributed in all study sites in a 50-m distance grid whenever possible. Nestbox  
213 disappearance data covered four years of study (2016-2019).

214 Frassboxes (Fig. 3 B & S1) were made with thick A4 white paper (at least 200g/m<sup>2</sup>), folded into  
215 containers of caterpillar frass by bending the walls and stapling them together (Sudyka et al., 2022). They  
216 measured *c.* W 24 x H 2,5 x D 15,5 cm, weighed *c.* 15,5 g., and were set in groups of three items (based on  
217 nearby nestbox occupancy), fixed to the ground with a long metal nail under the most common tree species of  
218 a given location. The frassboxes were used in all but one study site (site B, National park) where frass  
219 assessment was not possible due to permit restrictions. Frassboxes were placed at the exact same locations in  
220 both years of the study. Frassbox disappearance data covers two consecutive breeding seasons (from May to  
221 mid-June in 2018 and 2019).



222  
223 **Figure 3.** Field equipment assessed for disappearance consisted of nestboxes (A) and frassboxes (B). For  
224 pictures with scale see Fig. S1 in Supporting Materials.

225

226 **3. Equipment disappearance and its drivers**

227 For the empirical analysis of RAT-VIVA framework-based predictions (Fig. 1, Box 1), we used equipment  
228 disappearance data and analysed it in the context of equipment labelling, environmental variables contributing  
229 to fine-scale urban heterogeneity, equipment attributes and the time the equipment spent in the field.

230

231 **3.1 Equipment disappearance**

232 Nestboxes were regularly checked each year (2016 - 2019) during cleaning in October, in early spring and  
233 during the entire avian breeding season (March - July). Frassboxes were placed in the field around the 1st of  
234 May (2018, 2019) and checked every four days until mid- June (12 checks in 2018 and 11 checks in 2019).  
235 Each disappearance of either type of scientific equipment (nestbox or frassbox) was recorded and the missing  
236 item was replaced. At each replacement, new items always had a different type of labelling tone (see below).

237

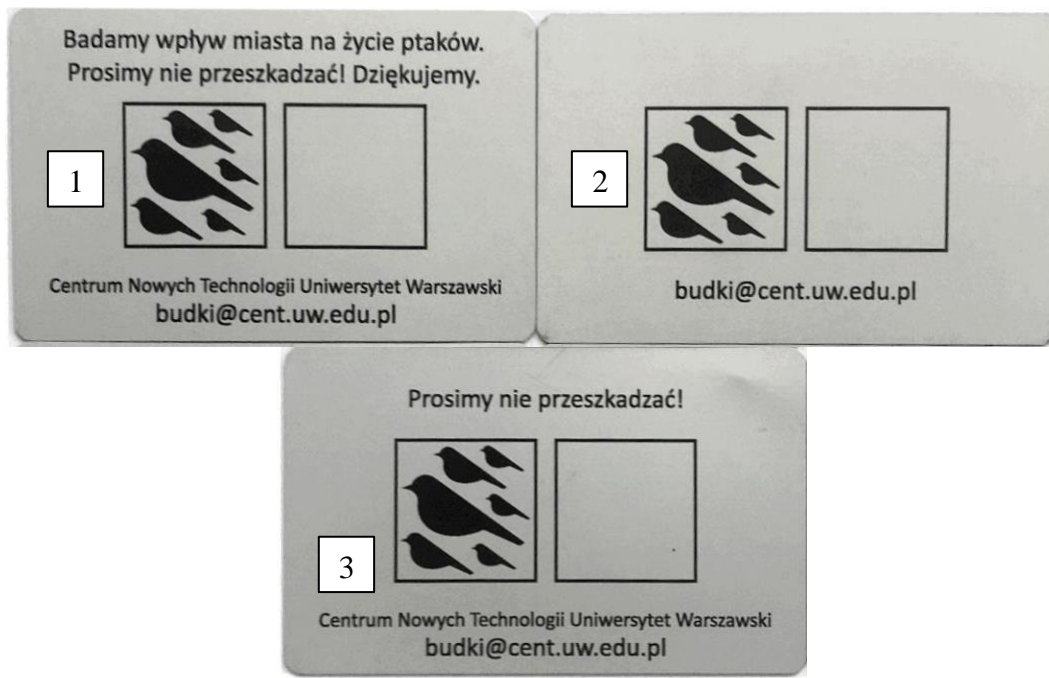
238 **3.2 Labels**

239 To assess the impact of labelling tone (phrasing), we applied the experimental design of Clarin et al. (2014),  
240 who tested the effects of contrasting labelling tone on the vandalism and theft of scientific equipment dummies  
241 left unattended in a 4 urban parks in Munich, for a total of 23 days. Here, the original approach was applied to  
242 an on-going research study set in a gradient of urbanisation in an Central Eastern European capital city  
243 (Warsaw). Both nestboxes and frassboxes were labelled with one of three types of labels (8 x 5 cm, metal for  
244 nestboxes and paper for frassboxes; Fig. 4). The message on each type of label was reported as follows (text  
245 translated from Polish):

- 246 1) *Informative: We are studying the effect of cities on the life of birds. Please do not disturb! Thank*  
247 *you. Centre of New Technologies University of Warsaw*
- 248 2) *Neutral: no message*
- 249 3) *Harsh: Please, do not disturb! Centre of New Technologies University of Warsaw*

250 An equal number of each type of label (1, 2, 3) was assigned to all nestboxes and frassboxes, which were  
251 further evenly spread across space in the study sites.

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260 **Figure 4.** Labels placed at the bottom of 474 nestboxes across 8 study sites: 1 (*Informative*), 2 (*Neutral*), 3  
261 (*Harsh*). Similar labels, printed on paper, were fixed to 121 frassboxes (Fig. 3).

262

### 263 **3.3 Environmental axes of urbanisation**

264 We characterised urban heterogeneity by measuring human presence, tree cover and distance to closest paths  
265 and roads at fine-scale resolution, specifically at the nestbox and at the frassbox level.

266

267 **Human presence.** At each study site, fieldworkers counted for 30 s all humans and dogs within a 15 m  
268 radius from each nestbox. Counts were repeated 20 times for every nestbox location (for more details, see  
269 Corsini et al., 2019). To extrapolate human presence data at each frassbox location, we used the open-source  
270 software QGIS (v.3.10.4) to calculate the Inverse Distance Interpolation (IDW) on the human presence data  
271 quantified at each nestbox location. Specifically, the IDW was derived from the geoprocessing toolbox:  
272 nestbox locations were fitted as vector layers, while the human presence index was fitted as the interpolation  
273 attribute (z). Each IDW was calculated by selecting manually the extent on canvas for each study site  
274 separately.

275 **Tree cover.** The percentage of tree cover was measured at the nestbox and frassbox level following (Szulkin  
276 et al., 2020). After downloading a raster layer from Copernicus Land Monitoring Services, the data was  
277 processed in QGIS. Averaged value of the tree cover (in %) was calculated in a 100 m radius from the nestbox  
278 using the *Zonal Statistics* function.

279 **Distances to paths and roads.** The spatial location of nestboxes was recorded using a GPS Garmin Map 64s  
280 and all the coordinates were downloaded using the open-source Software *DNRGPS Minnesota*. Distances to  
281 the closest road and closest path were measured in meters between the middle of the road/path and the  
282 equipment (i.e., frassbox or nestbox) location using the Measure line tool in *QGIS* (Szulkin et al., 2020).

283

### 284 **3.4 Novelty**

285 To measure the effect of *novelty* – passers-by habituation to specific items over time (Dinnin, 2009) – on  
286 disappearance probability of equipment, we used disappearance data collected over the years (see Methods  
287 (3.1)). Frassboxes were left in the field for two months in both 2018 and 2019, and their checks occurred at  
288 regular intervals – every four days from 1st of May to mid-June. *Frassbox novelty* in the environment was thus  
289 measured as the number of days an item spent in the field before disappearance occurred (starting from the  
290 set-up date until the end of frass collection each year). Each check was treated separately (consequently, the  
291 sample size of frassbox disappearance events was the outcome of the number of frassbox locations \* the  
292 number of frassbox checks performed; random effects were fitted to control for repeated sampling of the  
293 sample frassbox location (see below)). We were unable to perform an analogous *novelty* analysis on nestboxes  
294 as the study sites were set in different years (see Methods (2.1)) and the checks were performed infrequently  
295 over the year and during the field season (see Methods (3.1)).

296

### 297 **4. Statistical analysis**

298 Statistical analyses were computed in R (v. 3.6.2). Plots and diagrams were built and visualized using *ggplot2*  
299 (v.3.3.5) (Wickham, 2011) and the open-source software *Inkscape* (*Inkscape project, 2003*). Detailed R-  
300 packages used for each analysis are detailed below. Nestbox and frassbox disappearance was always analysed  
301 separately.

302



#### 303 **4.1 Effect of labels on scientific equipment disappearance**

304 We used Chi-squared tests to infer whether differences in scientific equipment disappearance are driven by  
305 label type. To test the effect of labelling on disappearance of both types of equipment, each item's label was  
306 treated separately (*i.e.*, both original and replacement labels). The items were replaced only if they were found  
307 missing or damaged (see *3.1 Equipment disappearance* for details on equipment checks). A new label,  
308 containing a different type of message than the phrasing that disappeared (see Fig. 4) was provided at each  
309 replacement. Because frassboxes were deployed in both 2018 and in 2019 for the duration of the breeding  
310 season (note that nestboxes remained throughout the entire duration of the study), we summed the number of  
311 disappearances and the total number of available frassboxes within each label type from the first and the second  
312 year of the study.

313

#### 314 **4.2 Environmental drivers of scientific equipment disappearance across the urban mosaic**

315 Nestbox disappearance was monitored across 4 years (2016-2019). As multiple disappearances of the same  
316 nestbox were rare ( $N = 4$ ), we fitted a binomial response variable as 0 - never disappeared - or 1 - disappeared  
317 at least once (contrarily to the label analysis where all disappearance events were analysed). Because the  
318 response variable was zero-inflated (*i.e.*, observed zeros in the dataset exceeded predicted zeros), we used the  
319 R-package *glmmTMB* (v.1.0.2.1) (Brooks et al., 2017), specifying the binomial family and the *ziformula* as 1,  
320 which applied a single-zero inflation parameter to each observation. Due to the high correlation ( $r_{\text{Pearson}} > 0.6$ ,  
321  $p < 0.001$ ,  $N = 474$ ) between the environmental variables *Distance to road*, *Distance to path*, and *Tree cover* in  
322 the nestbox dataset (see Fig. S2 and Table S3), we fitted three distinct models, which differed in including one  
323 of these variables in substitution of the other, but contained an analogous model structure in terms of the other  
324 predictors: specifically, *Human presence* (fitted as continuous explanatory variable) and *Site* (fitted as random  
325 effect to control for visitor behavioural differences (and approach towards scientific equipment) in the different  
326 sites, [e.g. national park vs urban park] (Zegras, 2004, Teixeira, 2021),  $N = 8$  levels).

327 Frassbox disappearance was analysed using *Generalised Linear Mixed Effects Models* (GLMMs),  
328 where the total number of disappeared frassboxes was fitted as a Poisson-distributed response variable (*glmer*  
329 function in *lme4*, v.1.1-21) (Bates et al., 2007). Because of the strong correlation between *Distance to the road*  
330 and *Tree cover* ( $r_{\text{Pearson}} = - 0.7$ ,  $p < 0.001$ ,  $N = 141$ , see Fig. S2 and Table S3), analyses were performed in two  
331 distinct models, which included one or the other environmental variable (as described earlier). The other

332 predictors included in both models were *Human presence*, *Distance to paths* (both as continuous), and *Year*  
333 (as a two-level factor). Frassbox ID, nested within *Site* (N=7 levels), were fitted as random effects to avoid  
334 pseudo replication in both models. Multicollinearity was checked using the R-package *performance* (v.0.8.0)  
335 (Lüdtke et al., 2021) and always resulted in  $vif < 2$ . All model fits and assumptions were verified using the  
336 *DHARMA* package (v.0.4.4) (see Fig. S3, Hartig, 2020). Continuous predictors in all models described above  
337 were scaled and mean-centred for estimation clarity. All interactions between predictors were tested and  
338 retained in the final models only if significant.

339

#### 340 **4.3 Novelty and scientific equipment disappearance**

341 To test whether *novelty* was associated with disappearance probability, we fitted a Generalised Linear Mixed  
342 Effect Model (GLMM) where the binomial-variable (disappeared or not disappeared, coded as 1 or 0,  
343 respectively) was set as response, and *Novelty* (starting with 1 from the day of equipment setup at the start of  
344 each breeding season; see Table 3 & Table S4a-b) was included as continuous predictor. Frassboxes were  
345 distributed on the ground across the study sites starting when the majority of great tit and blue tit nestlings  
346 were in the nest (from 1<sup>st</sup> of May until mid-June in 2018 and in 2019). *Year* was included as a two-level factor  
347 (2018 or 2019) and *FrassboxID* was fitted as a random effect, as the same frassbox was regularly checked  
348 (every four days) at multiple times each year (N of checks = 12 and 11 in 2018 and 2019, respectively).  
349 Multicollinearity issues, as well as model fit and assumptions, were checked as described in Methods 4.2. The  
350 *Novelty* analysis was not performed for nestboxes due to a different experimental setup (see Methods 3.4).



351 **RESULTS**

352 A total of 474 nestboxes and 141 frassboxes were followed over the duration of the study. 45,36% of nestboxes  
353 were followed for four years, 40,93% for three years and 13,71 % for two years. All frassboxes (100%) were  
354 followed for two field seasons (see Table S1 and S2).

355 **Different types of equipment disappear at different rates**

356 Over the duration of the study, 6.33% (N=30) of nestboxes disappeared at least once. In contrast, frassbox  
357 disappearance was *c.* eight times larger, as almost half (49,65%, N=70) of all available frassboxes  
358 disappeared at least once.

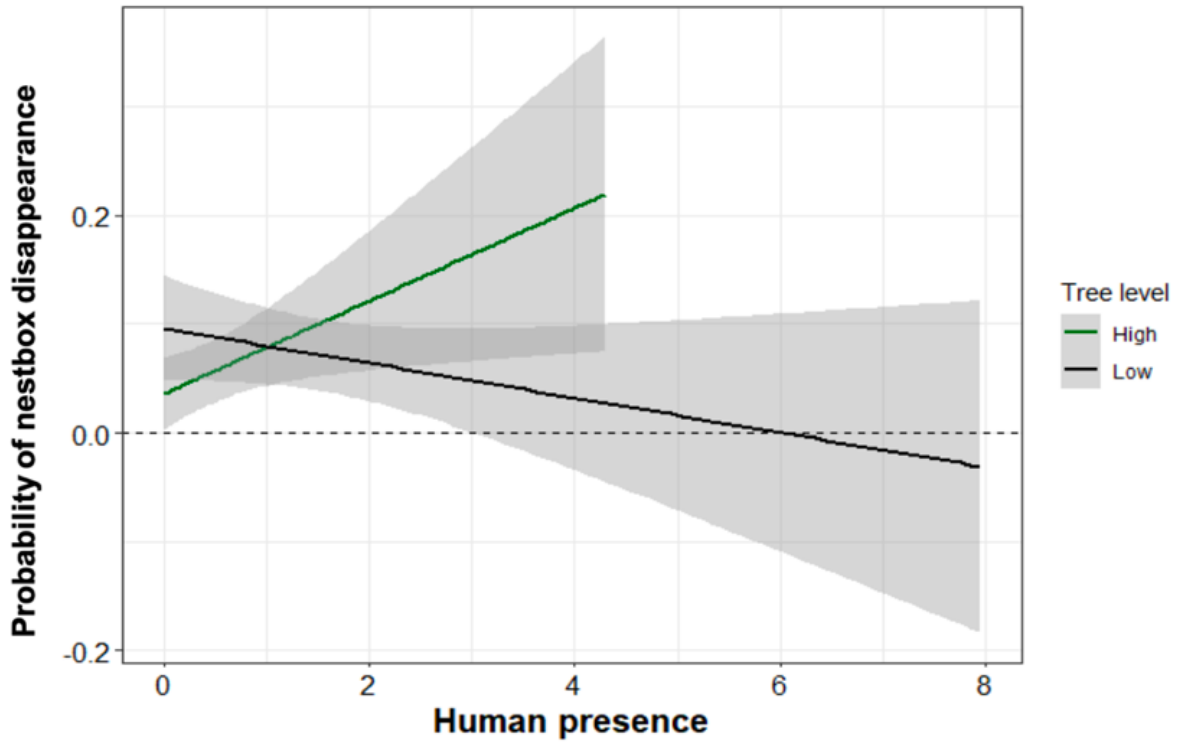
359 **No effect of labelling on scientific equipment disappearance**

360 Label type did not influence disappearance of either type of equipment. For nestboxes, we had 15  
361 disappearances of *informative* labelled items (out of 171 available items with this type of label), nine  
362 disappearances of *neutral* items (out of 163) and 10 disappearances of *harsh* items (out of 170) –  $\chi^2=1.4774$ ,  
363 d.f. = 2, p-value = 0.478. For frassboxes, we observed 91 disappearances of *informative* items (out of 217), 84  
364 disappearances of *neutral* items (out of 224) and 95 disappearances of *harsh* items (out of 212) –  $\chi^2=1.8021$ ,  
365 d.f. = 2, p-value = 0.600.

366 **Covariation between environmental variables and scientific equipment disappearance**

367 *Nestbox disappearance*

368 When applying the RAT-VIVA framework to scientific equipment disappearance patterns (Fig. 1), nestbox  
369 disappearance was associated with the interaction between human presence and tree cover. In other words,  
370 nestbox disappearance increased with higher human presence in areas with higher tree cover, and decreased  
371 with higher human presence in areas with low tree cover (Fig. 5, Table 1). Nestbox disappearance was not  
372 associated with nestbox distance to roads or distance to paths (see Table S5).



373

374

375 **Figure 5.** Linear regression (with 95% confidence intervals) reporting the probability of nestbox  
 376 disappearance in areas with high human presence and high tree cover. To visualise the interaction, we used  
 377 the *lm* function in *ggplot2*; tree cover was categorised based on the median value of the full dataset as low (N  
 378 = 237, values between 0 and 26.4, mean  $\pm$ se,  $7.46 \pm 0.45$ ); black line and high (N = 237, values above 26.4,  
 379 mean  $\pm$ se,  $63.2 \pm 1.01$ ; green line).

380

381

382

**Table 1. Zero-inflated models with binomial distribution testing the association between**

383

**nestbox disappearance and environmental variables.**

<b>Environmental drivers of nestbox disappearances</b>				
<i>Family:</i> zero-inflated with binomial (logit) distribution, N <sub>nestboxes</sub> = 474				
<i>Model structure:</i> <b>Disappeared nestbox (0/1)</b> ~ Human presence <sub>sc</sub> * Tree cover <sub>sc</sub> .				
<b>Variable</b>	<b>Estimate</b>	<b>se</b>	<b>z-value</b>	<b>p-value</b>
Intercept	2.261	1.825	1.239	0.215
<b><u>Human presence * Tree cover</u></b>	<b>4.138</b>	<b>2.076</b>	<b>1.993</b>	<b>0.046*</b>
Human presence	3.634	2.390	1.521	0.128
Tree cover	1.448	1.491	0.971	0.331

384

385

**Table 1.** Zero-inflated GLMMs models with binomial distribution testing the association between probabilities

386

of nestbox disappearance (fitted as never disappeared, 0, or disappeared at least once, as 1, in four years).

387

Models were analysed using the R-package *glmmTMB*. Continuous predictors were mean-centred and scaled

388

(sc). Significance levels are indicated in bold: \*p < 0.05, \*\*p < 0.01, \*\*\*p < 0.001.

389

390

*Frassbox disappearance*

391

As in the case of nestboxes, frassbox disappearance was also positively associated with the interaction between

392

human presence and tree cover (Fig. 5). Overall, frassbox disappearance increased with human presence, and

393

particularly so in areas with high tree cover (Fig. 6). At the same time, frassbox disappearance was also

394

associated with the interaction between distance to roads and distance to paths. Specifically, the disappearance

395

rate increased closer to roads, if those were located further away from paths (Table 2).

396

397 **Table 2. Generalised Linear Mixed Effects Models (GLMMs) with Poisson distribution testing**  
 398 **environmental drivers of frassbox disappearance across the urban mosaic.**

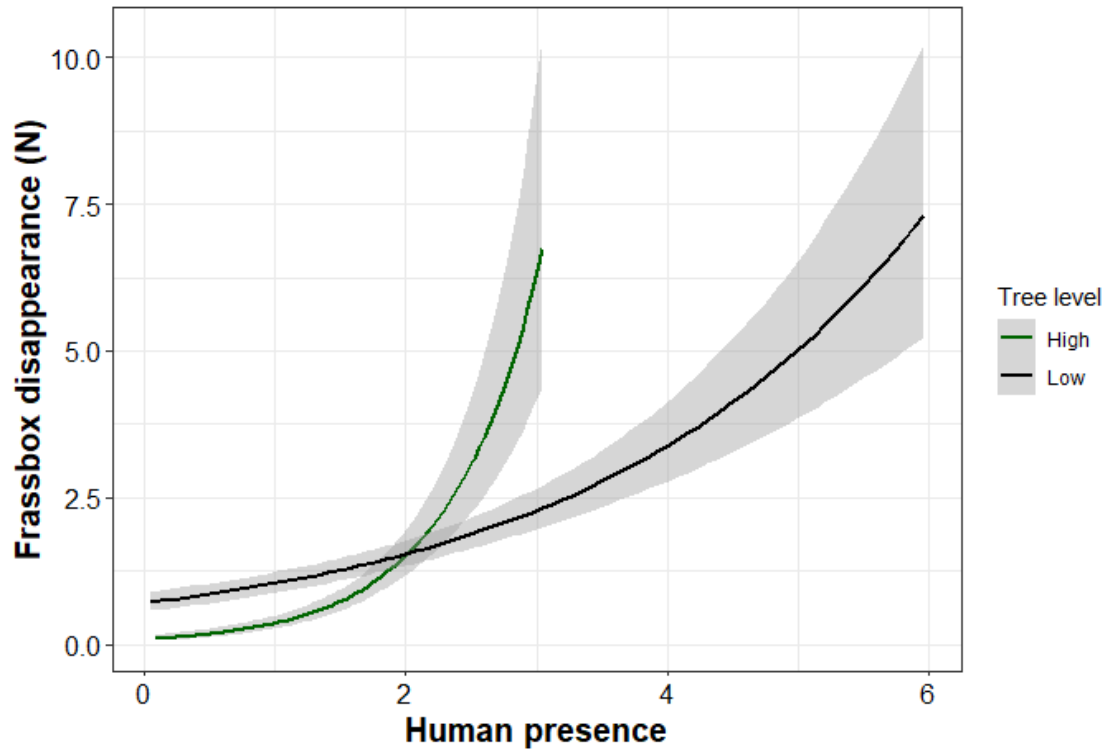
399

<b>Environmental drivers of frassbox disappearances</b>				
<i>Family:</i> Poisson (log), <i>Random:</i> Frassbox ID nested within Site, $N_{\text{frassboxes}} = 282$ , $N_{\text{sites}} = 7$				
<i>Model structure:</i> Frassbox disappearances <sub>(Total)</sub> ~ Human presence <sub>sc</sub> * Tree cover <sub>sc</sub> + Distance to paths <sub>sc</sub> + Year.				
<b>Variable</b>	<b>Estimate</b>	<b>se</b>	<b>z-value</b>	<b>p-value</b>
Intercept	-0.935	0.349	-2.680	0.007**
<b>Human presence * Tree cover</b>	<b>0.503</b>	<b>0.216</b>	<b>2.321</b>	<b>0.020*</b>
<b>Human presence</b>	<b>0.948</b>	<b>0.252</b>	<b>3.758</b>	<b>&lt;0.001***</b>
<b>Tree cover</b>	<b>-0.610</b>	<b>0.245</b>	<b>-2.487</b>	<b>0.012*</b>
Distance to paths	0.061	0.181	0.336	0.736
Year (2019)	-0.215	0.122	-1.759	0.078
<i>Model structure (glmer):</i> Frassbox disappearances <sub>(Total)</sub> ~ Distance to roads <sub>sc</sub> * Distance to paths <sub>sc</sub> + Human presence <sub>sc</sub> + Year.				
<b>Variable</b>	<b>Estimate</b>	<b>se</b>	<b>z-value</b>	<b>p-value</b>
Intercept	-0.841	0.509	-1.652	0.098
<b>Distance to paths * Distance to roads</b>	<b>-0.956</b>	<b>0.385</b>	<b>-2.482</b>	<b>0.013*</b>
<b>Human presence</b>	<b>0.406</b>	<b>0.183</b>	<b>2.212</b>	<b>0.027*</b>
Distance to roads	-0.089	0.277	-0.323	0.746
Distance to paths	-0.282	0.220	-1.279	0.201
Year (2019)	-0.214	0.122	-1.758	0.078

400

401 **Table 2.** Generalised Linear Mixed Effects Models testing the effects of environmental variables on  
 402 cumulated frassboxes disappearances. Continuous predictors were mean-centred and scaled (*sc*). Model  
 403 details are reported in Section 4.2. Significance levels are indicated in bold: \***p < 0.05**, \*\***p < 0.01**,  
 404 \*\*\***p < 0.001**.

405



406

407 **Figure 6.** 95% confidence intervals reporting frassbox disappearance in areas with high human presence  
 408 and high tree cover. To visualise the interaction, we used the *lm* function in *ggplot2*; *Tree cover* was  
 409 categorised based on the median value of the full dataset as low (N = 142, values between 0 and 27.42, mean  
 410  $\pm$ se,  $8.65 \pm 0.73$ ) and high (N = 140, values above 27.42, mean  $\pm$ se,  $51.68 \pm 0.9$ ).

411

412 **Novelty as a predictor of scientific equipment disappearance**

413 Frassbox disappearance was highly sensitive to the novelty effect, as the majority of frassboxes disappeared  
 414 in the initial stage of the study (at the start of the breeding season), when items were deployed in the field; the  
 415 frequency of these disappearances subsequently and gradually decreased. Most items ( $N_{2018} = 21$ ,  $N_{2019} = 24$ )  
 416 disappeared in the first, four days long period of frass collection in the season (Table 3, Fig. 7).

417

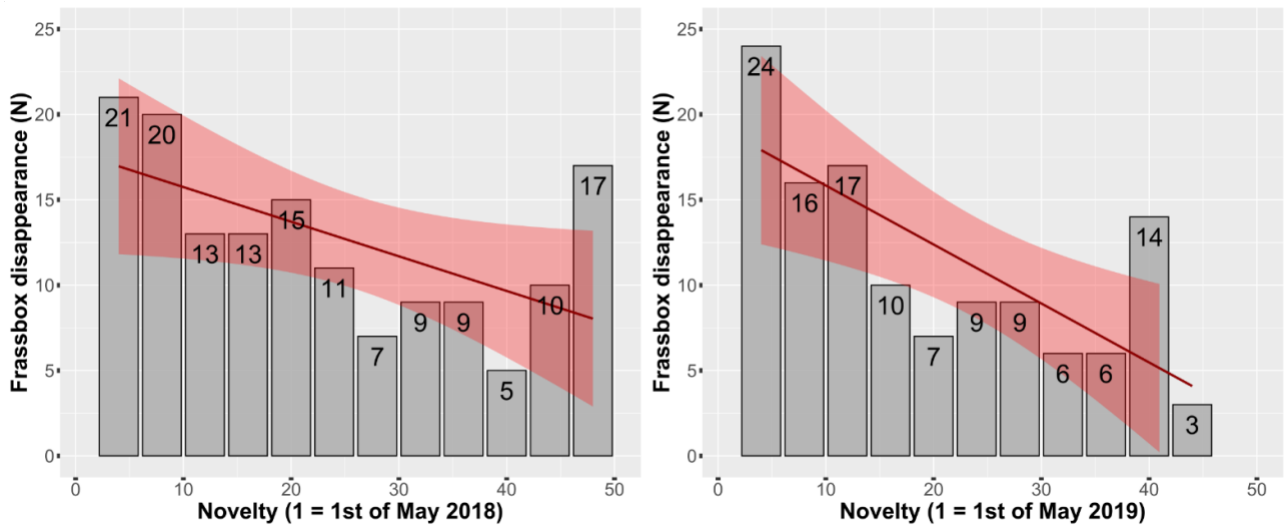
418

419 **Table 3. GLMMs testing the association between novelty and frassbox disappearance.**

<b>Effect of novelty on frassbox disappearance (2018 &amp; 2019)</b>				
<i>Family:</i> Binomial, Random = Frassbox ID (N = 141).				
<i>Model structure (glmer):</i> Disappeared <sub>Frassbox</sub> (0/1) ~ Novelty <sub>sc</sub> + Year.				
<b>Variable</b>	<b>Estimate</b>	<b>se</b>	<b>z-value</b>	<b>p-value</b>
Intercept	-2.832	0.296	-9.574	<0.001***
<b><u>Novelty</u></b>	<b>-0.037</b>	<b>0.006</b>	<b>-6.014</b>	<b>&lt;0.001***</b>
Year (2019)	-0.262	0.156	1.676	0.094

420

421 **Table 3.** Generalised Linear Mixed Effects Model testing the association between novelty and frassbox  
422 disappearance. **Novelty was calculated as the entire period - in days – the collectors were left in the field**  
423 **(1=1st of May, each year, as 2018 or 2019).** Continuous predictors were mean-centred and scaled (*sc*).  
424 Model details are reported in Methods (Section 4.3). Significance levels are indicated **in bold: \*p <0.05,**  
425 **\*\*p<0.01, \*\*\*p<0.001.**



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**Figure 7.** Frassbox disappearance was highest when frassboxes were novel in the environment. Barplots indicate the cumulated number of disappeared frassboxes per check in the field (over a total of 141 deployed frassboxes). The trend line was generated using a Linear regression (*stat\_smooth* function in *ggplot2*). Similar trends were found if the models were run separately for both years (208 & 2019; see Table S4a-b).

432 **DISCUSSION**

433 In this paper, we empirically applied event-focused theory developed in the context of criminal studies – the  
434 Routine Activity Theory (RAT; Cohen & Felson, 1979, Felson & Clarke, 1998) – to urban evolutionary  
435 ecology research. By doing so, we were able to successfully predict and statistically verify which external  
436 variables and equipment attributes are associated with field equipment disappearance.

437 The *potential offender* element of RAT (Fig. 1 (1); modelled by human presence), interacted with  
438 *visibility* (Fig. 1 (2.3); represented here by tree cover) to influence the disappearance of both nestboxes and  
439 frassboxes. Thus, in highly-frequented places, people were more likely to remove the scientific equipment if  
440 they felt less seen – for example in cases where trees could act as a cover. Indeed, urban greenery is reported  
441 to have a significant influence on rates of a variety of crimes: a recent study reporting property crimes over  
442 multiple cities from South Africa are fully in alignment with our findings, confirming that higher tree cover  
443 was associated with increased property crime (Venter et al., 2022).

444 The *absence of guardians* element of RAT (Fig. 1 (3)) was modulated by label tone. Contrary to Clarin  
445 et al. (2014), we did not find a significant difference in the disappearance of either type of equipment based on  
446 label types (see *Results*). A possible explanation is that the labels used in this study needed to be applied to a  
447 real-life scenario of efficiency and informativeness, worded specifically for the sake of the long-term study it  
448 was designed for. Consequently, the messages were more explicit (for example, they did not include images  
449 of a juvenile squirrel, or of an overly threatening warning sign), and were not as radically different from each  
450 other as in the hypothetical scenario assessed by Clarin et al. (2014). Therefore, the overall effect of labels on  
451 equipment disappearance in our study system may be weaker. Importantly, relative to Clarin et al. (2014), this  
452 study was run on two different types of equipment, considerably larger sample sizes (474 nestboxes and 141  
453 frassboxes vs 60 equipment dummies), and greater – and more diversified in terms of land use – number of  
454 study sites (eight sites set in a gradient of urbanisation vs four urban parks), as well as a longer study period  
455 (two to four years [nestboxes] and c. 90 days [frassboxes] vs. 24 days in Clarin et al. (2014)). Consequently –  
456 following recommendations in Clarin et al. (2014) regarding the need of replication in other regions of the  
457 world – our findings suggest that labelling may not be a sufficient method to protect the equipment if applied  
458 to a realistic, long-term project across different cultural and spatial contexts.

459 Based on the four VIVA attributes (*value, inertia, visibility* and *access*), we predicted that nestboxes  
460 are a type of scientific equipment that is less susceptible to disappear than frassboxes (Box 1(B)). This



461 prediction was confirmed, and reflected in the percentage of disappearances recorded as binary events (nestbox  
462 disappearance rate of 6,33% vs frassbox disappearance rate of 49,65%). As expected by the framework  
463 features, a small, light, eye-catching and easily accessible item such as the frassbox is significantly more prone  
464 to negative interactions with people than the unhandy, harder to spot and to reach nestbox; even with a  
465 considerable difference in value – visually a woodcrete nestbox is more valuable, than a paper frassbox, which  
466 is also reflected in items' price (Box 1).

467 Importantly, the VIVA framework allowed us to determine which attributes are influencing the  
468 disappearance of items within the same type of equipment (Fig. 1).

- 469 • *Value*, determined by *novelty*, influenced the disappearance of frassboxes (Fig. 7). As  
470 anticipated (Fig. 1), most disappearances occurred in the early period of equipment setup, after  
471 which the numbers gradually decreased. This strongly suggests that city dwellers lost their  
472 original interest in interfering and removing the equipment once it was familiar (Dinnin, 2009).  
473 Note that this might not be the case with considerably more valuable equipment, such as  
474 camera traps, where the financial cost of the equipment itself can interact with the temporal  
475 dimension of novelty (Meek et al., 2018)
- 476 • *Inertia* is consistent within equipment type (as the volume and weight of all items [e.g.  
477 nestboxes or frassboxes] is the same), thus it could not influence the disappearance dynamics  
478 at this level.
- 479 • *Visibility* – discussed above (see above).
- 480 • Finally, *access* – measured by item's distance to the closest path or road – was found to be  
481 associated with the disappearance of frassboxes, but not nestboxes. These findings suggest  
482 that researchers, site-managers and stakeholders should consider securing easily reachable  
483 field equipment, especially in accessible areas (see Introduction for examples of equipment  
484 securing methods). At the same time fixing the equipment beyond the reach of passers-by may  
485 also decrease a chance of equipment disappearance (as in case of nestboxes).

486 Our results thus confirm that the disappearance of field equipment, as tested in the context of a real-life research  
487 project run in the urban field, is the result of an interaction between external variables (Fig. 1) – such as  
488 *potential offender* (human presence), *relative value* (novelty), *visibility* (tree cover), *access* (distance to paths

489 \* distance to roads) – and equipment attributes (Box 1) – that is an item’s *assumed value* (here approximated  
490 by price), *inertia* (volume and weight), *visibility* (colour), *access* (type of installation).

491

## 492 **Conclusions**

493 The results reported here confirm that in urban areas, certain study site settings may facilitate or impede  
494 equipment disappearance. Similarly, some types of deployable scientific equipment may be predisposed for  
495 negative interactions with people. Moreover, the interactions between the two – the study site setting and  
496 equipment characteristics – also affect equipment disappearance. This observation further enhances the  
497 importance of accounting for sociological aspects while conducting eco-evo research in areas occupied by  
498 humans, such as cities (Des Roches et al., 2021).

499 Those findings illustrate the universal validity of the Routine Activity Theory (RAT), and the VIVA  
500 framework embedded within this theory for urban ecology and evolution research. Examining the equipment  
501 and the study locations under the RAT-VIVA framework is an easily applicable and inexpensive way to better  
502 understand patterns of equipment disappearance, thereby strengthening the potential for informed project  
503 planning and as a result – safer, and more effective studies not only in the urban space but also other frequently  
504 visited areas.

505 It is important to remember that this study was conducted in a European capital city (specifically – a  
506 democratic post-communist Central Eastern European capital city), and as such provides valuable insight into  
507 processes (equipment theft) that may carry both local features (shaped by specific socio-cultural norms), as  
508 well as universal ones pertaining to human psychology. Thus, our results fully align with a study on property  
509 crime committed in urban areas from the Global South (Venter et al., 2022). Importantly - the RAT-VIVA  
510 framework presented here is fully amenable to modifications of original predictions based on cultural and  
511 geographical variation, and as such can be applied to any location of interest. We encourage other researchers  
512 to conduct similar studies during their research, particularly by adding a greater understanding of the dynamic  
513 of scientific equipment disappearance in the urban space when tested in cities of variable size and in different  
514 social contexts.

515

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643 **Authors Contributions:**

644 **Ignacy Stadnicki** Conceptualization, Writing - original draft, Writing - review & editing, Formal  
645 Analysis. **Michela Corsini**: Conceptualization, Data collection, Writing - review & editing, Formal  
646 Analysis, Graphs design. **Marta Szulkin**: Initial conceptualization, Data collection, Writing - review &  
647 editing. All authors edited and approved the final version of the manuscript.

648

649 **Data accessibility statement:**

650 This manuscript is currently being submitted to an academic journal for the first time. Full datasets will be  
651 uploaded upon final acceptance in a peer-reviewed journal.