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4   Animal-appropriate housing of ball pythons (*Python regius*)

5   — Behavior-based evaluation of two types of housing systems

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Abstract

Considering animal welfare, animals should be kept in animal-appropriate and stress-free housing conditions in all circumstances. To assure such conditions, not only basic needs must be met, but also possibilities must be provided that allow animals in captive care to express all species-typical behaviors. Rack housing systems for snakes have become increasingly popular and are widely used; however, from an animal welfare perspective, they are no alternative to furnished terrariums. In this study, we therefore evaluated two types of housing systems for ball pythons (*Python regius*) by considering the welfare aspect animal behavior. In Part 1 of the study, ball pythons ($n = 35$) were housed individually in a conventional rack system. The pythons were provided with a hiding place and a water bowl, temperature control was automatic, and the lighting in the room served as indirect illumination. In Part 2 of the study, the same ball pythons, after at least 8 weeks, were housed individually in furnished terrariums. The size of each terrarium was correlated with the body length of each python. The terrariums contained substrate, a hiding place, possibilities for climbing, a water basin for bathing, an elevated basking spot, and living plants. The temperature was controlled automatically, and illumination was provided by a fluorescent tube and a UV lamp. The shown behavior spectrum differed significantly between the two housing systems ($p < 0.05$). The four behaviors basking, climbing, burrowing, and bathing could only be expressed in the terrarium. Abnormal behaviors that could indicate stereotypies were almost exclusively seen in the rack system. The results show that the housing of ball pythons in a rack system leads to a considerable restriction in species-typical behaviors; thus, the rack system does not meet the requirements for animal-appropriate housing.

Introduction

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42   The ball python (*Python regius*) has been a popular terrarium-housed exotic pet for more

43   than 30 years (DE VOSJOLI 1990). In Europe and North America, it is frequently bred, but

44   also imports of wild snakes or farmed breeds are commercially available. Due to the various

45   breeding goals (coloration, pattern, scaleless skin), the ball python has highly variable

46   phenotypes and thus is still one of the most frequently kept snake species. The international

47   website "www.worldofballpythons.com/morphs/" for the registration of color morphs

48   (accessed on 18 May 2020) lists 7,221 different color shades and patterns. Although the ball

49   python is listed in the Washington Endangered Species Act Appendix II

50   (https://www.cites.org/eng/app/appendices.php, accessed on 18 May 2020) and the German

51   directive VO EG 338/97 Appendix B (https://eur-lex.europa.eu/legal-

52   content/DE/TXT/PDF/?uri=CELEX:01997R0338-20130810, accessed on 18 May 2020), it is

53   exempt from reporting requirements ("Federal Directive on Species Protection"

54   [Bundesartenschutzverordnung] Appendix 5 regarding § 7 Section 2; https://www.gesetze-

55   im-internet.de/bartschv_2005/anlage_5.html, accessed on 18 May 2020); thus, the number

56   of ball pythons kept as pets in Europe and North America is speculative.

57   The ball python is native to West and Central Africa (Nigeria, Uganda, Liberia, Sierra Leone,

58   Guinea, Benin, Ghana, and Togo). It mainly inhabits arid savannas with temperature

59   extremes ranging from 16 to 43 °C (SCHMIDT 1994) and relative humidity ranging from 60%

60   to 95%, with high seasonal variation due to the dry (December to March) and rainy seasons

61   (April to November) (https://www.auswaertiges-amt.de, accessed on 21 April 2020;

62   https://www.iten-online.ch/klima/afrika, accessed on 21 April 2020). The "German Expert

63   Report on Minimum Requirements for the Keeping of Reptiles" (Federal Ministry of Food and

64   Agriculture [Bundesministerium für Ernährung und Landwirtschaft] [BMEL] 1997) stipulates a

65   temperature range of 26–32 °C with a nighttime reduction of 5 °C. A localized heat spot

66   (basking spot) with 38 °C must be provided. During daytime, the ball python often hides in

67   rodent burrows or abandoned termite mounds (SUTHERLAND 2009, SCHMIDT 2009).

68 These possibilities for hiding offer the snake relatively constant temperature and humidity

69 conditions. At dusk, the ball python leaves its hiding place to forage or fulfil other needs

70 (TRUTNAU 1988, SCHMIDT 1994, KÖLLE 2007). Being a synanthropic species, the ball

71 python is often found near settlements and cultivated fields, where it feeds on rodents (DE

72 VOSJOLI 1990). Due to its body shape, it can be considered a ground-dwelling snake,

73 although it can be seen at low heights on trees, sufficiently robust shrubs, or termite mounds

74 (KÖLLE 2007). Like almost all snakes, the ball python can swim, but its life cycle is not

75 dependent on the presence of water bodies (TRUTNAU 1988). It uses bathing possibilities

76 especially during the molting phase (SCHMIDT 1994).

77 The typical housing system used for pythons is the so-called rack system. It was first

78 designed in North America around 1992 (www.freedombreeder.com/freedom-breeder-rack-

79 systems, accessed on 21 April 2020; REPTIL TV 2014). A rack system is a shelving system

80 with individual bins arranged as drawers. In some models, the bins have individual lids, in

81 other models, they are open on the top and close flush with the upper shelf board. All bins

82 have ventilation holes. Rack systems usually have no lighting elements, so the ambient light

83 provides the only illumination. Heating elements are installed per drawer level, and heating

84 pads or heating cables are most frequently used. The heating elements should be equipped

85 with a thermostat that prevents overheating and undercooling. Racks are available in various

86 sizes. Most importantly, the bins should be flat. Depending on the manufacturers, the

87 synthetic material used for the bins varies from clear acrylic glass to non-transparent plastic.

88 Regarding the bin furnishing, several variants are available. The most used substrate is

89 newspaper, but also rodent litter or bark mulch are used. Most variants include a hiding place

90 and a water bowl (for drinking), in some cases arranged as a bowl with crawl space

91 underneath. Some variants contain additional structural elements such as artificial plants, a

92 water basin (for bathing), or tree branches. Rack housing offers the advantage of quick and

93 complete cleaning, and little space and time are needed to accommodate and maintain many

94 snakes. Because each animal is kept individually, precise animal monitoring is easily

95 possible. Moreover, the sparse furnishing keeps the injury risk low. Further arguments of

96   breeders and advocators of rack housing can be found in the relevant literature (e.g.,

97   WESTHOFF 2005, McCURLY 2011) and include the following: the animals accept feed more

98   readily in a rack system than in a terrarium; thus, feed refusal occurs less frequently; due to

99   the higher feed intake, the animals grow faster, resulting in a younger breeding age; the

100 animals reproduce more readily; accommodation in the rack system is more natural for the

101 ball python, which in nature lives in termite mounds; the flat design of the bins is thought to

102 cause less stress for the snake (LONGHITANO 2010); animals housed in rack systems are

103 considerably less aggressive (McCURLY 2011). Light causes stress for crepuscular and

104 nocturnal animals—a further argument for indirect or no illumination in the rack drawers.

105 Arguments against rack housing are comprehensively presented in the expert report of

106 Workgroup 8 (Pet Trade and Pet Husbandry) from 19 July 2013; the workgroup comprises

107 members of the "Veterinary Association for Animal Protection" (Tierärztliche Vereinigung für

108 Tierschutz e. V.), the "Federal Association for Expertise on Nature, Animal, and Species

109 Protection" (Bundesverband für fachgerechten Natur-, Tier- und Artenschutz e. V.), the

110 "Workgroup Diseases of Amphibians and Reptiles" (Arbeitsgemeinschaft Amphibien- und

111 Reptilienkrankheiten, a subdivision of the "German Society for Herpetology and

112 Herpetoculture" [Deutsche Gesellschaft für Herpetologie und Terrarienkunde e. V.]), the

113 "German Veterinarian Society" (Deutsche Veterinärmedizinische Gesellschaft e. V. [DVG]),

114 the DVG "Study Group Zoo Animal, Wild Animal, and Exotic Animal Medicine" (DVG

115 Fachgruppe Zootier-, Wildtier- und Exotenmedizin), the DVG "Study Group Pet Birds, Zoo

116 Birds, Wild Birds, Reptiles, and Amphibians" (DVG Fachgruppe Zier-, Zoo- und Wildvögel,

117 Reptilien und Amphibien), and the "Munich Rescue Center for Reptiles" (Auffangstation für

118 Reptilien München e. V.). In the expert report, the workgroup pointed out the lacking

119 possibility for three-dimensional locomotion due to the low height of the rack bins.

120 Furthermore, the small space allowance leaves little room for furnishings, excluding

121 possibilities for hiding in various places (dry, humid, elevated) and for climbing. Depending

122 on the substrate, burrowing may also be impossible. Another concern, not directly addressed

123 in the expert report, is illumination. At the most, rack systems allow illumination via ambient

124 light or via an LED strip fixed to the lid of the bin. Spotlights, for example with UV light,

125 cannot be installed.

126 In contrast to rack systems, terrariums have been used much longer for housing animals. In

127 1964, the "German Society for Herpetology and Herpetoculture" was founded in Germany

128 (www.dght.de, accessed on 21 April 2020). A terrarium is an enclosure or a container in

129 which various species of animals can be housed (RIECK et al. 2001). The interior climatic

130 conditions are adjusted to the needs of the housed animal species. At least one side of the

131 terrarium is transparent. In contrast to an aquarium, terrestrial elements and air space

132 predominate. Due to the rapid technical developments in almost every area, today's

133 terraristics is highly progressive. Daytime-dependent variations of temperature, lighting, and

134 humidity can precisely be planned, simulated, and controlled. A skilled use of UV lamps,

135 irrigation systems, and nebulizers in the terrarium allows creating a microclimate that is

136 nearly identical to the microclimate in the natural habitat. In "good terraristics practice," the

137 animal is provided with various elements for expressing its needs. Climbing possibilities,

138 various hiding places, substrate for burrowing, and plants are included according to the

139 housed animal species. Living plants not only ensure the formation of a natural microclimate

140 but also provide structural change over time. Various types of light sources can be used for

141 illumination. Energy efficient LED bulbs can provide basic illumination. To simulate natural

142 sunlight for the basking spot, UV lamps of appropriate wavelengths and intensity should be

143 selected according to the animal species. Similarly, heating elements should optimally

144 radiate heat like the sun, i.e., from the top to the bottom.

145 Beyond the body of specialized literature, we found a few arguments against housing the ball

146 python in a terrarium (e.g., WESTHOFF 2005, McCURLY 2011), but these arguments are

147 based on observations and have not been analyzed scientifically. According to the "German

148 Expert Report on Minimum Requirements for the Keeping of Reptiles" of 1997, the ball

149 python does not feel safe in a terrarium exceeding a certain height. Because this snake is a

150 ground dweller and not a good climber, a terrarium that is too high poses the risk of the

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151   animal falling and getting injured (WESTHOFF 2005). Furthermore, due to perception of the

152   surrounding environment (e.g., through a glass front), the snake feels threatened and often

153   reacts very aggressively (McCURLY 2011). Lighting additionally stresses the ball python

154   (McCURLY 2011). All these factors can lead to feed refusal, slow growth, and poor

155   reproduction rates in a terrarium. Moreover, growth of health hazardous bacteria and molds

156   often occurs in a terrarium (McCURLY 2011).

157   Many wild animals kept in captivity show stereotypical behaviors. A stereotypy is a repetitive,

158   invariant behavior or movement pattern without function or goal and is often seen due to

159   inadequate husbandry conditions (DÜPPJAN and PUPPE 2016). Therefore, stereotypies are

160   often considered as indicators of impaired wellbeing caused by acute or past suffering. As

161   seen almost exclusively in circumstances of confinement (LANGEN et al. 2011a, 2011b),

162   situations can arise in which an animal is strongly motivated to show a behavior but cannot

163   express it because the necessary circumstances are not given (WECHSLER 1992).

164   Endogenous and exogenous stimuli can induce a readiness to act that is displayed at varying

165   intensity. However, a desire-consuming final action never happens (SAMBRAUS 1982)

166   because the human-made environment does not allow it (FRASER et al. 1997; MORGAN

167   and TROMBORG 2007). Such a conflict situation evokes a coping strategy by which the

168   animal seeks alternative possibilities to cope with a frustrating situation that it can neither

169   avoid nor change. The associated action often begins with aggressive behavior, which is

170   expressed strongly or weakly, depending on the animal species. If this behavior does not

171   change the situation, deprivation develops. If the circumstances continue to remain

172   unchanged, certain stimuli will lead to behavior patterns that have no function or goal. In

173   invariant environmental conditions, these behavior patterns are shown increasingly often and

174   manifest as a stereotypy (WECHSLER 1992). Stereotypies can be divided into two

175   categories. One is referred to as redirected action, whereby a behavior is directed at an

176   inadequate object (e.g., a male tortoise may try to copulate with a shoe). The other category

177   is the so-called vacuum activity, whereby no object is used (e.g., walk stereotypies or, as in

178   the present study, crawl stereotypies). A walk or crawl stereotypy can be based on one of

179   two functional areas of behavior. The behavior may represent an escape attempt or a search

180   behavior (food, mate, other resources). An escape attempt always indicates a state of

181   arousal along with discomfort and thus a reduced wellbeing (WARWICK et al. 1995).

182   Therefore, the housing environment should be designed in a way that always allows the

183   animals to express their natural behavior repertoire and to cope with all arising challenges

184   (WECHSLER 1995, MASON et al. 2007). Moreover, enriched housing conditions can evoke

185   positive emotions, which cause improved wellbeing and contribute to solving behavioral

186   problems (MASON et al. 2007). The aim of the present study is a scientific, comparative

187   evaluation of ball python husbandry by considering animal welfare aspects when housing

188   these animals in a rack system or a terrarium.

189 # Animals, Materials, and Methods

190 ## Ball python (*Python regius*)

191   Thirty-five ball pythons (*Python regius*) were used for this study (see Table 1). Twenty-five of

192   them were male, nine were female, and one was juvenile of undetermined sex. Three of the

193   pythons had been handed in by private persons, whereas the others had been confiscated

194   from five snake keepers by authorized agencies. Thirteen of the pythons were between 3

195   and 18 years old. The age of the other pythons (n = 22) was unknown.

196   <u>Body weight, length, and color</u>

197   At the beginning of this study, the pythons had a body length ranging from 53 to 148 cm and

198   a body weight ranging from 0.11 to 2.50 kg. We did not find a sex-specific length or weight

199   distribution. Approximately half (n = 18) of the snakes had a color or a pattern (or both)

200   divergent from the wild type (see Table 1).

201

202   **Table 1:** Characteristics of the studied ball pythons (n = 35)

Animal number	Sex	Age (years)	Length (cm)	Weight (g)	Color/pattern	Origin
1	male	unknown	125	1,570	WT	CA
2	male	unknown	128	1,470	WT	CA
3	male	unknown	100	890	M, Albino	CA
4	female	unknown	104	1,400	WT	CA
5	male	unknown	95	420	M, Albino	CA
6	male	15	115	1,300	WT	PP
7	male	15	110	1,305	WT	PP
8	male	3	100	1,100	M, Albino	CA
9	male	unknown	98	1,000	M, Banana Spider	CA
10	male	unknown	100	1,190	WT	CA
11	male	unknown	110	970	M, Spider	CA
12	female	unknown	85	630	WT	CA
13	female	3	110	1,400	M, Cinnamon	CA
14	male	unknown	100	1,000	WT	CA
15	female	4	110	1,210	M, Butter Spider	CA
16	male	5	120	1,580	M, Enchi	CA
17	female	unknown	120	1,330	M, Desert Pin	CA
18	male	4	119	1,830	M, Pewter Blast	CA
19	female	4	120	1,580	M, Pastel	CA
20	female	7	115	1,530	WT	CA
21	male	unknown	120	1,440	WT	CA
22	male	4	125	1,590	M, Phantom	CA

9

Animal number	Sex	Age (years)	Length (cm)	Weight (g)	Color/pattern	Origin
					Bumble Bee	
23	male	4	100	1,200	M, Pewter	CA
24	male	unknown	105	1,100	M, Spider	CA
25	male	6	130	1,690	M, Yellow Belly	CA
26	male	unknown	115	1,300	M, Caramel	CA
27	male	unknown	120	1,090	M, Desert Ghost	CA
28	male	unknown	148	2,530	WT	CA
29	female	unknown	135	2,200	WT	CA
30	male	unknown	110	1,300	WT	CA
31	undetermined	unknown	53	118	WT	PP
32	male	unknown	135	1,654	WT	CA
33	male	18	112	755	WT	CA
34	male	unknown	98	731	M, Pastel	CA
35	female	unknown	110	758	WT	CA
Mean ± SD		7 ± 5	111.4 ± 16.6	1,233.5 ± 505.4		

203   WT = wild type; M = morph; CA = confiscating agency; PP = private person

204

205   <u>Feeding</u>

206   In feeding intervals of 2 weeks, the snakes were offered defrosted mice (*Mus musculus*)

207   warmed up to body temperature. The juvenile snake (No. 31) received "hoppers" (subadult

208   mice), the adult snakes received adult mice, and the largest snakes received subadult rats

209   (*Rattus rattus*). The numbers and sizes of the feeder animals were tailored to each snake

210 based on personal experience. Seventeen pythons ate dead mice from the first feeding

211 onward, whereas eighteen pythons refused to eat dead feeder animals despite multiple

212 offerings during various daytimes and with simulation of prey movement. Therefore, these

213 pythons were offered living mice from the third feeding onward, and five of them began

214 eating. From the sixth feeding onward, living multimammate mice (*Mastomys coucha*) and

215 living rats were offered. Seven snakes that had not accepted feed until then ate these feeder

216 animals, but another six feed-refusing pythons did not. Because young, small guinea pigs

217 (*Cavia porcellus*) were not available, defrosted mice were covered with pieces of guinea pig

218 fur. With this method, all feed-refusing snakes finally ate. This specialization on only one

219 species of feeder animal was due to the previous husbandry conditions in which the snakes

220 were mostly fed newborn guinea pigs (source: confiscating agency).

Housing systems
221

222 For the present study, the pythons were kept in two types of housing systems. First, they

223 were housed in a rack system. Afterwards, they were housed in terrariums.

224 <u>Housing in the rack system</u>

225 The rack system consisted of clear acrylic polypropylene bins (70 × 40 x 16 cm LWH) with

226 ventilation holes in the front and back sides (see Figures 1 and 2). The bins were placed

227 precisely fitted as drawers in a shelving system consisting of a non-transparent plastic frame

228 and boards made of oriented strand board. The back half of the bin was heated with a

229 heating cable and pad, controlled via a thermostat (Thermo Control Pro II, Lucky Reptile).

230 The daytime temperature from 8:00 a.m. to 8:00 p.m. was on average 28 °C (26–32 °C) at

231 the back end measured above the heater element and on average 26 °C (27–30 °C) at the

232 front end of the bin. In the time from 8:01 p.m. to 7:59 a.m., the temperature at each end was

233 3 °C less. The bottom was covered with newspaper. An upside-down plastic plant pot of

234 27 cm diameter with an entrance hole of 8 cm diameter served as hiding place. During the

235 molting period, moist towels were put inside the hiding place. Fresh water was provided ad

236 libitum in a bowl that was fixed to the bottom and one side of the bin with a hook-and-loop

237   fastening strap. For the nighttime observation, one side of each drawer had a hole of 0.5 cm

238   diameter, which allowed illuminating the drawer with red light (LED 650 nm). This wavelength

239   lies outside the visible spectrum of the ball python (SILLMAN 1999).

240

241   **Figure 1:** Schematic view of a rack drawer

242   **Figure 2:** Photo of a rack drawer

243

244   <u>Housing in the terrarium</u>

245   For housing the pythons in a terrarium (see Figures 3 and 4), three sizes of terrariums were

246   used. They met the minimum requirements for housing reptiles (BMEL 1997). The smallest

247   terrariums measured 100 × 50 × 50 cm (LWH, Size 1), the medium-sized 120 × 60 × 60 cm

248   (Size 2), and the largest 150 × 80 × 80 cm (Size 3). Basic illumination in all terrariums was

249   provided via a fluorescent tube (Osram 865, 6500 Kelvin; Size 1: 18 W, Size 2: 30 W, Size 3:

250   36 W). For protection, the tube was installed in a moisture-proof bracket. As spotlight, we

251   used a UV lamp (Size 1: Lucky Reptile Bright Sun UV Jungle 35 W, 34 cm above the basking

252   platform; Sizes 2 and 3: Lucky Reptile Bright Sun UV Jungle 50 W, 39 cm above the basking

253   platform) in a protective wire case (Lucky Reptile Thermo Socket plus Reflector). The

254   temperatures during daytime (8:00 a.m. to 8:00 p.m.) were 38 °C underneath the spotlight

255   and 25 °C in the coolest area. During nighttime, the measured temperature was on average

256   24 °C (22–26 °C). The substrate was a mixture of soil (60%), sand (20%), bark mulch (15%),

257   and loam powder (5%). In the back half, the substrate was raised to a height of 35 cm to

258   enable the snakes to burrow. The average substrate thickness in the front half was 10 cm.

259   Each terrarium had a hiding place like the one used in the rack system and an elevated

260   basking platform underneath the UV lamp. Furthermore, each terrarium contained a water

261   basin and a living plant, which was held in place by a layer of gravel. The remaining

262   furnishings included trunks, branches, twigs, clumps of grass, roots, moss, rocks, and bark

263   and had been collected outdoors. The arrangement of the furnishings was identical, but the

264   use of natural materials did not allow a 100% match. For video recordings, each terrarium

265   was illuminated with a single red LED bulb (650 nm) that was controlled with a timer.

266

267   **Figure 3:** Schematic view of a terrarium

268

269   **Figure 4:** Photo of a terrarium (Size 1)

270

Behavior observation

272   All pythons were observed in the rack system and the terrarium. In the rack system, a

273   camera (Qumox SJ 4000) was installed at the front end of the drawer and turned on for five

274   consecutive days. All lights on the camera were covered with tape so that only the red light

275   from the LED bulb (nighttime) and the ambient lighting in the room served as light sources.

276   To allow an adaptation period, the camera was installed on the rack 5 days before the

277   recording. The behavior observation began at 5:00 p.m. for 24 hours. The nighttime

278   observation in the terrarium was also facilitated by red LED illumination. For practical

279   reasons, the daytime observation was done without camera, although the switched-off

280   camera remained in the terrarium. Because an ethogram for ball pythons did not exist, we

281   created one based on the observations (see Table 2). It does not include interactions with

282   other individuals because all pythons were single housed during the whole study. Feeding

283   behavior is also excluded because feeding was a planned event that the individual could not

284   control.

285

286   **Table 2:** Ethogram for the ball python

Behavior	Abbreviation
Locomotion	L
1. Crawling forward	L1
2. Moving backward	L2

13

3. Lifting the front body up	L3
4. Climbing	L4
5. Burrowing	L5
6. Moving the head	L6
Exploration behavior directed at the camera	E
Comfort behavior	C
1. Basking	C1
2. Bathing	C2
3. Resting in the hiding place with side wall contact	C3
4. Resting outside of the hiding place, not under the basking spot, coiled	C4
5. Resting outside of the hiding place, not under the basking spot, stretched out	C5
Defensive behavior, aggressive behavior	A
Feeding behavior: drinking	F
Other behaviors	O
1. Yawning	O1
2. Pushing the mouth against a barrier (side walls, top)	O2
3. Pathological behaviors (wobbling, stargazing)	O3

287

Locomotion

289   Behaviors were classified as locomotion when none of the other behaviors listed in Table 2

290   additionally occurred. "Crawling forward" includes lateral undulation, retilinear locomotion,

291   and a combination of both. "Moving backward" refers to movements of the whole body or of

292   body parts. True backward crawling is not possible due to the scales, so the movement is a

293   pushing motion facilitated by partial or complete lifting of the body. "Climbing" includes all

294   movements during which at least half of the body does not touch the ground. "Burrowing" is

295   an activity during which at least the head up to the eyes is burrowed in the substrate.

296   Movements that include only the head were assessed separately.

297   Exploration behavior directed at the camera

298   This behavior means that the snake approaches the camera, touches it with its mouth, and

299   probes it with its tongue.

300   Comfort behavior

301   Comfort behavior includes behaviors that often accompany resting behavior. "Basking" is the

302   active visiting and staying at the basking spot, without differentiation of body positions.

303   "Bathing" describes an active visiting of the water basin and lying in the water. Crawling

304   through the water basin is not counted as bathing. "Resting in the hiding place with side wall

305   contact" can be viewed as resting behavior. Lying outside of the hiding place, either coiled or

306   stretched out, is a resting behavior and furthermore indicates a level of comfort in the snake

307   because this behavior does not offer protection, in contrast to lying inside the hiding pace.

308   Defensive behavior

309   Defensive behavior in most cases is a sequence of behaviors. The python moves its front

310   body into S-shaped loops and afterwards may vocalize by making a loud hissing sound. A

311   defensive bite can occur with the mouth closed or open. All these behaviors were also

312   recorded when they occurred individually.

313   Feeding behavior

314   The ethogram lists only "drinking" because the snakes could not control the timing of feeding.

315   During drinking, the mouth (and sometimes the head up to the eyes) is submerged under the

316   water surface in the water bowl, and water is sucked in through chewing movements.

317   Other behaviors

318   "Other behaviors," in contrast to the above-described ones, are not interconnected.

319   "Yawning" is often seen after feeding but can also occur spontaneously. Another typical

320   behavior is the crawling alongside the barriers of the enclosure whilst "pushing the mouth

321   against side walls or the top." The pushing could be a soft touching, but it could also be

322   strong enough to lead to temporary deformation of the mouth. "Wobbling" and "stargazing"

323   are abnormal behaviors that mostly occur in certain color morphs (e.g., Spider) or with the

324   onset of disease (e.g., arenavirus infection). They describe a disoriented, vibrating

325   movement with spiraling turns or crawling on the back. These movements are often

326   associated with a stimulus, such as the offering of feed.

327   ## Ethics statement

328   Before the beginning of this study, the study design was submitted to the ethics committee of

329   the Center for Clinical Veterinary Medicine, Faculty of Veterinary Medicine, LMU Munich,

330   Germany. The study was approved under protocol number 99-20-10-2017.

331   ## Behavior assessments

332   The behaviors were documented in 10-min intervals, resulting in a dataset of 144 behavior

333   units per day. This assessment was done on 5 days for each housing system. For

334   comparative data analysis, the area under the curve (AUC) was calculated. For a more

335   precise comparison of behavior rhythms in the two housing systems, we divided the day in

336   three periods. The presumed main activity phase (Period 1; P1) from late afternoon to early

337   night was between 4:00 p.m. and 11:00 p.m.; it was followed by the nighttime phase

338   (Period 2; P2) until 7:00 a.m. the next day and then the daytime phase (Period 3; P3) until

339   dusk (3:59 p.m.).

340

341   ## Statistical analysis

342   The collected data were first transcribed in Microsoft Excel 2007 (Microsoft Corporation,

343   Redmond, CA, USA). For statistical analysis, we used IBM SPPS Statistics (IBM

344   Deutschland GmbH, Ehningen, Germany) and MedCalc (MedCalc Software Ltd, Ostend,

345   Belgium). Differences between the housing systems in the frequency of shown behaviors

346   were determined with the t-test. Differences between the daytime periods within and between

347   the housing systems were analyzed with the t-test and the Wilcoxon test. The level of

348   significance was set at $p < 0.05$.

Results

350   In this study, we differentiated 17 behaviors (see Table 2). Defensive or aggressive behavior

351   (A) was never shown, nor was "moving backward" (L2). "Moving the head" (L6) was never

352   shown as a separate movement but could be observed associated with other behavior

353   components. Table 3 lists the relative frequency of all behaviors displayed in a 24-hour

354   period in the rack system and the terrarium.

355 **Table 3:** Comparison of the relative frequency of all behaviors displayed in 24 hours in the
356 two housing systems (rack system and terrarium)

Behavior	Rack system (%)	Terrarium (%)
Crawling forward (L1)	7.11 ± 0.25	15.90 ± 0.02
Lifting the front body up (L3)	0.78 ± 0.006	1.15 ± 0.005
Climbing (L4)	0	7.00 ± 0.02
Burrowing (L5)	0	1.17 ± 0.01
Exploration behavior directed at the camera (E)	0.55 ± 0.005	0
Basking (C1)	0	9.90 ± 0.05
Bathing (C2)	0	0.90 ± 0.01
Resting inside the hiding place (C3)	53.90 ± 0.15	33.33 ± 0.13
Resting outside of the hiding place, coiled (C4)	11.24 ± 0.08	11.85 ± 0.07
Resting outside of the hiding place, stretched out (C5)	14.64 ± 0.09	18.64 ± 0.10
Drinking (F)	0.03 ± 0.0006	0.07 ± 0.0009
Yawning (O1)	0.02 ± 0.0004	0.02 ± 0.0004
Pushing the mouth against a barrier (O2)	11.59 ± 0.02	0.04 ± 0.001
Pathological behaviors (O3)	0.12 ± 0.004	0.03 ± 0.001

357

358 For eight behaviors, we found a statistically significant ($p < 0.05$) difference between the

359 housing systems. The behavior "crawling forward" (L1) was the most frequent locomotion

360 behavior in both housing systems. It occurred significantly ($p < 0.05$) more often in the

361 terrarium (AUC = 21.6) than in the rack system (AUC = 9.7). "Pushing the mouth against a

362 barrier" (O2) occurred significantly ($p < 0.05$) more often in the rack system (AUC = 15.9)

363 than in the terrarium (AUC = 0.1). The pythons spent a large part of the day resting (C3–C5).

364 "Resting in the hiding place" (C3) was the most frequent variant and occurred significantly

365   ($p < 0.05$) more often in the rack system (AUC = 79.6) than in the terrarium (AUC = 50.9).

366   "Basking" under the UV lamp (C1), "climbing" (L4), and "bathing" (C2) occurred only in the

367   terrarium. These behaviors could not occur in the rack system because of its structural

368   design. "Exploration behavior directed at the camera" (E), although possible in the terrarium,

369   was shown only in the rack system (AUC = 0.9).

370   We also found daytime-specific differences within and between the housing systems. In the

371   following, P1 refers to the main activity phase from 4:00 p.m. to 11:00 p.m., P2 to the

372   nighttime phase from 11:01 p.m. to 7:00 a.m., and P3 to the early daytime phase from

373   7:01 a.m. to 3:59 p.m

374   In the terrarium, the behavior "crawling forward" (L1; see Figure 5) was shown most

375   frequently during P1 (AUC = 38.0) and considerably less during P2 (AUC = 5.8) and P3

376   (AUC = 6.9). During all periods, the values differed significantly ($p < 0.0035$) from those in

377   the rack system (P1: AUC = 16.0; P2: AUC = 3.1; P3: AUC = 2.3). In addition, the differences

378   between the periods were considerably smaller in the rack system than in the terrarium.

379

380   **Figure 5:** Boxplot with extreme outliers (*).Frequency of the locomotion behavior "crawling
381   forward" (L1) during the three daytime periods (P) depending on the two housing systems
382   ($p < 0.05$).

383

384   During all periods, "lifting the front body up" (L3) was observed similarly often in both housing

385   systems. This behavior occurred most frequently during P1, both in the rack system

386   (AUC = 0.5) and in the terrarium (AUC = 5.8). During the other two periods, it occurred less

387   often in both housing systems (AUC = 0.4 ± 0.1).

388   "Climbing" (L4) behavior in the terrarium also had its activity peak during P1 (AUC = 14.5)

389   and occurred considerably less often during the other two periods (P2: AUC = 2.6; P3:

390   AUC = 3.4). We made similar observations (see Figure 6) for the other three behaviors that

391   could only be shown in the terrarium. "Burrowing" (L5) occurred most frequently during P1

392 (AUC = 3.9), followed by P2 (AUC = 0.7) and P3 (AUC = 0.2). "Bathing" (C2) was observed

393 most frequently during P1 (AUC = 2.1), much less during P3 (AUC = 1.0), and not at all

394 during the nighttime period (P2). Because of the set lighting intervals, "basking" (C1) could

395 occur only during P1 (AUC = 14.7) and P3 (AUC = 10.8). The three albinotic ball pythons

396 were basking for on average 10 ± 2 min/day, much less than the other ball pythons, which

397 were basking for on average 144 ± 13 min/day.

398

399 **Figure 6:** Occurrence of four behaviors in the terrarium during the three daytime periods (P)

400

401 "Exploration behavior directed at the camera" (E) in the rack system occurred most

402 frequently during P1 (AUC = 0.9) and rarely during the other two periods (P2: AUC = 0.2; P3:

403 AUC = 0.1). It did not occur in the terrarium.

404 "Resting in the hiding place" (C3; see Figure 7) was most frequently observed during P1

405 (rack system: AUC = 63.8; terrarium: AUC = 36.4). During the other periods (P2 and P3

406 combined), it occurred at similar frequencies within each housing system (rack system:

407 AUC = 29 ± 7; terrarium: AUC = 18.2 ± 1.3).

408

409 **Figure 7:** Boxplot with outliers (°).Frequency of the comfort behavior "resting in the hiding
410 place" (C3) during the three daytime periods (P) depending on the two housing systems
411 ($p < 0.05$)

412

413 "Coiled resting outside of the hiding place" (C4; see Figure 8) was shown at similar

414 frequencies in both housing systems during all daytime periods. We found a small behavior

415 peak during P1 in both the rack system (AUC = 13.4) and the terrarium (AUC = 9.3). During

416 the other two periods, this comfort behavior occurred at almost identical frequencies within

417 each housing system (rack system: AUC = 6.2 ± 0.1; terrarium: AUC = 5.45 ± 0.45).

418

419 **Figure 8:** Boxplot with outlier (°) and extreme outliers (*).Frequency of the comfort behavior
420 "resting outside of the hiding place, coiled" (C4) during the three daytime periods (P)
421 depending on the two housing systems ($p > 37.92$)

422

423 By contrast, "stretched-out resting outside of the hiding place" (C5; see Figure 9) in the

424 terrarium was observed more frequently during the activity phase (P1: AUC = 18.9) and the

425 nighttime phase (P2: AUC = 14.6) and less frequently during the early day (P3: AUC = 5.6).

426 The frequency of this comfort behavior in the rack system during P1 and P2

427 (AUC = 11.6 ± 2.6) was also higher than during P3 (AUC = 5.6).

428

429 **Figure 9:** Boxplot with outliers (°) and extreme outliers (*).Frequency of the comfort behavior
430 "resting outside of the hiding place, stretched out" (C5) during the three daytime periods (P)
431 depending on the two housing systems ($p > 24.38$)

432

433 We found a considerable difference between the two housing systems for the behavior

434 "pushing the mouth against a barrier" (O2; see Figure 10). The pythons showed this behavior

435 significantly more often ($p < 0.05$) and almost exclusively in the rack system. In the rack

436 system, we furthermore observed a significant difference ($p < 0.05$) in this behavior between

437 P1 (AUC = 33.6) and the other two periods (AUC = 4.0 ± 1.9).

438

439 **Figure 10:** Boxplot with outliers (°).Frequency of the behavior "pushing the mouth against a
440 barrier" (O2) during the three daytime periods (P) depending on the two housing systems
441 ($p < 0.05$)

442

443 A difference in "drinking" (F), "yawning" (O1), or „pathological behaviors" (O3) was not

444 observed. The pythons showed all three behaviors sporadically during all daytime periods

445 and in both housing systems.

Discussion

446

447 This work compared the behavior of ball pythons in two types of housing systems, namely, a

448 rack system and a terrarium. We found significant differences in the assessed behaviors

449 depending on the housing system. The pythons in this study showed several often-

450 underestimated behaviors (basking, climbing, bathing, burrowing), indicating the necessity

451 for a new definition of animal-appropriate husbandry of the ball python. Although the results

452 showed that the pythons spent most of the day resting (in the rack system: 80%, in the

453 terrarium 64% of a 24-hour day), the way in which they rested differed between terrarium and

454 rack system. Especially the stretched-out resting outside of the hiding place tended to occur

455 more frequently in the terrarium. During the remaining time, the snakes also showed different

456 frequencies in the assessed behaviors depending on the housing system.

457 Locomotion behaviors such as climbing and burrowing were exclusively shown in the

458 terrarium; they could not be expressed in the rack system due to spatial and structural

459 conditions. The ball python is considered a ground-dwelling snake (SCHMIDT 1994).

460 However, it may occasionally crawl onto a termite mound or climb within waist-high branch

461 wood. An animal-appropriate accommodation must therefore enable the snake to move in

462 three-dimensional space. Burrowing and bathing were shown less often, but they are

463 important components of the behavioral repertoire and must be facilitated for the ball python.

464 Although bathing, a type of comfort behavior, plays only a minor role in the natural behavior

465 of the ball python, this snake species has access to water in its natural habitat. Therefore, a

466 large enough water basin should be provided in a housing system.

467 Many authors (e.g., McCURLY 2011) believe that snakes do not need UV light to stay

468 healthy. However, the behavior of the herein studied pythons clearly showed that UV light is

469 necessary for an animal-appropriate environment that meets the needs of a ball python. The

470 pythons actively visited the basking spot and used it daily for on average 144 min. In a

471 preliminary study, we had found that basking spots without UV light were used significantly

472 less than basking spots with UV light. Most ball pythons have a daily rhythm, in which they

473   crawl to the basking spot when the light is switched on and stay there to warm up. This

474   phase of warming up is followed by a phase of activity, which is followed by a phase of

475   resting. Before the UV light is switched off, the snakes revisit the basking spot to warm up

476   before dusk, when their phase of main activity begins. This natural rhythm clearly shows how

477   the breeding of color morphs (e.g., Albino) can restrict normal behaviors. Due to their

478   heightened light sensitivity, the albinotic pythons in our study visited the basking spot under

479   UV light less often and for much shorter duration (daily average: 10 min) than the pigmented

480   pythons did. Because basking, with approx. 10% of the 12-hour light period, made up a large

481   share in the behavior repertoire of the ball python, the question arises in how far the selective

482   breeding of albinotic morphs represents cases of so-called torture breeding in terms of the

483   German Animal Welfare Act (§ 11b, German Animal Welfare Act as promulgated on 18 May

484   2006 [BGBl. I S. 1206, 1313], last amended by Article 101 of the act on 20 November 2019

485   [BGBl. I S. 1626]).

486   The pythons showed an excessive interest in the camera only when they were housed in the

487   rack system. This finding indicates that the ball python accepts any stimulus to express

488   exploration behavior. Furthermore, it might explain why ball pythons easily feed and

489   reproduce in a rack system. However, it is no evidence of animal-appropriate housing but

490   simply indicates that the snakes use every opportunity to compensate for the lack of stimuli.

491   In a furnished environment with many stimuli, an individual new stimulus that neither meets a

492   basic need nor poses a clear advantage or disadvantage for the animal does not elicit

493   interest.

494   In the present study, non-species-typical behavior occurred significantly more frequently

495   ($p < 0.05$) in the rack system than in the terrarium. In rack housing, 12% of all shown

496   behaviors were stereotypical movements, in terrarium housing, the respective frequency was

497   less than 0.04%. The snakes crawled alongside the entire rack drawer and pushed their

498   mouth against the sides (mostly the upper edges) and partially against the top. Several of the

499   pythons ($n = 10$) stuck their nose through the ventilation holes and tried to widen them

500   through burrowing movements. Because all pythons stopped showing this "mouth pushing"

501   behavior as soon as they were transferred to a terrarium, this behavior cannot be considered

502   a classical stereotypy, in which the behavior would be continued despite the change in

503   circumstances (MASON and LATHAM 2004). However, during the rack housing period, we

504   observed individual differences. Several pythons ($n = 9$) showed the above-described "mouth

505   pushing" behavior on the first day of rack housing but then entered a resting state. Others

506   ($n = 16$) initially showed a resting phase of several days, but once they started showing the

507   "mouth pushing" behavior, they did not stop showing it for the remaining rack housing period.

508   The remaining pythons ($n = 10$) did not show a specific pattern in the "mouth pushing"

509   behavior. We could not find a link to any other assessed parameter. By contrast, the

510   pathological behavior "wobbling" was not shown depending on the housing type but was

511   exclusively shown by the color morph Spider and those resembling it ($n = 5$). Presumably,

512   due to a deformation of the inner ear, these morphs have difficulties keeping their balance,

513   especially in states of arousal (SCHRENK et al. 2019).

514   The non-occurrence of defensive behavior in our study may be explained by the lack of a

515   stimulus (predator, disturbance). The same applies to backward movement, which usually is

516   observed when snakes are threatened and keep their gaze on the source of the threat while

517   they retreat. In the present study, a threat stimulus was not given.

518   In summary, our study results show that based on the assessed aspects, the housing in a

519   rack system cannot be considered an animal-appropriate accommodation for the ball python.

520   The only animal-based advantage of rack housing is the possibility for complete and fast

521   cleaning. This aspect can be useful for keeping sick animals or facilitating quarantine

522   conditions. Further aspects such as the keeping of many animals in small spaces or the time-

523   saving maintenance of these animals are in no case in the interest of the snakes. These

524   conditions are rather reminiscent of intensive mass husbandry, in which economic aspects

525   are considered to be of higher priority than animal welfare.

526   Our results do not support the argument that the ball python accepts feed more readily in a

527   rack system than in a terrarium. With the rack system, we initially encountered difficulties in

528   feed acceptance, but these were most likely due to the kind of offered feed. Because the

529   snakes in both housing systems did not differ in their readiness to eat, the reason for

530   previously reported higher growth rate in the rack system (McCURLY 2011) is most likely a

531   lower calory use due to reduced locomotion. Crawling forward alone made up 15% (on

532   average) of all shown behaviors in the terrarium. In the rack system, the share of this

533   locomotion behavior was only 7%. Moreover, other calory-burning activities such as

534   burrowing and climbing occurred only in the terrarium. These results suggest that the ball

535   pythons used less energy for locomotion in the rack system and thus could invest excess

536   calories in growth. Snakes that move little have a reduced muscle mass and tonus, as

537   compared with snakes that can express their full behavior repertoire. Due to the reduced

538   muscle tonus, the snakes are less able to keep their body in certain positions. A ball python

539   that has the possibility to express all physiological movements because it lives in a furnished

540   environment can be assumed to have stronger muscles than a ball python that lives in an

541   unstructured and spatially restricted environment.

542   The statement of McCURLEY (2011) that illumination is a stressor for ball pythons could be

543   disproved in our study. If light had caused stress in the snakes, they would not have exposed

544   themselves to it because they always had the possibility to seek shelter in a hiding place.

545   Even the albinotic pythons, for which the duration (on average 10 min/day) of basking

546   differed considerably from that of the pigmented pythons (on average 144 min/day), used the

547   offered light source. For albinotic pythons, a UV lamp of low intensity should be installed.

548   Housing with indirect illumination or in complete darkness is animal-welfare-adverse and thus

549   not acceptable. Darkness would amplify the scarcity of stimuli in the rack system.

550   A terrarium must be adapted to the needs of the housed individual. For instance, the need for

551   protection in juvenile snakes should be met with multiple hiding places and many structural

552   elements, such as dense vegetation. The terrarium dimensions alone cannot be used to

553   determine if a terrarium is appropriate for housing a ball python. An unstructured, large

554   terrarium in which the animal-appropriate needs are not met is not acceptable. The terrarium

555   should contain several hiding places, possibilities for climbing, substrate for burrowing, a

556   large enough water basin that the snake can use for bathing, and a basking spot with UV

557   light. The natural needs of the ball python are known and thus must be met.

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666

cave

water dish
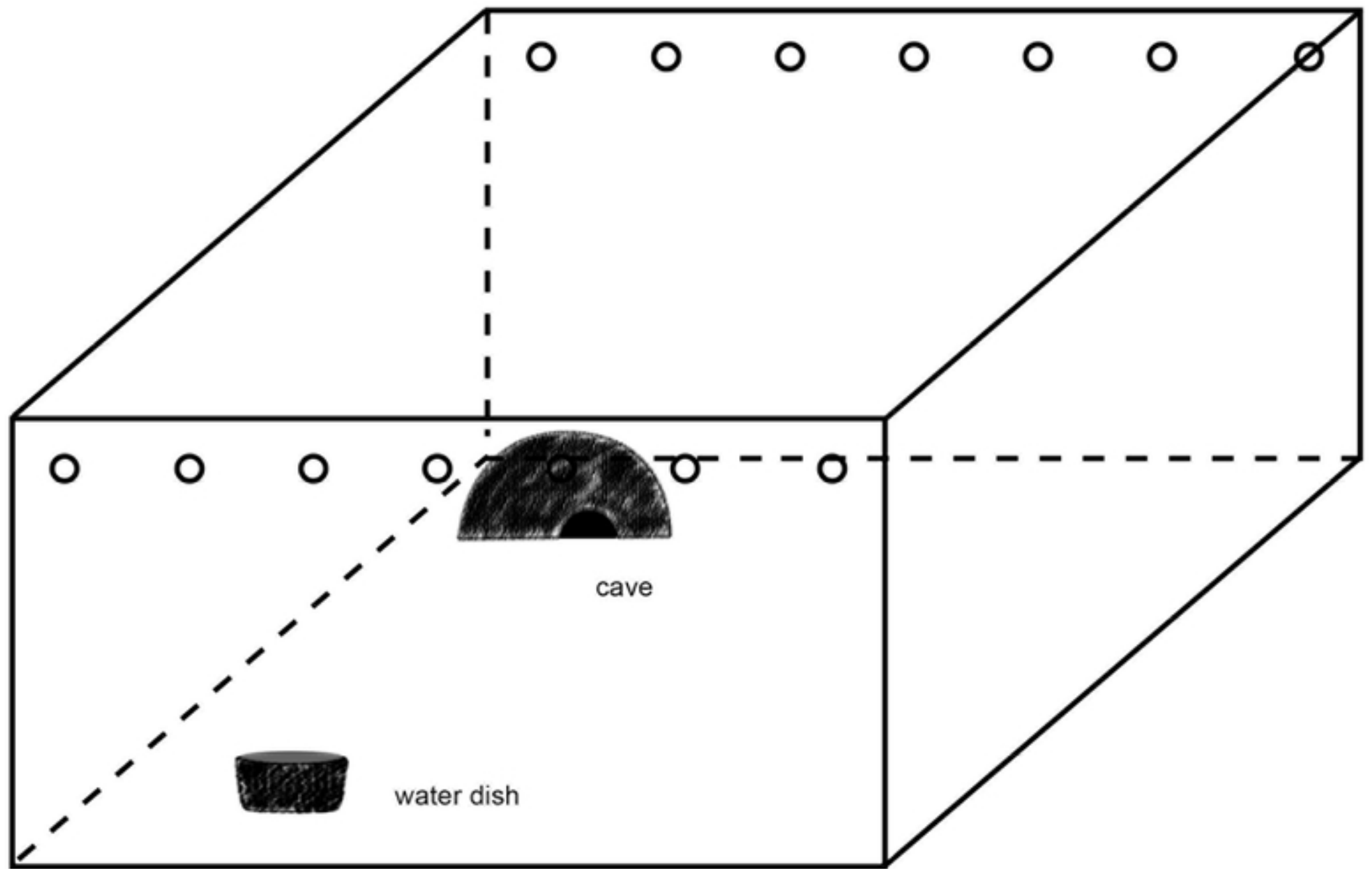
Figur 1:Schematic view of a rack drawer

Figur 2:Photo of a rack drawer

neon tube

branch

UV light

cave

basking platform

water dish

plant
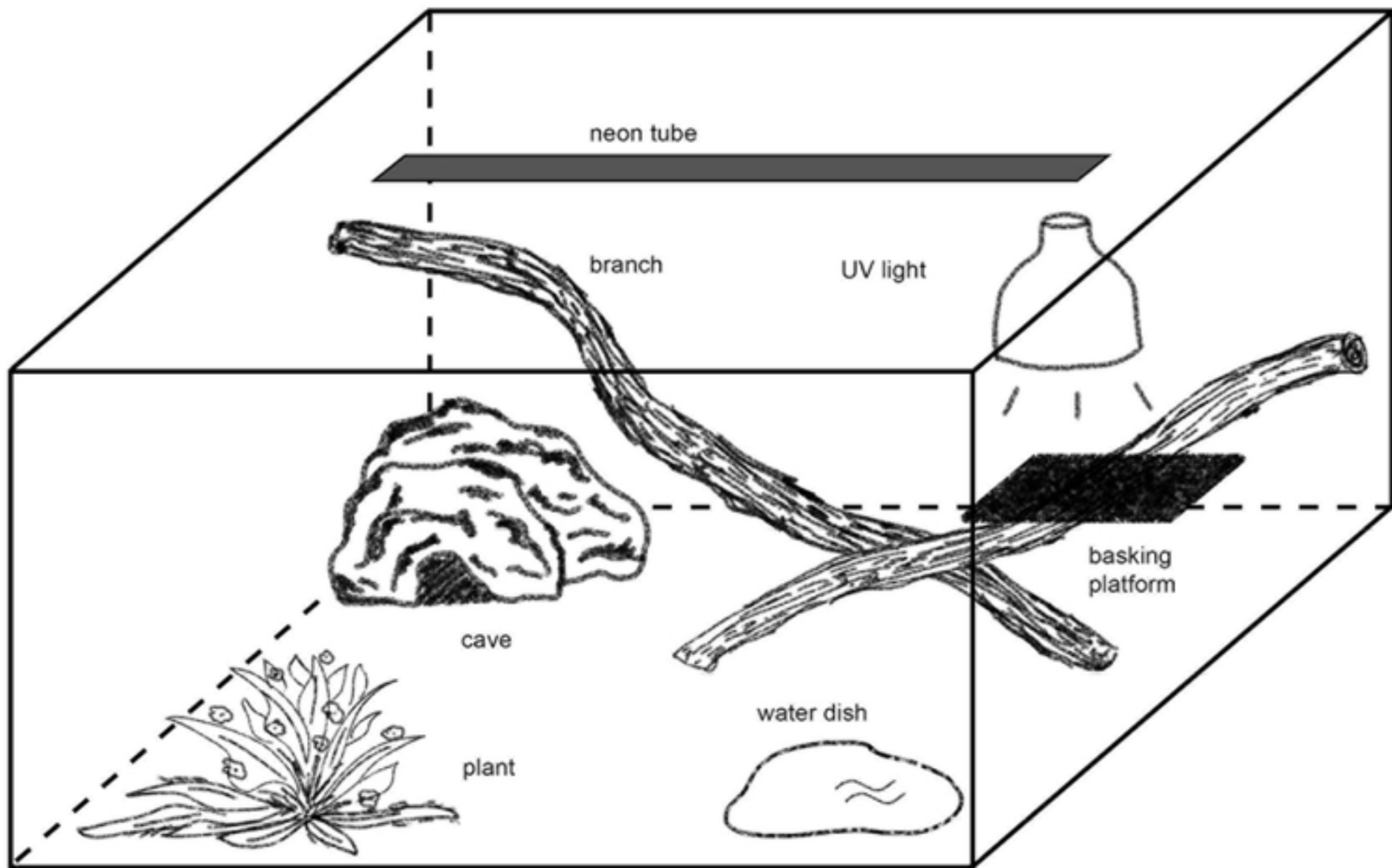
Figure 3:Schematic view of a terrarium

Figure 4:Photo of a terrarium (Size 1)
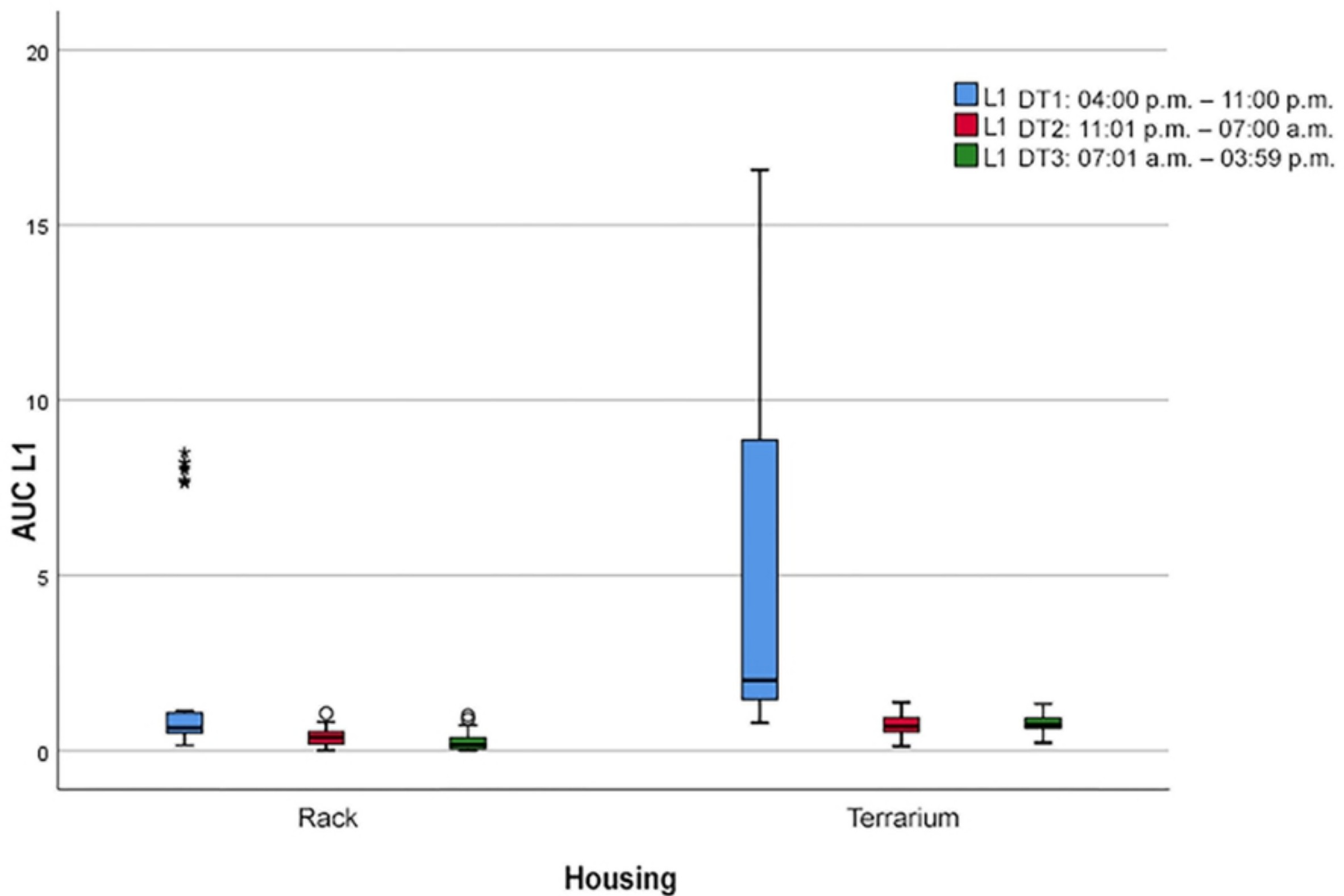
Figure 5:Boxplot with extreme outliers (*).Frequency of the locor
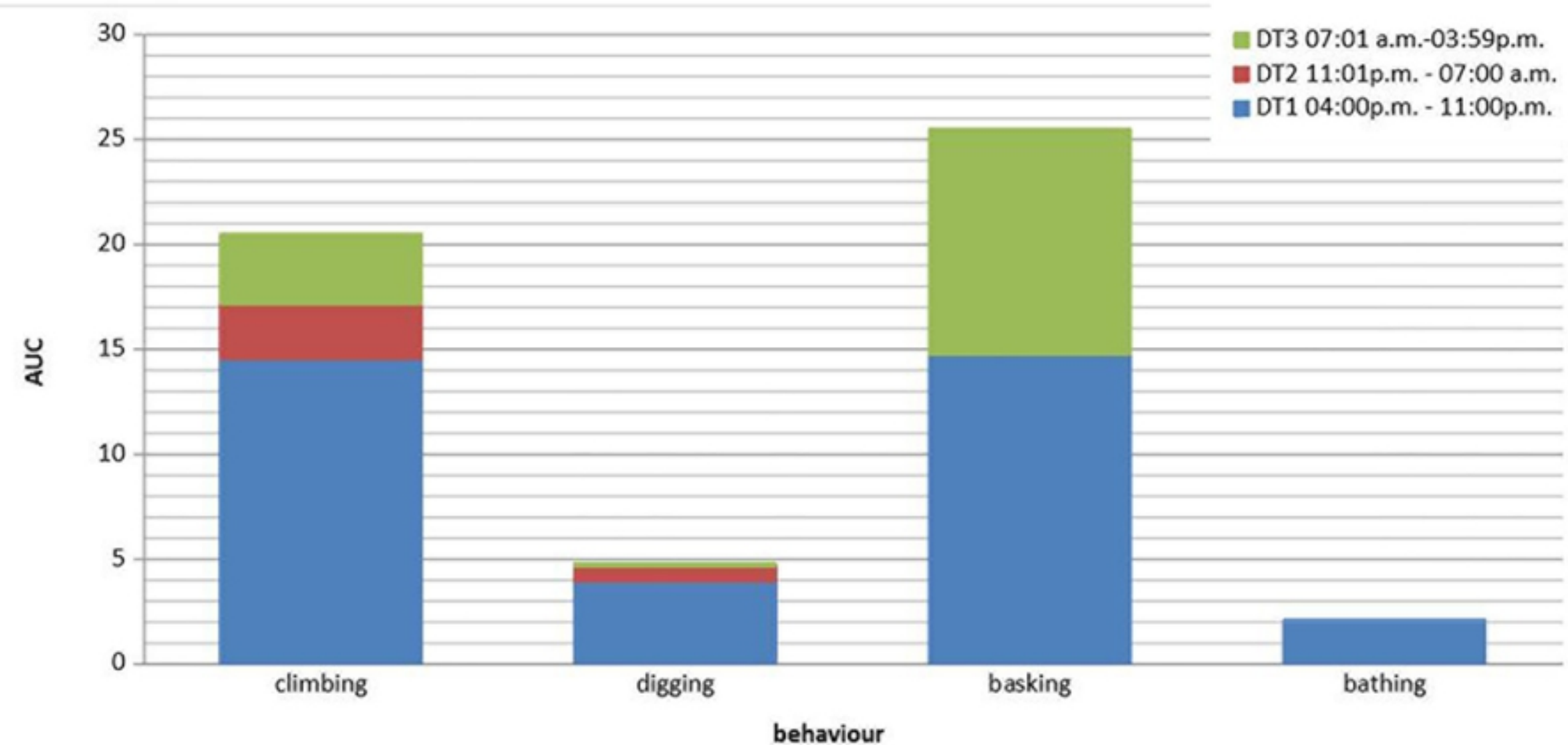
Figure 6:Occurrence of four behaviors in the terrarium during th

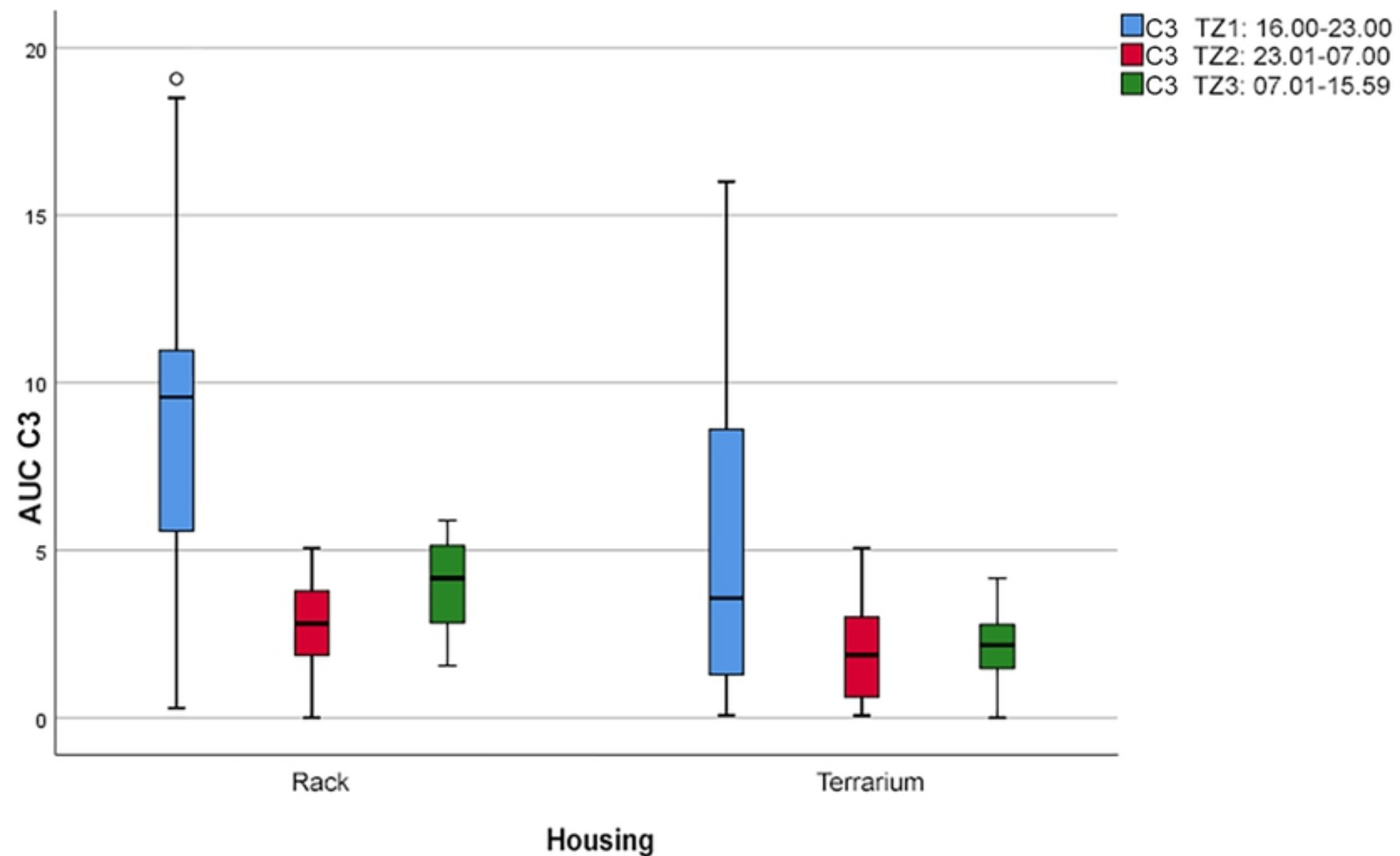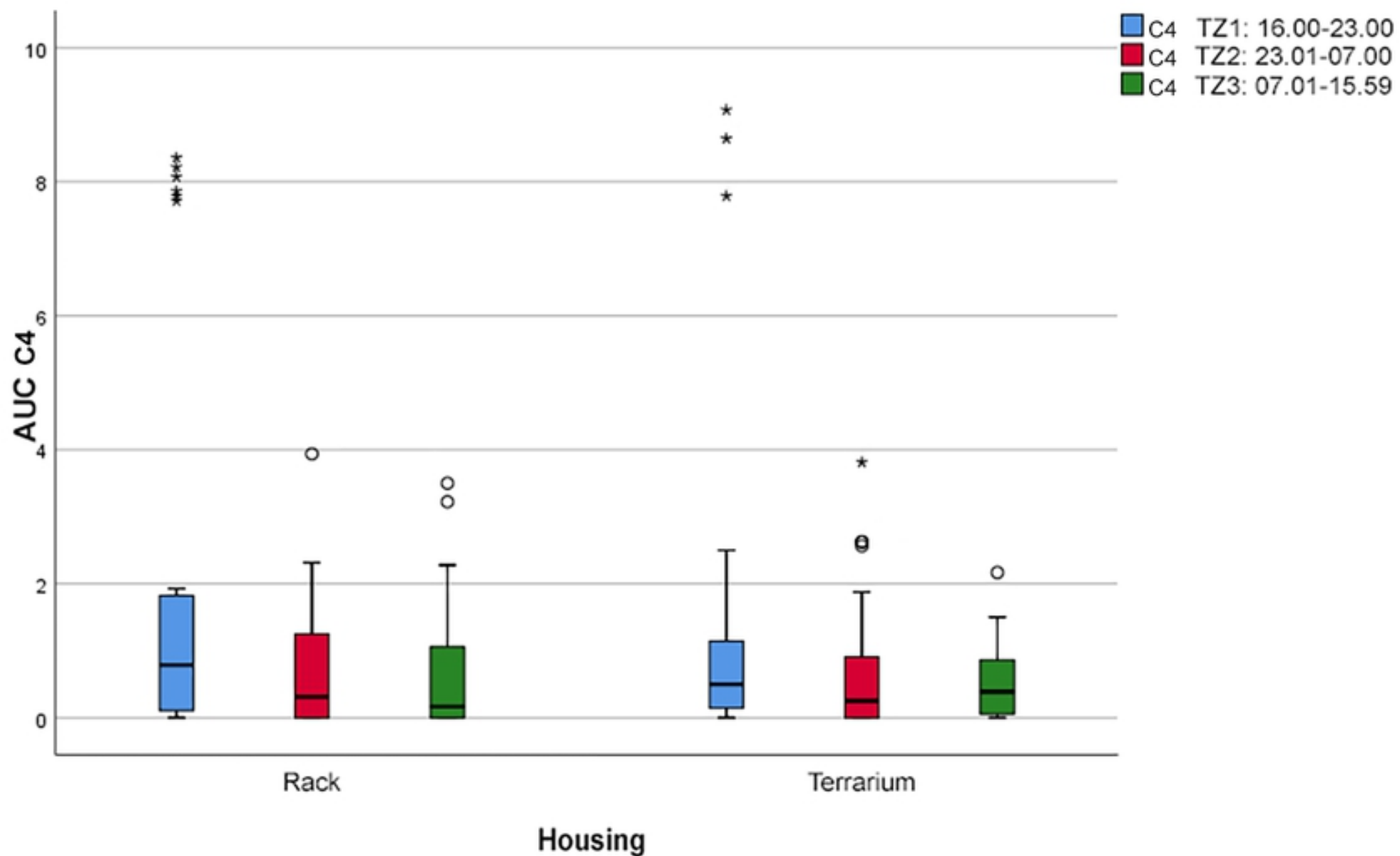Figure 7: Boxplot with outliers (°).Frequency of the comfort beha

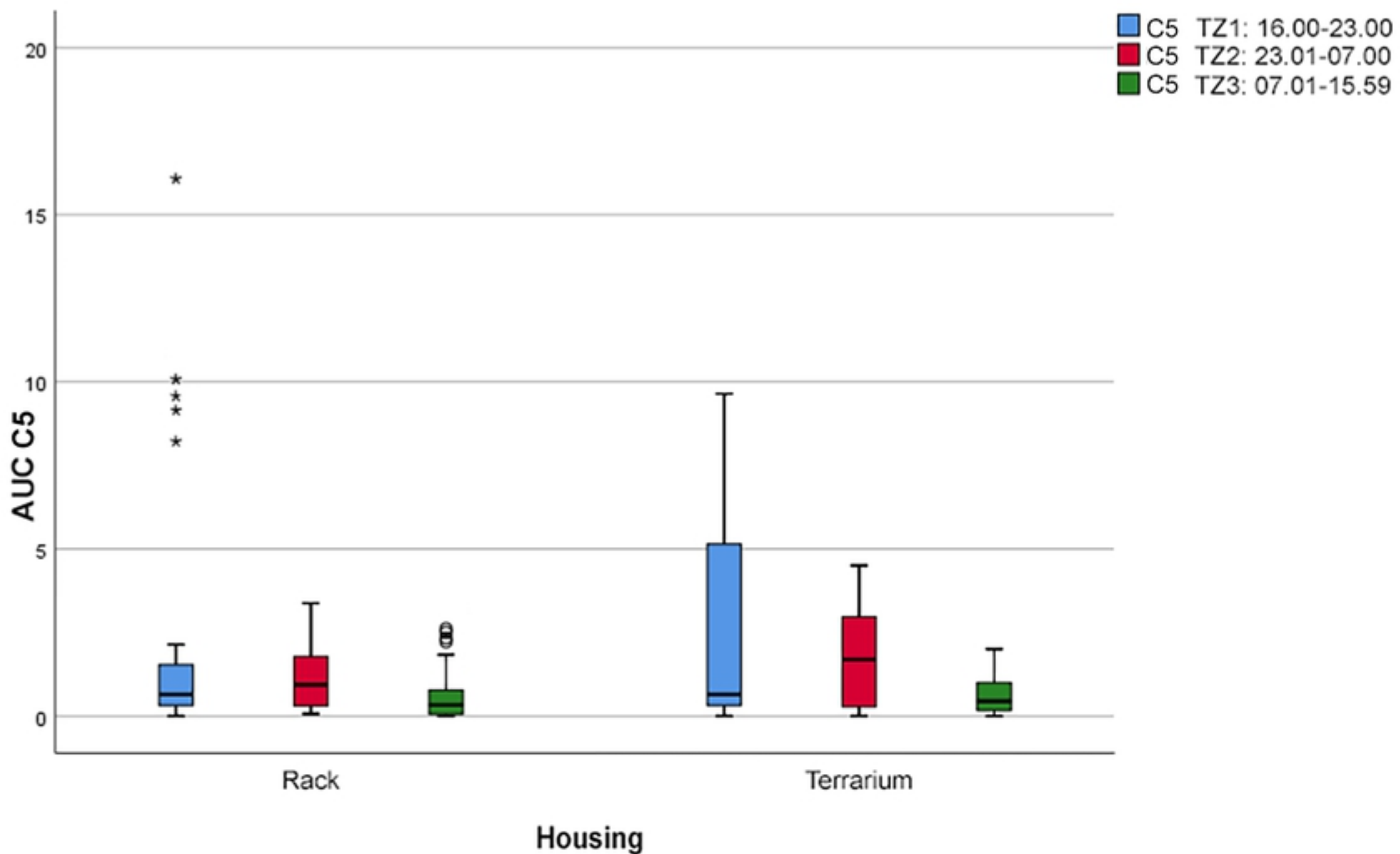Figure 8: Boxplot with outlier (°) and extreme outliers (*).Freque

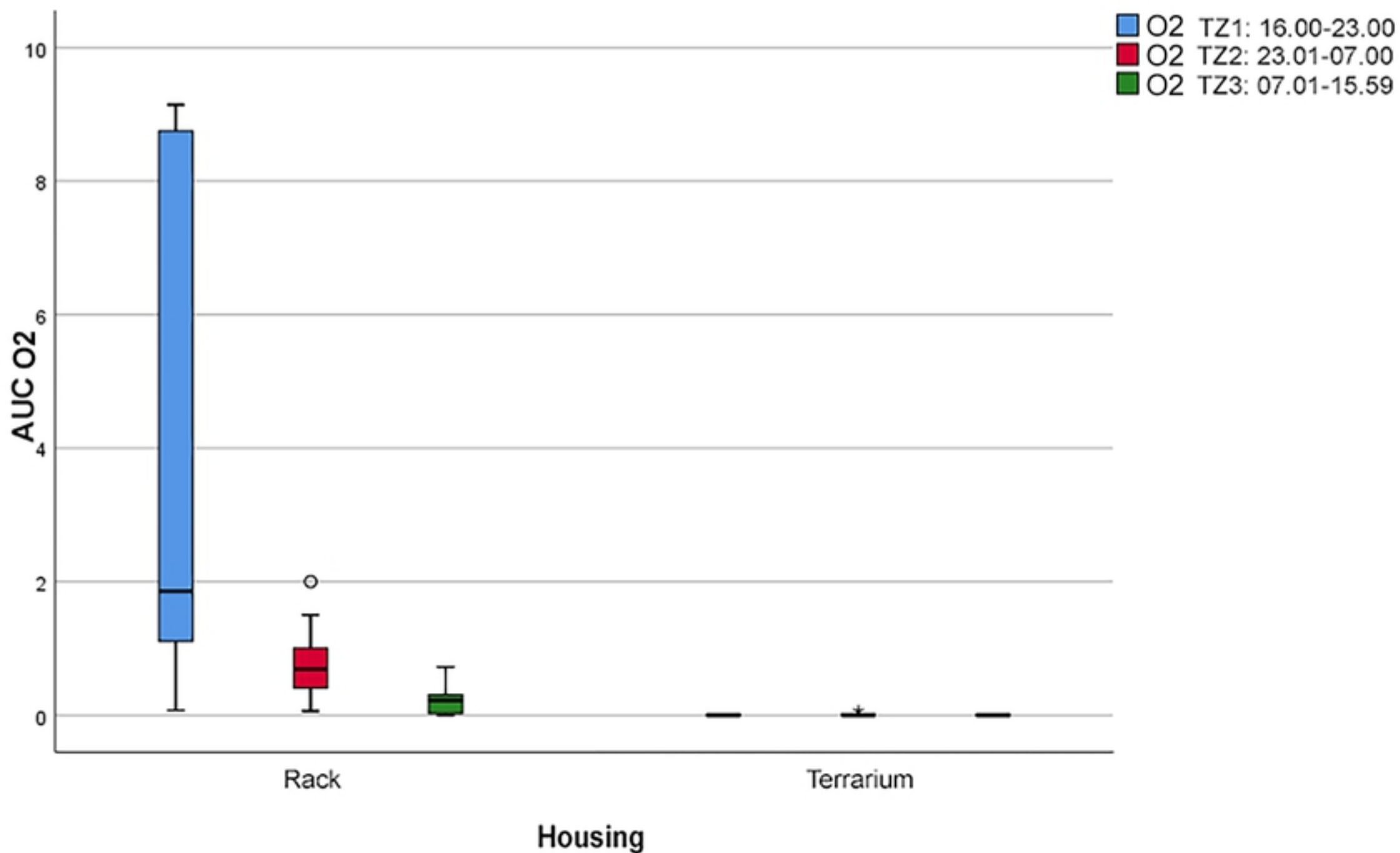Figure 9: Boxplot with outliers (°) and extreme outliers (*).Freque

Figure 10: Boxplot with outliers (°).Frequency of the behavior "pu