Do Snakes Give a Hiss? Examining the Impact of Zoo Visitors on Captive Snakes

Article *in* Zoo Biology · October 2025

DOI: 10.1002/zoo.70033

Sara Hanson
The University of Adelaide

Bridget Cooper-Rogers
The University of Adelaide

Eduardo J Fernandez
The University of Adelaide

Zoo Biology

WILEY

ZOOBIOLOGY

RESEARCH ARTICLE

Do Snakes Give a Hiss? Examining the Impact of Zoo Visitors on Captive Snakes

Sara L. Hanson[1] | Bridget Cooper-Rogers[1] | Paige Klingner[1] | Pij Olijnyk[2] | Eduardo J. Fernandez[1]

[1]School of Animal and Veterinary Sciences, The University of Adelaide, Roseworthy, South Australia, Australia | [2]Zoos South Australia (Royal Zoological Society of South Australia), Adelaide, South Australia, Australia

Correspondence: Sara L. Hanson (Sara.Hanson@Adelaide.edu.au)

Received: 12 March 2025 | **Revised:** 13 August 2025 | **Accepted:** 25 September 2025

Keywords: animal welfare | animal–visitor interactions | reptile welfare | snake behavior | visitor effects

ABSTRACT

Zoos are interested in assessing the well-being of the animals in their care, including potential impacts from environmental and anthropogenic factors which could alter welfare. Zoos also provide a unique environment whereby visitors can get within proximity to wild animals, which can have positive, neutral, or negative impact for the exhibited animal's welfare. Within zoo settings, there has been little research published on these welfare impacts for reptiles, specifically snakes. Additionally, there is limited knowledge on their behavior in relation to captive welfare. Three snakes were selected, and conditions were implemented outside of their habitats to alter visitor proximity. The three conditions experimentally altered the proximity of people near the snake habitats and included Visitor-Natural (regular visitor proximity), Visitor-Control (no visitors within a 210 cm radius), and Visitor-Experimenter (an experimenter within close proximity throughout the observation time). An ethogram was developed and measured across a within-subject reversal design for all three conditions. Results indicated that overall, there was a neutral to positive impact of the Visitor-Natural condition. However, the highest negative impacts were observed during the Visitor-Experimenter condition, including increased abnormal behaviors. This study suggests that snakes will habituate to people but may be affected by short-term, unpredictable behavior from visitors. The results are discussed in terms of visitor impacts on exhibited snakes, as well as implications for assessing overall snake welfare.

1 | Introduction

Empirically assessing the welfare of animals under human care is becoming increasingly important for zoos (J. D. Altmann 1998; Moss and Esson 2010; Skibins and Powell 2013). Zoological organizations such as the Association of Zoos and Aquariums (AZA), European Association of Zoos and Aquaria (EAZA), and Zoo and Aquarium Association (ZAA) typically outline four general guidelines, including: (1) high standards of care, husbandry, and welfare, (2) educating visitors, (3) animal conservation, and (4) academic research (Fernandez et al. 2009; Bacon 2018; Zoo and Aquarium Association Australasia 2022; Association of Zoos and Aquariums 2024; European Association of Zoos and Aquaria 2024). Many zoos also rely on revenue generated from visitor attendance and purchasing of merchandise, therefore it is in their best interest to attract as many visitors as possible and to ensure that visitors are having an enjoyable experience, not only to generate income but to fulfill the second key role: educating the public (Carr and Cohen 2015; D'Cruze et al. 2019; Godinez and Fernandez 2019). Zoos also provide a unique experience whereby visitors can closely view and possibly interact with exotic animals, which has the potential for visitors to be perceived as a stressor to the animals. Therefore, initiatives and experiences that allow guests to interact with zoo animals can conflict with other key roles of zoos, such as ensuring high standards of care, husbandry, and welfare (Hosey 2005; D'Cruze et al. 2019).

Summary

- Snakes are a common occurrence in zoos, yet little is known how the presence of visitors could impact them.
- Three snakes were observed in three different conditions which experimentally manipulated the intensity of visitors.
- Snakes appeared to habituate to normal visitor traffic but less so when conditions were altered.
- Future research should focus on using species-specific welfare assessments for snake species.

Animal–Visitor Interactions (AVIs) research explores the relationships between animals housed in zoological institutions and visitors. Research in this field primarily splits into two distinct aspects: (1) the visitor effect, where the impacts of the visitor to the animal are the focus, and (2) the visitor experience, where the impact of exhibited animals on visitors is analyzed (D'Cruze et al. 2019; Fernandez and Chiew 2021; Learmonth et al. 2021; Fernandez and Sherwen 2024).

With respect to visitor effects, zoo visitors can have three possible impacts on zoo-housed animals: (1) a neutral response—where no or little difference is observed when visitors are present, (2) positive—where animals view visitors as a potential enriching presence, and (3) negative—where visitors are viewed as a stressor, which could lead to avoidance, defensive, or displacement behaviors (Hosey 2000; Davey 2007; Fernandez and Sherwen 2024). By understanding the impacts of visitors on zoo-housed animals, zoos can make informed decisions around their husbandry and adjust experiences that zoos offer to the public that do not compromise the welfare of the animal.

Earlier AVI research has investigated a range of taxa and has largely utilized methods that focus on observational, correlational information as opposed to experimental, causal relationships (Sherwen and Hemsworth 2019; Fernandez and Chiew 2021). However, there is a need for alternative methodologies that can indicate causation rather than correlation between visitor presence and changes in animal behavior. By understanding more about the direct causal impacts of various aspects of the captive environment, we can identify areas for improvement and implement new strategies to mitigate these potential stressors. Thus, aiming to improve the welfare of the animals housed in captive conditions through experimental examination.

A range of taxa have been investigated within zoos in relation to AVIs, however, this study has predominantly focused on mammals, particularly primates and carnivores (Edes and Hall 2023; E. Williams et al. 2023). The skew toward mammals for welfare research has resulted in many taxa that are commonly housed in zoological organizations being understudied, thus, informed decisions around their welfare cannot be made. One such taxa are reptiles, which encompassed 11% of all animals in the International Species Information System in 2011 (ISIS; a database of zoo captive animals kept within 586 institutions across 72 countries; Conde et al. 2013). However, reptiles were disproportionally represented in welfare research, where they were the focus of 3% of all zoo welfare publications between 2008 and 2017 (Binding et al. 2020).

The underrepresentation of reptiles in research impacts our ability to understand the visitor effect, as there are many unfounded misconceptions around aspects of their husbandry needs, behavior, and cognitive capabilities (Melfi 2009; Burghardt 2013; Azevedo et al. 2021). This also impacts on the ability to empirically assess their welfare. Furthermore, reptiles are often associated with negative stereotypes and beliefs which could indicate to the lack of interest in terms of research (Benn et al. 2019; Ogle and Devlin 2022). Snakes, in particular, are often the subject of negative perceptions. For example, a survey carried out at Durrell Wildlife Park found that snakes were voted the least favorable animal by zoo visitors (Carr 2016).

Considering our current limited knowledge of captive snake welfare, the subject of AVIs with snakes has also been severely understudied. To date, there have only been two AVI publications that have investigated the effects that zoo visitors have on snakes (Carter et al. 2021; Hamilton et al. 2022). It is therefore imperative that research focuses on this understudied taxon, but specifically focusing attention on environments that many species are in and have to be in potentially unnatural conditions.

This study aims to fill some of the gaps in AVI snake research by examining the effects of visitors on three species of snakes. The aims of this study were to: (1) investigate the effect that visitors have on snakes, specifically by manipulating visitor proximity and (2) establish positive and negative welfare metrics for the snakes studied. By doing so, two hypotheses were proposed: (a) that there would be an increase in the occurrence of Abnormal behaviors during the Visitor-Experimenter condition (the highest visitor presence and closest proximity condition), and (b) that the highest within-session variability of area usage would be observed when zoo visitor presence and proximity was highest.

2 | Materials and Methods

2.1 | Subjects and Habitats

Method procedures were created in accordance with the Australian code for the care and use of animals for scientific purposes, 8th edition (National Health and Medical Research Council: Canberra 2021). Prior to its implementation, this project was approved by the Animal Ethics Committee at the University of Adelaide on Wednesday, May 22, 2024 (S – 2024-034).

Three snakes of different species were utilized for this study and consisted of a red-bellied black snake (*Pseudechis porphyriacus*; RBBS), an inland taipan (*Oxyuranus microlepidotus*; taipan), and a rough-scaled python (*Morelia carinata*; RSP), all of which are outlined in Table 1. A fourth snake, a woma python (*Aspidites ramsayi*), was originally included in the study, however, they were removed from any continued study or analyses due to multiple shedding events.

All snakes were housed in the reptile house at Adelaide Zoo, Australia and were cared for by the Adelaide Zoo Reptile Team.

TABLE 1 | Details of the individual snakes utilized for this study.

Common name	Species	Sex	Origin	Weight (g)
Red-bellied black snake (RBBS)	*Pseudechis porphyriacus*	Female	Wild caught (2015)	1025 (05/27/2024)
Inland taipan (taipan)	*Oxyuranus microlepidotus*	Male	Captive bred (2006)	1080 (05/27/2024)
Rough-scaled python (RSP)	*Morelia carinata*	Male	Wild caught (2010)	1120 (05/16/2024)

They were housed individually and specifications for their habitats are outlined in Table 2. All snakes had artificial lighting and heating, as well as access to hides, furnishings, and water throughout the study. All habitats consisted of walled sides with the front side being glass to allow visitors to see into the habitat. Each habitat had an entrance to the rear to allow staff access. The RBBS and taipan had an additional loft box at the back of the habitat as a safety measure for keeper access. The RBBS and RSP habitats had substrate which consisted of wood chippings and leaves, while the taipan's consisted of a sand substrate. Heating and lighting were controlled throughout the experiment and the temperatures of the habitats were recorded weekly with average temperatures outlined in Table 2.

All snakes had the same feeding schedule of two mice provided fortnightly on Tuesdays. Daily maintenance of habitats was carried out every morning before opening to the public. Snakes were not removed or handled when the observer was present; furthermore, snakes did not receive enrichment devices during the study. Snakes were not observed on feed days, 1 day postfeeding, on monthly weigh days, or during periods of shedding. All snakes permanently lived in their habitats, which were viewable to the public from 10:00 a.m. until 4:30 p.m. daily. A fixed barrier was in place to stop visitors standing within 135 cm from the habitat glass.

2.2 | Materials

Materials included a handheld tablet with the ZooMonitor (version 4.1) app (Lincoln Park Zoo 2022) to record observational data. Additionally, three Syneco 250 cm Expandable Safety Barriers were used to implement the experimental conditions. Signs were created and positioned onto the barriers during observation periods to inform zoo visitors of the study.

2.3 | Data Collection

A mutually exclusive and exhaustive ethogram (see Table 3) was developed prior to data collection. The ethogram was adapted from Spain et al. (2020), M. L. Williams et al. (2022), Warwick (2023), and Zdenek et al. (2023). Behaviors were split into "Active," "Inactive," "Abnormal," "Out of Sight," and "Other" classes. The "Other" class of behaviors allowed our ethogram to be exhaustive, but only two instances of "Other" behavior occurred across the three snakes utilized for inferential statistics, and therefore excluded from all further analyses.

Snakes were observed one snake in their individual habitat at a time (three exhibits total), from ~10 a.m. until 12 p.m. in 30 min sessions and repeated in the afternoon, between approximately 2 p.m. and 4 p.m. The order that snakes were observed changed daily; this order was semirandomized to ensure that snakes were not observed at the same time on consecutive days. ZooMonitor was utilized on an iPad to record data. Pinpoint (instantaneous time) focal sampling (J. Altmann 1974; Brereton and Fernandez 2022) of 30-s intervals was employed for each session (60 intervals/30 min). At each interval, the behavior of the snake (Table 3), location in the habitat (Figure 1a–c), and number of visitors were recorded.

To measure area usage, all three habitats were split into quadrants: "front top," "back top," "front bottom," and "back bottom." The location in the habitat recorded was determined by the location of the snakes' head. If the head was not viewable then the body part that was visible determined the location. Throughout the study, the snakes were always viewable even if utilizing hides. To determine the four quadrants, specific landmarks were used within the habitat. Figure 1a–c illustrates the three species' habitats for both the taipan and the RSP, the main climbing branch in the center of the habitat was utilized as the landmark to separate front and back. To differentiate between top and bottom, the first main branching of that tree was used. Due to differences in furnishings, the RBBS' habitat used different landmarks, the rock line that ran along the whole habitat was utilized as the landmark to determine front and back. The top of this rock line determined top and bottom.

Visitor number was counted during the Visitor-Natural condition (see Section 2.4), with both adults and children included, unless the child was carried by an adult or in a pushchair. Zoo volunteers were also included in the count, but zookeepers were not.

Observations were taken from Tuesdays through to Sundays, starting on Wednesday June 12, 2024 until Thursday September 12, 2024. Days immediately around feed days were not observed. Furthermore, if snakes were undergoing shedding or medical checks, they were also not observed during that time. Any days missed during a condition were repeated at a later date.

2.4 | Procedure

The presence and proximity of people, largely dependent on visitors, was experimentally manipulated to ascribe any differences in the behavior of the snakes to the examined variables. The following three conditions were presented to test different visitor intensities:

- *Visitor-Natural* (V-N)—No change to barriers at Adelaide Zoo (i.e., normal visitor attendance). There was a permanent barrier set up 135 cm away from the habitat glass. Both visitors and the observers were at least 135 cm away from the habitat. Observers would typically situate themselves on the far sides of the area (~210 cm from the habitat glass)

TABLE 2 | Dimensions, lighting, and temperatures recorded for each of the snakes.

Snake	Lighting and heating elements	Average minimum temperature (°C)	Average maximum temperature (°C)	Enclosure dimensions (cm)	Loft box dimensions (cm)	Window dimensions (cm)
RBBS	4 Ceramic Heat Emitters, Exo Terra 300 W basking spot	23.46 ± 0.40	28.00 ± 0.38	190 × 138 × 134	96 × 52 × 50	200 × 85
Taipan	2 Ceramic Heat Emitters, Underfloor heating (28°)	25.42 ± 0.38	30.92 ± 0.40	126 × 91 × 134	45 × 52 × 41	115 × 85
RSP	2 Ceramic Heat Emitters, Underfloor heating (28°)	24.93 ± 0.37	31.36 ± 0.78	126 × 91 × 134	n/a	115 × 85

and would not walk in front of the habitat, unless visibility to the animal was restricted.

- *Visitor-Control* (V-C)—An additional temporary barrier created by three Syneco 250 cm Expandable Safety Barriers. This separated visitors and the observers a further 75 cm away from the habitat (a total of 210 cm). A distance of 210 cm was selected as this was the furthest distance available that still allowed for visitor accessibility past the habitat. As in the V-N condition, observers would situate themselves to the far sides of the area ~210 cm from the habitat glass and would not walk in front of the habitat, unless visibility to the animal was restricted.
- *Visitor-Experimenter* (V-E)—In order to increase the presence and proximity of people, we ran the Visitor-Experimenter condition, which presented the experimenter continuously within close distance of the habitat. The temporary barrier was installed to keep zoo visitors distanced; however, the observer was directly in front of the habitat (within the barriers) for the entire observation session. The observer stood 65 cm away (a small permanent wall blocked the observer from standing directly in front of the habitat) from the habitat but would lean their hand on the glass and behave in more conspicuous ways (e.g., waving arms around and sudden movements). The observer would remain centrally situated in front of the habitat throughout the observation time. The hand on the glass activity of the experimenter occurred for the majority of a session, while the conspicuous behaviors of the experimenter were semirandomized and typically only occurred several times a session.

During the Visitor-Natural condition, crowd size was calculated to produce an average visitor per interval within a 210 cm radius of the habitat front. As described in the V-N condition description, observers were typically not within the 210 cm visitor radius, and therefore were not included when visitor numbers were counted. For every observation interval (30 s), the habitats averaged 0.595 ± 0.044 visitors (RBBS 0.508 ± 0.086; taipan 0.554 ± 0.079; RSP 0.583 ± 0.079). The crowd size ranged per interval from 0 to 18. During the Visitor-Control condition, 0 visitors per interval were present within 210 cm radius of a habitat, and during the Visitor-Experimenter condition, 1 visitor per interval (the observer) was present at the habitat.

The temporary barriers used during experimental conditions V-C and V-E were set up for the observation time only (30 min in the morning and 30 min in the afternoon) and were taken down as soon as observations concluded. Each condition was observed for 6 days (12 sessions) and repeated with a counterbalanced reversal design (see Figure 2). For each snake, a total of 72 sessions were recorded, with 24 sessions for each of the three conditions. A total of 144 h of data were collected.

2.5 | Interobserver Agreement (IOA)

To examine the reliability (agreement) of our data collection, a secondary observer collected data for 30.5% of all observations. This was conducted in person and for all data collected by

TABLE 3 | Ethogram describing snake behavior, adapted from Spain et al. (2020), M. L. Williams et al. (2022), Warwick (2023), and Zdenek et al. (2023).

Behavior class and behaviors	Description
Active	
Locomotion in view	More than 25% of the body is in view and moving in any direction to a new location.
Locomotion out of view	Less than 25% of the body is in view and moving in any direction to a new location.
Climbing	Animal is using branches and other furnishings in the enclosure to change elevation up or down.
Investigative	Head and neck moving about in a relaxed pace exploring immediate surroundings, with or without tongue flicking.
Inactive	
Coiled view	Nonmovement, with more than 25% of the body is in view and more than 75% of body assumes a spiral position.
Stretched out	Nonmovement with more than 25% of the body is in view, stationary and not in coiled position.
Abnormal	
Freezing	Head and neck are elevated, body and head are stationary, no tongue flicking is occurring.
Window strike	Mock strikes toward observer, head is elevates off the ground, recoils into an "S"/"Z" shape then lunges forward, quick movement and hitting the glass of the enclosure. Snake begins more than 10 cm away from the glass and connects with glass in < 2 s.
Boundary contact	Head is pushing, "surfing," climbing, or digging at the walls/windows of the enclosure.
Rapid body movement	Abnormal movement that appears "jerky." Can include the whole body or just the head and neck.
Tail flicking	Tail is moving from side to side. The rest of the body is stationary.
Out of Sight	
Obstructed view	Animal is viewable with difficulty or using objects within the enclosure to reduce visibility, not enough is viewable to ascribe any other behavior.
In hide/loft box	Animal is in their purpose-built hide or in their loft box (RBBS and Taipan).
Other	
Other	Animal is displaying behavior not described.

the second observer, who like the primary observer typically stood at least 210 cm away from the habitat glass across all conditions. As before, a conscious effort was made to situate the second observer to the far side of the habitat to reduce their impact on any results. Interobserver agreement (IOA) was calculated based on total agreement of the behaviors observed ([smaller count/larger count]*100; Cooper et al. 2020). A percentage was determined for each class of behavior. Classes had over 89% agreement with an average of 92% agreement across all behavioral categories (Active—93.83%; Inactive—94.31%; Abnormal—89.09%; Out of Sight—90.89%).

2.6 | Statistical Analysis

Data were downloaded from ZooMonitor and entered into Microsoft Excel where descriptive statistics were calculated (mean and standard error of the mean, SEM) for all three snakes combined. Snakes were combined for statistical purposes, as well as because similar patterns of behavior were observed for each class across all three snakes. Individual snakes were compared for the few differences observed between snakes, namely, individual habitat area usage (see later Section 3). Behavior classes for each of the sessions were converted from a count into a percentage.

Data were then compiled and transferred to GraphPad Prism, version 10, where graphs were generated using the average percentage of occurrence for each of the behavioral classes and Entropy (enclosure use variability; see below) for each condition. Inferential statistics were also calculated. To ascertain significant behavioral differences between the conditions, snakes were combined and tested for normality using a Shapiro–Wilk test. As all failed normality, Friedman tests (nonparametric, repeated measures, one-way ANOVAs) were utilized to compare behavioral class differences between conditions. A p value of 0.0125 was calculated using a Bonferroni correction according to the four behavior classes (0.05/4). When significant ($p < 0.0125$) or near-significant ($p < 0.05$) differences were demonstrated post hoc pairwise comparisons (Dunn tests) were carried out to determine differences between conditions.

FIGURE 1 | (a) Red-bellied black snake habitat, the raised rock line spanning the length of the habitat determined front and back, while the top of this line determined top and bottom. (b) Inland taipan habitat. The main climbing branch in the center of the habitat separated the front and back of the habitat, while the main split in the climbing branch separated top and bottom. (c) Rough-scaled python habitat, the main climbing branch in the center of the habitat separated front and back of the habitat. While the main split of the branch separated top and bottom. [Color figure can be viewed at wileyonlinelibrary.com]

Area usage was converted into a measure of Entropy for each session (Brereton and Fernandez 2022). The proportion of time spent in each area resulted in a percentage = *p(I)*. The following formula was then used to calculate the value of Entropy for each session:

$$H = -\Sigma\, p(I) \log p(I).$$

This resulted in a value from 0 to 1, with 1 indicating a higher variability in area usage for one 30-min session. The three snakes were combined and the mean and SEM for each condition was calculated. A test for normality was conducted (Shapiro–Wilk test). Again, this failed normality and therefore, a Friedman's test was used to examine Entropy differences.

3 | Results

Below are the inferential statistics and graphs for the combined results of the three snakes.

3.1 | Behavior and Entropy for All Snakes

Figure 3 illustrates the combined average percentage of occurrence of behavioral class observed over the three conditions. A statistically significant difference was observed for Abnormal behaviors ($\chi^2_2 = 21.27$, $p = < 0.0001$). Post hoc tests revealed that abnormal behaviors occurred significantly more in the Visitor-Experimenter condition ($M = 8.50\% \pm 1.64$) compared to the Visitor-Natural condition ($M = 1.41\% \pm 0.36$, $p = 0.0046$), and the Visitor-Control condition ($M = 2.32\% \pm 0.77$, $p = 0.0138$). Active behaviors showed a difference that approached significance (i.e., not significant with the correction; $\chi^2_2 = 7.57$, $p = 0.0227$). Post hoc tests revealed a greater occurrence in the Visitor-Experimenter condition ($M = 18.03\% \pm 2.54$) compared to the Visitor-Natural condition ($M = 10.07\% \pm 1.91$, $p = 0.0419$). No significant differences were observed in Inactive behaviors ($\chi^2_2 = 2.770$, $p = 0.2503$) or Out of Sight behaviors ($\chi^2_2 = 0.5253$, $p = 0.7690$). The descriptive statistics for those classes of behavior were as follows: (Inactive: V-N: $M = 39.61\% \pm 5.20$; V-C: $M = 36.20\% \pm 4.95$; V-E: $M = 26.55\% \pm 4.17$; Out of Sight: V-N: $M = 48.82\% \pm 5.54$; V-C: $M = 44.03\% \pm 5.36$; V-E: $M = 46.85\% \pm 5.22$).

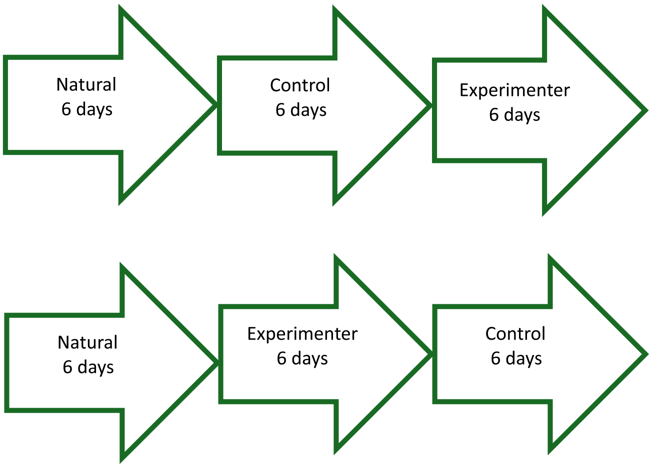

FIGURE 2 | Illustration of the repeated reversal design of A-B-C-A-C-B. [Color figure can be viewed at wileyonlinelibrary.com]

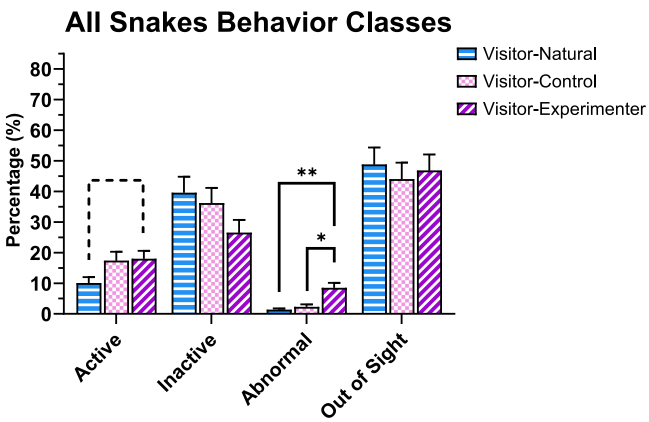

FIGURE 3 | Graph showing the combined snake average occurrences across the three conditions. The mean and SEM are displayed in the graph, with solid lines representing significant differences (**$p < 0.01$; *$p < 0.05$). The dotted line indicates p value approaching significance ($p < 0.05$, but not significant with the correction). [Color figure can be viewed at wileyonlinelibrary.com]

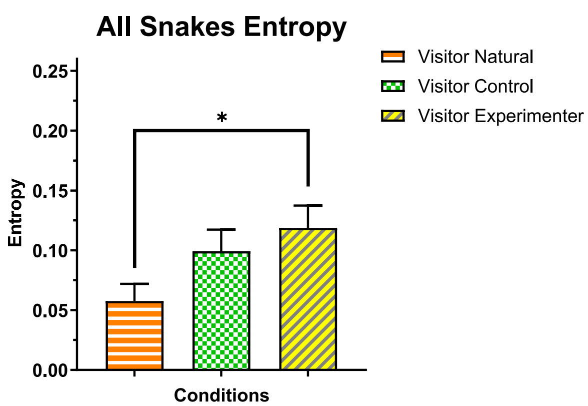

FIGURE 4 | Graph showing average Entropy scores for the combined three snakes. The mean and SEM are displayed in the graph, with solid lines and an asterisk (*$p < 0.05$) indicating significance. [Color figure can be viewed at wileyonlinelibrary.com]

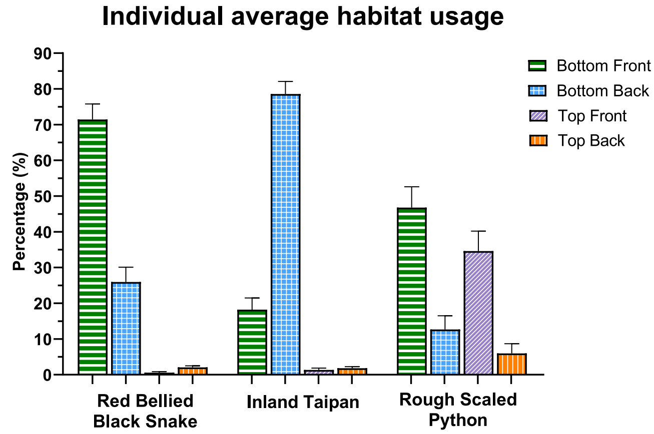

FIGURE 5 | Graph showing the breakdown of average area use for each snake across all three conditions. [Color figure can be viewed at wileyonlinelibrary.com]

Figure 4 illustrates the combined Entropy scores for the three snakes. A statistically significant difference was observed for the combined Entropy scores ($\chi^2_2 = 11.26$, $p = 0.0036$). Post hoc tests revealed a significantly greater Entropy score for the Visitor-Experimenter condition ($M = 0.12 \pm 0.02$) compared to the Visitor-Natural condition ($M = 0.06 \pm 0.01$, $p = 0.029$). Differences between the combined Entropy scores for the Visitor-Control condition ($M = 0.10 \pm 0.02$) and the other two conditions were not significant.

3.2 | Area Usage Versus Entropy

Although inferential statistics were not calculated on an individual level. Figure 5 illustrates the average time spent in each section of the habitat for each snake. Variations between species were observed, with the RBBS and taipan spending more time in lower areas of the habitat (RBBS bottom front: $M = 71.44\% \pm 4.36$; bottom back: $M = 25.95\% \pm 4.14$ and the taipan bottom front: $M = 18.22\% \pm 3.27$; bottom back: $M = 78.56\% \pm 3.49$), while the RSP spent more time in the top portion of their exhibit and at least 5% of its time in all four quadrants (bottom front: $M = 46.76\% \pm 5.82$; top front: $M = 34.61\% \pm 5.61$; bottom back: $M = 12.66\% \pm 3.84$; top back: $M = 5.95\% \pm 2.72$).

4 | Discussion

4.1 | Combined Snakes

Visitor proximity had a direct impact on the combined snake results. Specifically, a significant increase in the occurrence of abnormal behavior during the Visitor-Experimenter condition was observed. Previous reptile research utilized the presence of abnormal behaviors as negative indices for welfare (Bashaw et al. 2016; Benn et al. 2019; Spain et al. 2020; Hollandt et al. 2021; M. L. Williams et al. 2022), which could indicate that zoo visitors have the potential to negatively affect captive snakes.

Nonetheless, in our study, it was not clear how proximity compared to behavior impacted these responses, as other AVI studies have found that altering visitor behavior impacted animal activity (Chamove et al. 1988; Mitchell et al. 1991). Therefore, it is possible that the experimenter's activity (e.g., putting hand on viewing glass) impacted the increased display of abnormal behaviors. In addition, Hamilton et al. (2022) reported no obvious negative changes in behavior, such as freezing, when visitors were present, like our low levels of abnormal behaviors during the Visitor-Natural condition. Regardless, some increased aspect of the proximity of people, whether continued proximity or activity, resulted in an increase in the display of abnormal behaviors.

Although not significant, active behaviors increased, nearing significance during the Visitor-Experimenter condition. It has been proposed that hyperactivity is a potential sign of stress in reptiles, this behavior specifically was not included within the "abnormal" category within the ethogram used and instead would have been recorded as "active" behavior (Warwick et al. 2013; Warwick 2023). This also highlights a need to reevaluate the use of active behaviors as a positive welfare indicator for reptiles. Other research has reported an increase in activity and exploratory behaviors in snakes and concluded these as positive measures of welfare (Bashaw et al. 2016; Spain et al. 2020; Hoehfurtner et al. 2021). However, as noted above, behaviors in our study that could have been associated with stress may have been coded as an active behavior, as active behavior was greatest during the highest visitor density (Visitor-Experimenter condition).

Despite the proximity of visitors, the Visitor-Natural condition reflected what may be considered the most positive welfare indicators. There was an absence of abnormal behaviors, the lowest occurrences of active behaviors and the highest occurrences of inactivity, all of which could be signs of positive welfare for snakes. It is important to note that inactivity is when snakes chose to rest in view rather than seek hides or out of sight spaces. This could indicate that habituation to visitors had occurred and that visitors were not perceived as a threat (Carter et al. 2021; Hamilton et al. 2022). In addition, the presence of some abnormal behaviors during the Visitor-Control condition, when visitors were not within 210 cm, further supports the potential for at least some habituation to visitors to have occurred during the Visitor-Natural condition. Nonetheless, the impact of all visitor activity, including factors such as potential noise, is difficult to assess for snakes, as there is still conflicting evidence regarding snakes and their hearing capabilities (Christensen et al. 2012; Zdenek et al. 2023).

The greatest Entropy score, which is typically associated with positive welfare, occurred during Visitor-Experimenter conditions, which had the highest average visitor presence and produced the highest abnormal behavior scores. Similarly, Hamilton et al. (2022) observed a higher variability in habitat usage for rattlesnakes when the zoo was open to the public. Evaluation of area use has been utilized to assess welfare impacts in a range of zoological species. As noted above, for mammals and birds, greater variability in habitat usage is often correlated with better welfare (Rose et al. 2018; Brereton 2020; Fernandez and Harvey 2021; Zacchi et al. 2024). However, it appears that for short observation times, a higher Entropy score could be a negative indicator of welfare for snakes (Warwick 1990). Regardless, the snakes did use multiple areas of their habitats throughout the study, as observed in the individual area use graph (Figure 5). These differences between both behavioral and enclosure assessments, as well as in the type of enclosure use assessment used, highlight the need to have multiple measures to adequately assess welfare, particularly for understudied species. This includes greater use of field-based observations in assisting welfare assessments for taxa such as reptiles, where "normal" activity patterns may be less known (Warwick et al. 2013).

4.2 | Significance

There is a lack of experimental approaches toward current published AVI studies, which has led to many authors incorrectly inferring causal relationships from correlational data between zoo-housed animals and visitors. By applying an experimental approach, we are more likely to assess whether visitors have a direct impact on zoo animals (Goodenough et al. 2019; E. Williams et al. 2023).

Reptiles, particularly snakes, are severely understudied within animal behavior and welfare research (Burghardt 2013; Binding et al. 2020). Despite the limited time frame of this project, behavioral data have been provided for individuals within the suborder Serpentes. Most welfare knowledge around captive snakes have involved investigating specific areas of husbandry and its impacts on behavior. However, there is still debate over which metrics can be utilized to assess reptile welfare, with some authors reporting an increase in activity and, in particular, exploration as a potential positive indicator of welfare (Mellor 2013; Bashaw et al. 2016; Spain et al. 2020; Hoehfurtner et al. 2021). In contrast, other authors have questioned whether greater activity is a positive welfare index and suggests an understanding of baseline behaviors needs to be considered, which may include lower levels of activity compared to other taxa (Hill and Broom 2009; Carter et al. 2021). In addition, the absence of abnormal behaviors has been used as an indication of positive welfare (Bashaw et al. 2016; Benn et al. 2019; Manteca et al. 2016). It appears from the results of this project that the monitoring of abnormal behaviors is a crucial component of assessing snake welfare.

Variation of habitat usage has been utilized for other taxa to assist in assessing welfare (Rose et al. 2018; Fernandez and Harvey 2021; Zacchi et al. 2024). Evidence from this study supports this, however, unlike mammals and birds, a higher variation of area use in a session may not equate to better welfare, and for short durations of observations it may be a negative welfare indicator. It is still important for proper welfare assessments to observe overall area use separately, as all areas of each habitat were still utilized by each snake despite entropy scores indicating lower variability in a 30-min session associated with positive welfare.

Our results suggest that the Visitor-Natural condition produced the best welfare results, which could have been either because it was (a) least stressful, or (b) potentially enriching. Other researchers have found enriching impacts of zoo visitors

(Nimon and Dalziel 1992; Cook and Hosey 1995; Eltorai and Sussman 2010; Fernandez et al. 2021). With respect to stress, this could be due to habituation to normal zoo traffic and that the implementation of a regular barrier keeps zoo visitors far enough away that they are not perceived by the snakes as a potential stressful stimulus (Bloomfield et al. 2015).

4.3 | Limitations

Zoo welfare research is often limited to small sample sizes (Goulart et al. 2009). Although our research combined three species of snakes for our analyzed results, they were still based on one individual from each species ($n = 3$). Therefore, the external validity of our results is limited, which could additionally be hampered by individual bias from the snakes (e.g., rearing history). Additionally, the differences between species should not be understated, there were differing natural histories as well as differing sensory ecologies. For example, one species was nocturnal and uses heat pits, while the other two species were diurnal. These factors could have influenced their responses to differing conditions.

This study was limited by two behaviorally based measures (ethograms and area use variability). Utilizing additional measures, including physiological indices, can greater benefit our welfare understanding (Bacon 2018; Benn et al. 2019). It should not be ignored that potential welfare impacts on snakes may not always be behavioral (Cannon et al 2002).

Additionally, observations were limited to daytime and on-exhibit activity. In total, 24-h observations would be helpful to further assess welfare (Brando and Buchanan-Smith 2018; Queiroz and Young 2018; Hamilton et al. 2022). Particularly for species that are active at night, such as some of the snakes in our study.

Despite animals being housed in environments where the conditions are artificially controlled, there could be variations in temperature which may have impacted results. Furthermore, data collection occurred during winter (albeit with artificially controlled indoor conditions), which may have altered results. External conditions such as temperature changes have been suggested as more influential on behavior than visitors in reptiles (Riley et al. 2021; Gray et al. 2024).

4.4 | Future Research

This study highlights a greater need for captive snake welfare research. There are limited indices to assess welfare for snakes, with most current welfare assessments being mammal and bird focused (de Azevedo et al. 2007; Melfi 2009; Binding et al. 2020). Snake welfare research has gained some focus in recent years, with evidence highlighting the importance of providing space to allow for rectilinear posture (Warwick et al. 2019, 2021) and providing environmental enrichment (Burghardt 2013; Nagabaskaran et al. 2022). However, welfare assessments for snakes often relate to an absence of negative-based measures rather than exploring animal-based positive indices. Therefore, further research is required to devise welfare assessments for snakes as assessments for mammals and birds may not be appropriate (Benn et al. 2019).

Assessments of reptile husbandry practices have often been found to be based on nonevidence-based “folklore” husbandry (Arbuckle 2013; D'Cruze et al. 2020; Jessop et al. 2023), therefore, there is a need to reevaluate these regimes and investigate them empirically. Burghardt (2013) termed captive husbandry for reptiles as “depauperate” and “controlled deprivation”; consequently, there is a need to investigate various aspects of husbandry and question how we keep snakes in captivity.

5 | Conclusion

Modifications to visitor presence and proximity appear to impact snake behavior and, therefore, their welfare. The results indicate that snakes appear to either habituate to or find “normal” visitor presence and/or proximity enriching. However, high visitor activity can adversely impact their welfare. Furthermore, this study highlights the need for (a) better experimental control in applied settings to investigate visitor effects, and (b) snake-sensitive metrics when evaluating snake welfare. By experimentally manipulating the proximity of visitors, the clear functional impact of zoo visitors can be illustrated. The results support both hypotheses predicted. This project has identified that short-term stress can be caused by changes in visitor proximity which has not been evident in previous AVI studies with snakes. However, it is unclear whether changes in proximity or visitor behavior were the cause of increased negative indicators of welfare. Furthermore, the use of behavioral observations was vital to draw these conclusions, and therefore, behavioral indices are crucial for future welfare-related research with snakes. Additionally, measurements utilized for mammal and bird welfare studies may not be suitable for snakes or other reptile species. Future research should investigate reptile-specific indices for welfare.

Acknowledgments

This study would not have been possible without the reptile team at Adelaide Zoo, as well as the zoo itself for providing the animals and setting for this project.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Altmann, J. 1974. “Observational Study of Behavior: Sampling Methods.” *Behaviour* 49, no. 3: 227–266. https://doi.org/10.1163/156853974x00534.

Altman, J. D. 1998. “Animal Activity and Visitor Learning at the Zoo.” *Anthrozoös* 11, no. 1: 12–21. https://doi.org/10.1080/08927936.1998.11425083.

Arbuckle, K. 2013. “Folklore Husbandry and a Philosophical Model for the Design of Captive Management Regimes.” *Herpetoculture Review* 44, no. 3: 448–452.

Association of Zoos and Aquariums. 2024. *Strategic Plan*. Association of Zoos and Aquariums. https://www.aza.org/strategic-plan.

Azevedo, A., L. Guimarães, J. Ferraz, M. Whiting, and M. Magalhães-Sant'Ana. 2021. "Pet Reptiles - Are We Meeting Their Needs?" *Animals* 11, no. 10: 2964. https://doi.org/10.3390/ani11102964.

de Azevedo, C. S., C. F. Cipreste, and R. J. Young. 2007. "Environmental Enrichment: A GAP Analysis." *Applied Animal Behaviour Science* 102, no. 3: 329–343. https://doi.org/10.1016/j.applanim.2006.05.034.

Bacon, H. 2018. "Behaviour-Based Husbandry—A Holistic Approach to the Management of Abnormal Repetitive Behaviors." *Animals* 8, no. 7: 103. https://doi.org/10.3390/ani8070103.

Bashaw, M. J., M. D. Gibson, D. M. Schowe, and A. S. Kucher. 2016. "Does Enrichment Improve Reptile Welfare? Leopard Geckos (*Eublepharis macularius*) Respond to Five Types of Environmental Enrichment." *Applied Animal Behaviour Science* 184: 150–160. https://doi.org/10.1016/j.applanim.2016.08.003.

Benn, A. L., D. J. McLelland, and A. L. Whittaker. 2019. "A Review of Welfare Assessment Methods in Reptiles, and Preliminary Application of the Welfare Quality® Protocol to the Pygmy Blue-Tongue Skink, *Tiliqua adelaidensis*, Using Animal-Based Measures." *Animals* 9, no. 1: 27. https://doi.org/10.3390/ani9010027.

Binding, S., H. Farmer, L. Krusin, and K. Cronin. 2020. "Status of Animal Welfare Research in Zoos and Aquariums: Where Are We, Where to Next?" *Journal of Zoo and Aquarium Research* 8, no. 3: 166–174. https://doi.org/10.19227/jzar.v813.505.

Bloomfield, R. C., G. R. Gillespie, K. J. Kerswell, K. L. Butler, and P. H. Hemsworth. 2015. "Effect of Partial Covering of the Visitor Viewing Area Window on Positioning and Orientation of Zoo Orangutans: A Preference Test." *Zoo Biology* 34, no. 3: 223–229. https://doi.org/10.1002/zoo.21207.

Brando, S., and H. M. Buchanan-Smith. 2018. "The 24/7 Approach to Promoting Optimal Welfare for Captive Wild Animals." *Behavioural Processes* 156: 83–95. https://doi.org/10.1016/j.beproc.2017.09.010.

Brereton, J. E. 2020. "Current Directions in Animal Enclosure Use Studies." *Journal of Zoo and Aquarium Research* 8, no. 1: 1–9.

Brereton, J. E., and E. J. Fernandez. 2022. "Investigating Unused Tools for the Animal Behavioral Diversity Toolkit." *Animals* 12, no. 21: 2984. https://doi.org/10.3390/ani12212984.

Burghardt, G. M. 2013. "Environmental Enrichment and Cognitive Complexity in Reptiles and Amphibians: Concepts, Review and Implications for Captive Populations." *Applied Animal Behaviour Science* 147, no. 3: 286–298. https://doi.org/10.1016/j.applanim.2013.04.013.

Cannon, K., M. Horrocks, T. Wadding, and R. Meek. 2002. "Husbandry of Captive Bearded Dragons (*Pogona vitticeps*); Does Handling Influence Thermoregulation?" *Herpetological Bulletin* 82: 5–9.

Carr, N. 2016. "An Analysis of Zoo Visitors' Favourite and Least Favourite Animals." *Tourism Management Perspectives* 20: 70–76. https://doi.org/10.1016/j.tmp.2016.07.006.

Carr, N., and S. Cohen. 2015. "The Public Face of Zoos: Images of Entertainment, Education and Conservation." *Anthrozoös* 24, no. 2: 175–189. https://doi.org/10.2752/175303711X12998632257620.

Carter, K. C., I. A. T. Keane, L. M. Clifforde, L. J. Rowden, L. Fieschi-Méric, and C. J. Michaels. 2021. "The Effect of Visitors on Zoo Reptile Behaviour During the COVID-19 Pandemic." *Journal of Zoological and Botanical Gardens* 2, no. 4: 664–676. https://doi.org/10.3390/jzbg2040048.

Chamove, A. S., G. R. Hosey, and P. Schaetzel. 1988. "Visitors Excite Primates in Zoos." *Zoo Biology* 7, no. 4: 359–369. https://doi.org/10.1002/zoo.1430070407.

Christensen, C. B., J. Christensen-Dalsgaard, C. Brandt, and P. T. Madsen. 2012. "Hearing With an Atympanic Ear: Good Vibration and Poor Sound-Pressure Detection in the Royal Python, *Python regius*." *Journal of Experimental Biology* 215, no. 2: 331–342. https://doi.org/10.1242/jeb.062539.

Conde, D. A., F. Colchero, M. Gusset, et al. 2013. "Zoos Through the Lens of the IUCN Red List: A Global Metapopulation Approach to Support Conservation Breeding Programs." *PLoS One* 8, no. 12: e80311.

Cook, S., and G. R. Hosey. 1995. "Interaction Sequences Between Chimpanzees and Human Visitors at the Zoo." *Zoo Biology* 14, no. 5: 431–440. https://doi.org/10.1002/zoo.1430140505.

Cooper, J. O., T. E. Heron, and W. L. Heward. 2020. *Applied Behavior Analysis*. Merrill Publishing Company.

Davey, G. 2007. "Visitors' Effects on the Welfare of Animals in the Zoo: A Review." *Journal of Applied Animal Welfare Science* 10, no. 2: 169–183. https://doi.org/10.1080/10888700701313595.

D'Cruze, N., S. Khan, G. Carder, et al. 2019. "A Global Review of Animal-Visitor Interactions in Modern Zoos and Aquariums and Their Implications for Wild Animal Welfare." *Animals* 9, no. 6: 332.

D'Cruze, N., S. Paterson, J. Green, et al. 2020. "Dropping the Ball? The Welfare of Ball Pythons Traded in the EU and North America." *Animals* 10, no. 3: 413. https://doi.org/10.3390/ani10030413.

Edes, A. N., and K. Hall. 2023. "Through the Looking Glass: Effects of Visitors on Primates in Zoos." In *Developments in Primatology: Progress and Prospects*, edited by T. McKinney, S. Waters, and M. A. Rodrigues, 289–306. Springer. https://doi.org/10.1007/978-3-031-11736-716.

Eltorai, A. E. M., and R. W. Sussman. 2010. "The 'Visitor Effect' and Captive Black-Tailed Prairie Dog Behavior." *Der Zoologische Garten* 79, no. 2: 109–120. https://doi.org/10.1016/j.zoolgart.2010.07.002.

European Association of Zoos and Aquaria. 2024 *About Us*. EAZA. https://www.eaza.net/about-us/eaza/.

Fernandez, E. J., and S. J. Chiew. 2021. "Animal-Visitor Interactions: Effects, Experiences, and Welfare." *Animal Behavior and Cognition* 8, no. 4: 462–467. https://doi.org/10.26451/abc.08.04.01.2021.

Fernandez, E., and E. Harvey. 2021. "Enclosure Use as a Measure of Behavioral Welfare in Zoo-Housed African Wild Dogs (*Lycaon pictus*)." *Journal of Zoo and Aquarium Research* 9, no. 2: 88–93. https://doi.org/10.19227/jzar.v9i2.526.

Fernandez, E. J., and S. L. Sherwen. 2024. "An Introduction to Human-Animal Interactions in Zoos and Aquariums." In *Human-Animal Interactions in Zoos*, edited by E. J. Fernandez and S. L. Sherwen, 1–5. CABI Books.

Fernandez, E. J., M. A. Tamborski, S. R. Pickens, and W. Timberlake. 2009. "Animal-Visitor Interactions in the Modern Zoo: Conflicts and Interventions." *Applied Animal Behaviour Science* 120, no. 1: 1–8.

Fernandez, E. J., B. Upchurch, and N. C. Hawkes. 2021. "Public Feeding Interactions as Enrichment for Three Zoo-Housed Elephants." *Animals* 11, no. 6: 1689. https://doi.org/10.3390/ani11061689.

Godinez, A. M., and E. J. Fernandez. 2019. "What Is the Zoo Experience? How Zoos Impact a Visitor's Behaviors, Perceptions, and Conservation Efforts." *Frontiers in Psychology* 10, no. 1: 1746. https://doi.org/10.3389/fpsyg.2019.01746.

Goodenough, A. E., K. McDonald, K. Moody, and C. Wheeler. 2019. "Are 'Visitor Effects' Overestimated? Behaviour in Captive Lemurs Is Mainly Driven by Co-Variation With Time and Weather." *Journal of Zoo and Aquarium Research* 7, no. 2: 59–66. https://doi.org/10.19227/jzar.v7i2.343.

Goulart, V. D., P. G. Azevedo, J. A. van de Schepop, et al. 2009. "GAPs in the Study of Zoo and Wild Animal Welfare." *Zoo Biology* 28, no. 6: 561–573. https://doi.org/10.1002/zoo.20285.

Gray, K. L., J. E. Brereton, and A. Theodorou. 2024. "Does Zoo Visitor Presence and Noise Impact the Behaviour and Enclosure Use of Zoo-Housed Siamese Crocodiles? A Case Study." *Journal of Zoo and Aquarium Research* 12, no. 3: 145–153. https://doi.org/10.19227/jzar.v12i3.778.

Hamilton, J., K. N. Gartland, M. Jones, and G. Fuller. 2022. "Behavioral Assessment of Six Reptile Species During a Temporary Zoo Closure and

Reopening." *Animals* 12, no. 8: 1034. https://doi.org/10.3390/ani12081034.

Hill, S. P., and D. M. Broom. 2009. "Measuring Zoo Animal Welfare: Theory and Practice." *Zoo Biology* 28, no. 6: 531–544. https://doi.org/10.1002/zoo.20276.

Hoehfurtner, T., A. Wilkinson, G. Nagabaskaran, and O. H. P. Burman. 2021. "Does the Provision of Environmental Enrichment Affect the Behaviour and Welfare of Captive Snakes?" *Applied Animal Behaviour Science* 239: 105324. https://doi.org/10.1016/j.applanim.2021.105324.

Hollandt, T., M. Baur, and A.-C. Wöhr. 2021. "Animal-Appropriate Housing of Ball Pythons (*Python regius*)—Behavior-Based Evaluation of Two Types of Housing Systems." *PLoS One* 16, no. 5: e0247082. https://doi.org/10.1371/journal.pone.0247082.

Hosey, G. R. 2000. "Zoo Animals and Their Human Audiences: What Is the Visitor Effect." *Animal Welfare* 9: 343–357.

Hosey, G. R. 2005. "How Does the Zoo Environment Affect the Behaviour of Captive Primates?" *Applied Animal Behaviour Science* 90, no. 2: 107–129. https://doi.org/10.1016/j.applanim.2004.08.015.

Jessop, M., A. Pilny, C. Warwick, and M. Whitehead. 2023. "Evidential Threshoolds for Species Suitability in Captivity." In *Health and Welfare of Captive Reptiles*, edited by C. Warwick, P. C. Arena, and G. Burghardt, 509–534. 2nd ed. Springer.

Learmonth, M. J., S. J. Chiew, A. Godinez, and E. J. Fernandez. 2021. "Animal-Visitor Interactions and the Visitor Experience: Visitor Behaviors, Attitudes, Perceptions, and Learning in the Modern Zoo." *Animal Behavior and Cognition* 8, no. 4: 632–649. https://doi.org/10.26451/abc.08.04.13.2021.

Lincoln Park Zoo. 2022. *ZooMonitor (Version 4.1)*. https://zoomonitor.org.

Manteca, X., M. Amat, M. Salas, and D. Temple. 2016. "Animal-Based Indicators to Assess Welfare in Zoo Animals." *CABI Reviews* 11, no. 10: 1–10.

Melfi, V. A. 2009. "There Are Big Gaps in Our Knowledge, and Thus Approach to Zoo Animal Welfare: A Case for Evidence-Based Zoo Animal Management." *Zoo Biology* 28, no. 6: 574–588. https://doi.org/10.1002/zoo.20288.

Mellor, D. 2013. "Positive Animal Welfare States and Reference Standards for Welfare Assessment." *New Zealand Veterinary Journal* 63, no. 1: 17–23. https://doi.org/10.1080/00480169.2014.926802.

Mitchell, G., F. Herring, S. Obradovich, et al. 1991. "Effects of Visitors and Cage Changes on the Behaviors of Mangabeys." *Zoo Biology* 10, no. 5: 417–423. https://doi.org/10.1002/zoo.1430100505.

Moss, A., and M. Esson. 2010. "Visitor Interest in Zoo Animals and the Implications for Collection Planning and Zoo Education Programmes." *Zoo Biology* 29, no. 6: 715–731. https://doi.org/10.1002/zoo.20316.

Nagabaskaran, G., M. Skinner, and N. Miller. 2022. "Western Hognose Snakes (*Heterodon nasicus*) Prefer Environmental Enrichment." *Animals* 12, no. 23: 3347. https://doi.org/10.3390/ani12233347.

National Health and Medical Research Council. 2021. *Australian Code for the Care and Use of Animals for Scientific Purposes* (8th ed.). Canberra. http://nla.gov.au/nla.obj-2996247165.

Nimon, A. J., and F. R. Dalziel. 1992. "Cross-Species Interaction and Communication: A Study Method Applied to Captive Siamang (*Hylobates syndactylus*) and Long-Billed Corella (*Cacatua tenuirostri*S) Contacts With Humans." *Applied Animal Behaviour Science* 33, no. 2: 261–272. https://doi.org/10.1016/S0168-1591(05)80013-9.

Ogle, B. W., and S. Devlin. 2022. "Public Perceptions of Herpetofauna in Zoos." *Anthrozoös* 35, no. 4: 515–526. https://doi.org/10.1080/08927936.2022.2027094.

Queiroz, M. B., and R. J. Young. 2018. "The Different Physical and Behavioural Characteristics of Zoo Mammals That Influence Their Response to Visitors." *Animals* 8, no. 139: 139. https://doi.org/10.3390/ani8080139.

Riley, A., M. Terry, H. Freeman, A. C. Alba, J. Soltis, and A. Leeds. 2021. "Evaluating the Effect of Visitor Presence on Nile Crocodile (*Crocodylus niloticus*) Behavior." *Journal of Zoological and Botanical Gardens* 2: 115–129.

Rose, P. E., J. E. Brereton, and D. P. Croft. 2018. "Measuring Welfare in Captive Flamingos: Activity Patterns and Exhibit Usage in Zoo-Housed Birds." *Applied Animal Behaviour Science* 205: 115–125. https://doi.org/10.1016/j.applanim.2018.05.015.

Sherwen, S. L., and P. H. Hemsworth. 2019. "The Visitor Effect on Zoo Animals: Implications and Opportunities for Zoo Animal Welfare." *Animals* 9, no. 6: 366. https://doi.org/10.3390/ani9060366.

Skibins, J. C., and R. B. Powell. 2013. "Conservation Caring: Measuring the Influence of Zoo Visitors' Connection to Wildlife on Pro-Conservation Behaviors: Conservation Caring." *Zoo Biology* 32, no. 5: 528–540. https://doi.org/10.1002/zoo.21086.

Spain, M., G. Fuller, and S. Allard. 2020. "Effects of Habitat Modifications on Behavioral Indicators of Welfare for Madagascar Giant Hognose Snakes (*Leioheterodon madagascariensis*)." *Animal Behavior and Cognition* 7, no. 1: 70–81.

Warwick, C. 1990. "Reptilian Ethology in Captivity: Observations of Some Problems and an Evaluation of Their Aetiology." *Applied Animal Behaviour Science* 26, no. 1: 1–13. https://doi.org/10.1016/0168-1591(90)90082-O.

Warwick, C. 2023. "Psychological and Behavioural Principles and Problems." In *Health and Welfare of Captive Reptiles*, edited by C. Warwick, P. C. Arena, and G. M. Burghardt, 239–285. 2nd ed. Springer.

Warwick, C., P. Arena, and C. Steedman. 2019. "Spatial Considerations for Captive Snakes." *Journal of Veterinary Behavior* 30, no. 6: 37–48. https://doi.org/10.1016/j.jveb.2018.12.006.

Warwick, C., P. Arena, S. Lindley, M. Jessop, and C. Steedman. 2013. "Assessing Reptile Welfare Using Behavioural Criteria." *In Practice* 35: 123–131.

Warwick, C., R. Grant, C. Steedman, et al. 2021. "Getting It Straight - Accommodating Rectilinear Behaviour in Captive Snakes - A Review of Recommendations and Their Evidence Base." *Animals* 11: 1459.

Williams, E., V. Hunton, G. Hosey, and S. J. Ward. 2023. "The Impact of Visitors on Non-Primate Species in Zoos: A Quantitative Review." *Animals* 13, no. 7: 1178. https://doi.org/10.3390/ani13071178.

Williams, M. L., L. A. Torrini, E. J. Nolan, and Z. J. Loughman. 2022. "Using Classical and Operant Conditioning to Train a Shifting Behavior in Juvenile False Water Cobras (*Hydrodynastes gigas*)." *Animals* 12, no. 10: 1229. https://doi.org/10.3390/ani12101229.

Zacchi, A., F. Bandoli, P. A. Accorsi, and G. Marliani. 2024. "Enclosure Design and Welfare of Plains Zebras: Impact of Enclosure Design on Behavior and Space Use of Plains Zebras Under Human Care." *Journal of Applied Animal Welfare Science* 27, no. 4: 779–795. https://doi.org/10.1080/10888705.2024.2393132.

Zdenek, C. N., T. Staples, C. Hay, L. N. Bourke, and D. Candusso. 2023. "Sound Garden: How Snakes Respond to Airborne and Groundborne Sounds." *PLoS One* 18, no. 2: e0281285. https://doi.org/10.1371/journal.pone.0281285.

Zoo and Aquarium Association Australasia. 2022. *About the Zoo and Aquarium Association (ZAA)*. Zoo and Aquarium Association Australasia. https://www.zooaquarium.org.au/public/Public/About/About.aspx?hkey=c739b4cc-fd49-4115-a4fd-2437f3d576cd.