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Research article

The effect of basking light provision on sun beetle enclosure use

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Abstract

Widely kept in zoological collections, the sun beetle *Pachnoda marginata peregrina* is an African frugivorous scarabid. Despite its availability in captivity, few studies have researched the behaviour and husbandry of this beetle. A novel study was initiated to identify zone preference in sun beetles, using observations over an eight-month study period at Beale Wildlife Park in England. A low-heat basking light was provided within the enclosure, and the Electivity Index was used to assess zone use. General linear models were run to determine whether the basking light or environmental variables were significant predictors of sun beetle zone use. The study revealed that overall, sun beetles under-utilised much of their exhibit. The sun beetles tended to over-utilise elevated branches, irrespective of basking light availability. Zones such as the substrate and plants tended to be under-utilised during all times. The general linear models were all significant and for three of five zones, the basking light was a significant predictor of zone use. Under the conditions of this study, it appears that the provision of basking lights does influence zone use. However, the areas closest to the light, the elevated branches, were used well during all times and conditions. Future husbandry and enclosure designs for sun beetles should therefore consider including elevated climbing areas, ideally with access to basking lights, to best accommodate adult beetles.

Introduction

The frugivorous sun beetle *Pachnoda marginata peregrina* is commonly kept in both private and public zoological collections (BugzUK 2016). *P. m. peregrina* originates from savannah and rainforest habitats and has a wide distribution across Africa (Heinrich and McClain 1986). Belonging to the family Scarabaeidae, the sun beetle undergoes complete metamorphosis and has a three-stage development with a larval, pupal and adult beetle form (Andert et al. 2008). The larva of this species is frequently used as a food source for captive birds and herptiles, whereas the beetles make attractive exhibits or pets (Orozco and Philips 2012). As a result of its availability and reproductive success, *P. m. peregrina* has been the focus of many scientific studies, including investigations into flight metabolism (Bengtsson et al. 2011; Stensmyr et al. 2001), digestive microbiology (Andert et al. 2010; Orozco and Philips 2012), nutritional value (Lamsal et al. 2019), claw biomechanics (Bußhardt and Gorb 2013; Shima et al. 2020) and biochemistry (Auerswald and Gäde 2000).

Despite their popularity in research, there remains limited information available on *P. m. peregrina* behaviour or husbandry, and for invertebrates more generally, despite their common appearance in zoos and aquaria (Brereton and

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Brereton 2020). With growing interest in animal welfare (Keller 2017) and the critical importance of evidence-based husbandry, there is a need to better understand the behaviour of a wider range of captive species (Melfi 2009). As a commonly kept yet underrated invertebrate, *P. m. peregrina* may be an insightful study species and may also act as an initial research beetle to provide the foundation for research into more endangered scarabaeids or tenebrionid beetles.

Enclosure use

Enclosure use and design, particularly for zoo species, is currently a popular area of research. There are now a wide range of different assessment methods available that allow researchers to investigate how animals use their enclosures (Brereton and Fernandez 2022). Currently, enclosure use studies typically focus on large, charismatic species such as big cats (Mallapur et al. 2002) or primates (Daoudi et al. 2017), whereas there are comparatively few invertebrate studies in published literature (for a review of taxonomic representation, see Brereton 2020).

Enclosure use studies may be used to evaluate the overall relevance of an animal's environment (Hedeen 1982; Melfi 2009). If specific enclosure zones are avoided, this may be indicative that some aspect of the zone is not biologically relevant for the species (Plowman 2003). By contrast, zones or resources that are over-utilised could be identified using research, and then used to inform future exhibit design (Stensmyr et al. 2001). Long-term enclosure studies are essential to identify zones that are preferred or avoided by animals.

One key method of enclosure use investigation is the Electivity Index, which was originally used for assessing resource use in wild animals (Vanderploeg and Scavia 1979) but more recently has been applied to captive animal enclosure use studies (Brereton et al. 2023). The index allows animal enclosures to be separated not into rectangles, but into irregular sized zones based on biological differences.

Sun beetles

Despite spending a large portion of its activity budget in an inactive state or feeding, *P. m. peregrina* is a capable flier, and can endothermically warm its body temperature in preparation for flight (Auerswald and Gäde 2002). Despite their ability to fly, sun beetles tend to move slowly unless threatened (Stensmyr et al. 2001). This slow movement is theorised to be a strategy for conserving energy (Auerswald and Gäde 2000). Sun beetles are also able to burrow (Andert et al. 2010), so enclosures should be versatile to accommodate natural behaviours, including of larval and pupal forms, as fully as possible. Enclosures in captivity range from a box of substrate to complex environments containing live plants (Larsson et al. 2003).

Few studies have focussed on preference in invertebrates (Goulart et al. 2009), and extending enclosure use research to insects is a comparatively affordable initiative for collections to engage in. Invertebrate research should be encouraged, as the biological requirements of this taxon are not understood as fully as those of other, more charismatic zoo species.

Many invertebrates are at risk of extinction: a recent review of IUCN (2021) statistics revealed that 18.7% of classified species are recorded as threatened. These vulnerable species can be easily accommodated in collections, helping to increase the conservation breeding output of the zoo (Cardoso et al. 2011). For these species, greater understanding of enclosure requirements, temperature parameters and nutrition should be priorities for conservation breeding (Goulart et al. 2009). This work on sun beetles may act as a foundation for a range of further studies on more endangered species.

Materials and methods

Study location and subjects

The study was initiated on 1 September 2015 and data collection finished on 7 May 2016. The colony of *P. m. peregrina* was housed at Beale Wildlife Park in Berkshire, UK. Adult beetles were identifiable using individual markings, which were applied when beetles emerged from their cocoons. Markings are currently not known to cause any behavioural changes and last for a long period without further application (Hagler and Jackson 2001). At the end of each two-week period, the full colony was counted. Throughout these counts, any new beetles were tagged and deaths were recorded. During the study period, colony population size fluctuated from 25 to 57 individuals.

Enclosure

The study enclosure consisted of one large glass tank, measuring 30 cm width by 60 cm length by 40 cm height. The exhibit was in a room which received natural light. An Exo Terra™ Repti-Glo 18-inch, 15-watt tube was attached to the enclosure roof. This emitted infra-red, ultra-violet and visible light. To examine the effects of the light on sun beetle behaviour, the light was switched on for ten hours per day on alternating weeks (e.g. in an ABABAB experimental design). During weeks when the light was switched off, sun beetles still had access to ambient light through a nearby window.

The enclosure was heated using a large heat mat, which was placed below the glass tank. A thermostat was placed within the exhibit and set to 25°C. Ambient temperature and humidity were monitored with the provision of Komodo™ thermo-hygrometers at both sides of the exhibit, and average temperature and humidity was calculated for each observation. The enclosure was misted with a spray can once daily to maintain humidity levels between 50 and 80%, with a view to mirroring natural humidity levels.

The study enclosure included a range of surfaces and objects, including live and artificial plants, rotten wood and elevated climbing twigs. Live plants consisted of several spider plants *Chlorophytum comosum*. A leaf litter and compost substrate was provided at a depth of 13 cm for larvae to feed upon and for adult beetles to hide in.

Food was provided once per day and scattered in all areas of the enclosure. Foods included apples, oranges, bananas and mangos (Andert et al. 2008), as this beetle species is purported to be largely frugivorous. Some of the food was buried into the soil to provide extra feeding opportunities for larvae.

Data collection

To collect data, the enclosure was categorised into different zones based on biological relevance (Table 1). Elevated branches, for example, may present sun beetles with opportunities to express

Table 1. Size in cm^2 of each enclosure zone.

Enclosure zone:	Area (cm^2)
1. ground	1574
2. living plants	100
3. artificial plants	1524
4. decomposing wood	226
5. elevated branches	125
total	3,549

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different types of behaviour than in subterranean environments. All elevated branches were therefore classed as one specific zone. Subsequently, all enclosure zones were labelled and measured in cm2: these were calculated by measuring the dimensions of each surface or object available to the beetles. Where complex shapes (such as branches) were available to the beetles, the zone size was calculated by breaking the object into two dimensional rectangles, triangles and circles, and then adding the size of all shapes together.

Beetles and their larvae always had access to the deep substrate. Due to issues associated with comparing three-dimensional and two-dimensional zones, any beetles that were submerged in soil were not counted. Larvae were also not considered or counted during this study because they spent their time under the soil. Other than under the soil, all areas were visible to the camera and therefore any beetle above-ground could be counted.

Observations took the form of counts of beetles in each enclosure zone. Observations were conducted either in person or using an APEMAN 16MP 1080P Trail Wildlife Camera Trap, which provided a bird's eye view of the enclosure. Counts were conducted at the beginning of each hour to avoid issues associated with pseudoreplication. In addition, environmental variables were noted: these included temperature (°C), humidity (%) and whether the enclosure light was on or off.

The Electivity Index was used to measure enclosure use. The formula for Vanderploeg and Scavia's (1979) Electivity Index is:

$$E^* = (W_i - (1/n))/(W_i + (1/n))$$

$$W_i = (r_i / p_i)/(\sum (r_i / p_i))$$

ri refers to the observed use of zone *i*, and *pi* refers to the expected use of zone *i*, as calculated based on zone size. The letter n denotes the total number of zones or resources available to the study species. The index provides a value between −1 (no use of a zone) to 1 (over-utilisation of a zone). The Electivity Index also considers the size of each enclosure zone and the animal population size, as expected use (*pi*) values are generated based on population size.

Statistical analysis

Data were recorded in Excel™ 2013 and statistical analysis was undertaken using SPSS®, version 23. General linear models were used to investigate the effect of basking light provision on Electivity Index values. The additional variables of month, time of day (hour), temperature and humidity were included as predictors to determine their effect on index values. Graphs were also developed to demonstrate the respective effects of the basking light and time of day on sun beetle zone use.

Results

Overall, sun beetles did not use their enclosures evenly, with most zones being under-utilised (Figure 1). Only the elevated branches were consistently over-utilised. This over-utilisation of the elevated branch zone appeared to be consistent over time and did not appear to be influenced by the absence (Figure 2) or presence (Figure 3) of the basking light.

General linear models were run to determine whether the use of the basking light, temperature, humidity, time of day and month were predictors of Electivity Index (Table 2). All models

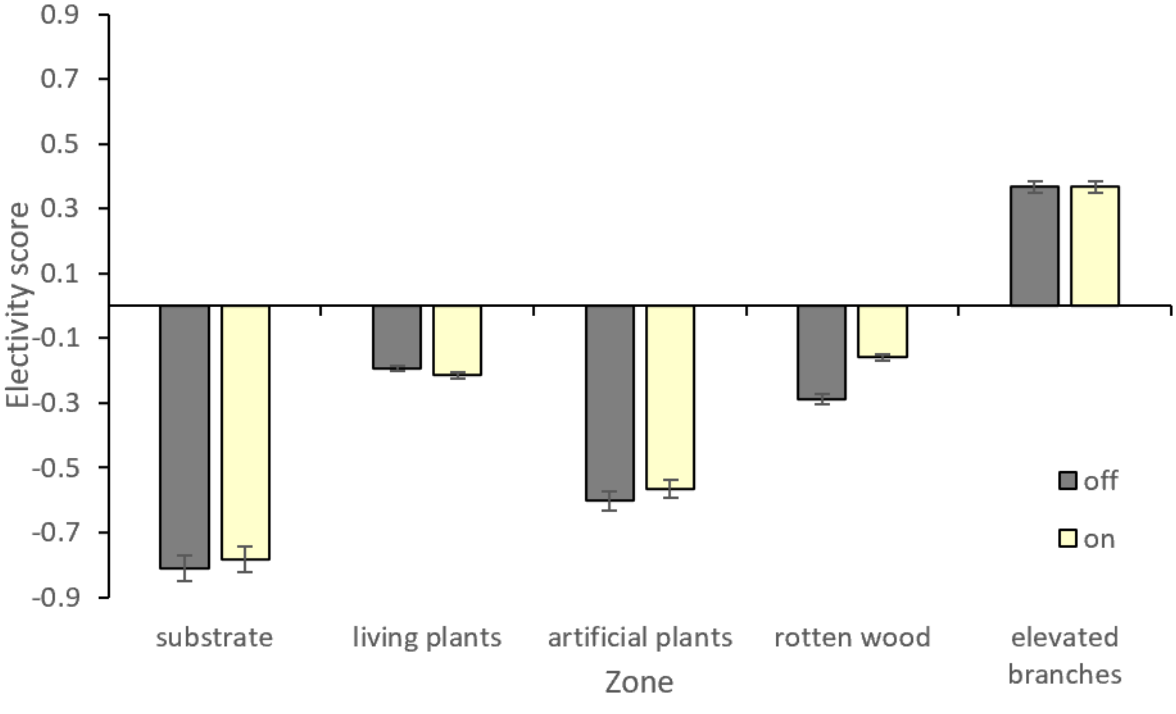

Figure 1. Average Electivity index per zone (+/- standard error) for observations when the basking light was off (grey bars) or on (yellow bars).

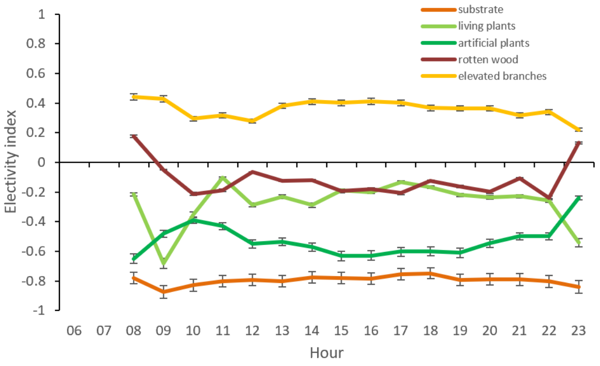

Figure 3. Average Electivity index, broken down by hour (+/- standard error), per zone, when the basking light was switched on.

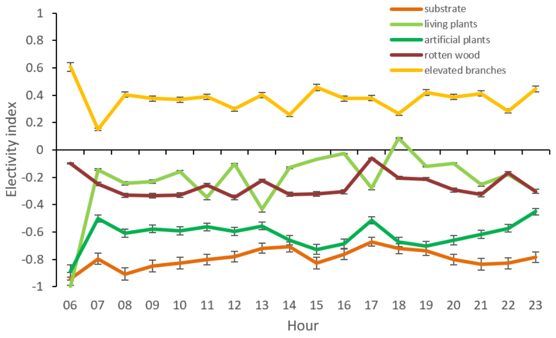

Figure 2. Average Electivity index, broken down by hour (+/- standard error), per zone, when the basking light was switched off.

Table 2. Results from General Linear Models on Electivity Indices per enclosure zone. * denote significant P values.

Zone (P value)	Adj R^2	Predictor	DF	SE Coefficient	P
Substrate (P<0.001) *	33.31%	Temperature	1	0.002	0.368
		Humidity	1	0.003	0.375
		Time	18	0.177	*<0.001
		Light	1	0.010	*0.015
		Month	8	0.010	*<0.001
Living plants (P<0.001) *	36.81%	Temperature	1	0.005	0.121
		Humidity	1	<0.001	0.316
		Time	18	0.480	0.003
		Light	1	0.027	*0.043
		Month	8	0.270	*<0.001
Artificial plants (P<0.001) *	46.17%	Temperature	1	0.002	0.054
		Humidity	1	<0.001	*<0.001
		Time	18	0.210	*<0.001
		Light	1	0.012	0.711
		Month	8	0.118	*<0.001
Rotten wood (P<0.001) *	35.53%	Temperature	1	0.004	0.470
		Humidity	1	0.001	*0.001
		Time	18	0.360	0.788
		Light	1	0.230	*<0.001
		Month	8	0.203	*<0.001
Elevated branches (P=0.001) *	23.88%	Temperature	1	0.0352	*0.001
		Humidity	1	0.006	0.984
		Time	18	0.311	0.505
		Light	1	0.018	0.468
			8	0.175	*<0.001

were significant, but provision of the basking light was a significant predictor of electivity values for the substrate, living plants and rotten wood only.

Discussion

Overall, sun beetles under-utilised much of their enclosure. Elevated branches were the only zone that was over-utilised: these branches were well used irrespective of whether the basking light was on. The general linear models were significant and explained some of the variation in the Electivity Index, with time of day, basking light provision, temperature and humidity as significant predictors.

Elevated zones

Of all zones available to the *P. m. peregrina* colony, only the elevated branches were consistently over-utilised. There are several possible reasons for the aggregations in elevated enclosure zones. One theory is that the elevated zones gave the beetles the greatest access to basking opportunities. In order to fly, sun beetles need to raise their body temperature (Heinrich and McClain 1986). While *P. m. peregrina* can endothermically raise their body temperature, Auerswald and Gäde (2002) suggest this mechanism is used rarely: sun beetles use basking behaviours as an energy saving option. Basking may be a key component of *P. m. peregrina* behavioural biology and can be easily accommodated in zoo enclosures with use of artificial lights or access to natural sunlight.

However, it should be noted that these aggregations in the elevated zones did not occur only during the day or when basking lights were on. This suggests that the elevated zones may serve other functions for adult beetles. For example, it is possible that branches provide a protective environment away from predators during periods of inactivity at night. Sun beetles are also able to burrow (Andert et al. 2008, 2010) and some individuals were noted to burrow at night. However, larvae were active beneath the soil and it is possible that cannibalism may take place by the larvae, as has been seen in other beetle taxa (Ichikawa and Kurauchi 2009). Resting in elevated areas could be an avoidance strategy against larvae, though more research may be required. It should also be considered that the actual area of elevated branches was relatively small, resulting in low expected values for the zone's use.

During aggregations of basking individuals in elevated zones, breeding behaviours were observed. While it is beyond the scope of this study to investigate breeding, basking spots may hold benefits for sociality and reproduction. Specifically, the opportunity to raise body temperature may allow *P. m. peregrina* to become more active, and therefore engage with energy-expensive behaviours (Auerswald and Gäde 2000).

Ground and plants

In comparison to the elevated branches, the substrate, rotten wood and artificial and living plants were under-utilised. It has been hypothesised that living plants might have some biological relevance to *P. m. peregrina*, particularly for climbing and hiding. However, the variety of plant species was limited, with only spider plants available. The leaves of the spider plants were low-lying and did not provide much height nor basking opportunities for the beetles. However, the use of living plants was affected by environmental variables. Specifically, the time of day, the month and light provision were associated with greater use of plants. Night and absence of light tended to decrease use of this zone. It is possible that plants play a similar yet less extreme function as the elevated branches. A greater diversity of plant species, incorporating more species found in the natural habitat of *P. m. peregrina*, would be useful for future studies.

Rotten wood, a valuable resource for larvae (Andert et al. 2008), was consistently under-utilised as a resource by adult beetles. Humidity, light and the month of observation were predictors of rotten wood zone use. Use of this resource may have been linked to light presence, though the effect was minimal. Rotten wood is used as food by the larval *P. m. peregrina*, who use a hindgut fermentation system to break down fibrous food (Andert et al. 2010). The rotten wood is also used by the pupal form, whose cocoons were often built into the rotten wood sections. This resource may therefore have more value for the larvae and pupae than for adult beetles. The substrate was the most under-utilised of all enclosure zones. This may be in part because it was the largest zone. For the substrate to be recorded as over-utilised, many beetles would have had to be sighted in this area. The time of day, basking light and month were predictors of substrate use. The highest use of substrate occurred during the day, especially when the basking light was on. This suggests that sun beetles may be using this zone more during the day, potentially as they transitioned between other zones.

Future directions

The role of food in modifying enclosure use was not considered during this study. Food was scattered across all exhibit zones (including branches), so this should not have affected the beetle's choice of zones. However, future studies could investigate preferred foods for the sun beetle and their effects on exhibit use. There are already several papers that suggest sun beetles have excellent olfaction and can discriminate between scents (Bengtsson et al. 2011; Stensmyr et al. 2001). Studies in the form of food preference tests could be used to identify favoured fruits or flowers that could be used to inform husbandry practices. It should be noted that preference does not always equate to nutritionally balanced diets, but food preference may be used to identify enriching foods.

There is limited research available on the use of enrichment for beetle species in captivity: sun beetles are no exception to this. Further research focusing on enrichment practices may therefore have value in filling a gap and in generating further interest in invertebrate husbandry and behavioural research. There are several papers investigating flowers as attractants for P. marginata (Larsson et al. 2003; Stensmyr et al. 2001), as the beetles in the wild feed on the nectar of several species. To the authors' knowledge, flowers are rarely provided as enrichment for the species in captivity. Further research could investigate the potential effects of flowers on behaviour and flower preference.

Conclusions

P. m. peregrina consistently over-utilised climbing zones in their exhibit. Provision of climbing zones above the substrate may be a valuable part of *P. m. peregrina* enclosure design. The provision of a basking light influenced the use of three of five enclosure zones. Providing opportunities for basking may allow *P. m. peregrina* to modify their body temperature and behaviour and may therefore have value for improved welfare.

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