Meshing animal behavior and enclosure use analysis using a new tool for zoo researchers

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**Abstract**

Welfare audits that contain behavior and enclosure use assessments are commonly used in zoos and aquaria. However, the two components are often used separately to one another, and many enclosure use studies are limited by problems with unequal zone sizes, despite the fact that enclosure use indices such as Entropy, Spread of Participation Index (SPI) and Electivity Index are available. The dawning of behavior monitoring apps has led to additional challenges, as these apps are not always developed for space use analysis. There is a need, therefore, to make enclosure use indices compatible with modern behavior recording apps, and to provide ways in which behavior and space use can be analysed together. This paper introduces a new ShinyApp, entitled the Enclosure MonitoR Use (EMU). This new tool uses ZooMonitor-based behavior and XY enclosure use data to evaluate animal data. The tool is able to 1) provide heat maps of space use, showing where each behavior occurs, and 2) facilitate the use of enclosure use indices, whilst also generating indices for individual behaviors. These tools have the potential to identify areas that an animal finds valuable in its exhibit for specific behavior types and can be used to inform exhibit design decisions. EMU also allows researchers to look beyond the previous assumptions that an animal should use all its exhibit in order to experience the best welfare. In combination with ZooMonitor, this tool removes many obstacles that prevent detailed analysis of animal space use. Future developments of EMU may further facilitate animal space use studies.

**Keywords:** analysis,behavioral observations, Entropy, Electivity Index, exhibit,space use, Spread of Participation Index, ZooMonitor

**Running title:** *EMU, a new enclosure use analysis tool*

1. **Introduction**

Enclosure use studies play an important role in the assessment of zoo and aquarium exhibit design (Fernandez et al., 2023; Goh et al., 2017; Maple & Finlay, 1987). When used in combination with animal behavior, the methods can identify not only what an animal does with its time, but also what it finds valuable in its exhibit (Breton & Barrot, 2014). Analysis of enclosure use reveals more than behavioral research alone. Enclosure use analysis may reveal subtle visitor effects: for example, when animals do not change their behavior when high numbers of visitors are present, but distance themselves from viewing areas (Brereton et al., 2023; Learmonth et al., 2018). When used in conjunction, behavior and enclosure use assessments are synergistic. However, the two measures are often siloed, and are rarely combined together effectively (e.g. to see what an animal does in each enclosure zone). Clearly, there is potential benefits for combining these tools.

1. **Challenges in zoo animal enclosure use studies**

Enclosure use has featured in the zoo biology literature since at least the 1960’s (Hediger, 1964), though limited formal assessment was conducted until the 1980’s (Hedeen, 1983). One of the central premises of enclosure use analysis is that enclosures are divided into areas labelled ‘zones’, and the amount of time that an animal spends in each respective zone is quantified (de Azevedo et al., 2023). These zones could reflect biologically different areas (such as sand, rocks and water) or proximity to a feature of interest, such as public viewing areas (Goh et al., 2017). Early studies tended to break into equal-sized zones, such as quarters (Hedeen, 1983), which limited the ability of researchers to focus on biological structures.

Taken in their raw form or as percentage occupancy, enclosure use data may be misleading. For example, one might intuitively suggest that an animal is avoiding a specific zone if it spends 10% of its time in that area. However, if the zone occupies only 1% of all exhibit space, the animal is spending more time than would be expected in this area. To counter this challenge, indices such as the modified Spread of Participation Index (SPI) (Plowman, 2003) were developed, enabling quantification of evenness of space use for an entire enclosure. Here, researchers could identify improvements in animal space use and potentially welfare by quantifying how evenly an animal used its exhibit (Clark & Melfi, 2012; Mallapur et al., 2005).

Several enclosure use indices have been developed, including Entropy, traditional and modified SPI (Brereton & Fernandez, 2022; Fernandez & Harvey, 2021; Fernandez & Timberlake, 2019). These tools focus on evenness of space use from an entire exhibit perspective. As a result, it can be more challenging to identify which aspects of an exhibit an animal finds valuable. One tool, Electivity Index, assesses space use on a zone-by-zone basis (Goh et al., 2017; Ross et al., 2009; Vanderploeg & Scavia, 1979). This can provide a more informative estimate as to whether an area is being under- or over-utilized based on its proportional size. A new tool, the Zone Overlap Index, quantifies the overlap in space use between two animals, but ignores areas not used by either animal (Pianka, 1973; Brereton & Rose, 2023). As for the previously mentioned indices, this tool takes into account zone size: the index places a higher weighting when animals share small zones that they would be unlikely to occupy purely by chance.

While enclosure use indices add robustness to a project, they are not always used in enclosure use research. For example, a review of enclosure use literature identified that 56.45% (35/62) of papers did not use any index, but instead reported raw data or percentage zone occupancy (Brereton, 2020). This means that differences in zone size were not accounted for, thus limiting the value of the outputs. If zone size is not considered, then animals may be using the space purely because it takes up most of the exhibit. It is not known why these studies did not use any indices, but the technicalities of calculating values could be off-putting for some.

New apps, such as ZooMonitor (Snyder & Barrett, 2023; Wark et al., 2019; Wark et al., 2020, 2022), are intuitive and improve the accessibility of behavior and space use observations. These tools allow researchers to upload enclosure maps and then facilitate observation of exact animal location in the exhibit (Wark, 2022). As such, many zoo researchers now use the app for their behavior recording (Cairo-Evans et al., 2022). While excellent for behavioral studies, the app was not developed for in-depth enclosure use analysis, but rather generates heat maps. While heat maps are visually appealing, they do not lend themselves to formal analysis. This can lead enclosure use studies into a dead end in terms of statistical analysis, which is important when comparing conditions (such as pre- and post-enrichment, or following social group changes, van dert Marel, 2022).

One of the assumptions built into all enclosure use indices is that animals should use all parts of their exhibit evenly (Plowman, 2003; Ross et al., 2009). In reality, this assumption is biologically inappropriate for many taxa, such as reptiles, which spend long periods in specific areas for thermoregulatory or prey capture purposes (Warwick et al., 2013). There is a need, therefore, for new enclosure use measures that can consider the complex interplay of variables (such as visitor proximity, temperature and substrate) and their effects of animal space use. There is also a need for analysis methods that acknowledge that animals may use different areas of their exhibits for different purposes. For example, animals may use areas for courtship or nesting only rarely, but access to these resources is highly important.

There is also a need for tools that are compatible with modern behavior recording apps, such as ZooMonitor. The incorporation of multiple predictive variables into enclosure use analysis is possible, but it involves moving away from the traditional zone premise. The purpose of this paper is to demonstrate a novel enclosure use technique that can combine behavior and enclosure use analysis and uses predictive modelling to identify what an animal prefers within its exhibit.

1. **The solution: meshing enclosure use and behavior analysis**

In order to facilitate analysis of zoo enclosure use data, we built a ShinyApp, entitled the Enclosure MonitoR Use (EMU, accessible at <https://jonotuke.shinyapps.io/monitoR/>). The app was developed using several behavior and enclosure use Excel™ files which had been developed using ZooMonitor. The ShinyApp was developed to process enclosure use data in the form of XY coordinates, as are the common output of apps such as ZooMonitor. The app is able to process the Excel™ outputs from ZooMonitor and converts them into an interactive enclosure use interface. Here, an enclosure map can be uploaded, onto which a heat map of enclosure occupancy will be overlaid. This app also allows inputting of extra variables, such as animal behavior and zones. The purpose of the app is:

1. To visualize enclosure use data at a behavioral level
2. To facilitate use of enclosure use indices

The purpose of this paper is to demonstrate the application of EMU for behavior and space use studies. To achieve this, an existing ZooMonitor dataset, which had investigated the behavior and space use of a group of Gidgee skinks (*Egernia striolata),* was used. The data were used simply to showcase the functionality of EMU.

* 1. ***Combining behavior and enclosure use***

The EMU ShinyApp was developed to recognize enclosure use data in a XY form, and automatically identifies corresponding behaviors. The app was developed with ZooMonitor outputs in mind, though other data, if formatted into XY coordinates, could also be uploaded. Once uploaded, the program automatically places the enclosure use data onto a grid. If behavioral data are provided, then enclosure use observations of different behavior types appear as different colors (Figure 1).

A screenshot of a grid with blue and orange dots

Description automatically generated

Figure 1. An example of animal enclosure use output from the EMU ShinyApp. Here, different behaviors appear as different colors. This image shows where individual behaviors are most likely to occur.

From a visualization standpoint, the segregation of space use by behavior type is a breakthrough. Generally, behavioral research considers space use as a separate study component to behavior analysis (Blowers et al., 2012). Using this new method, enclosure areas that are important for specific behaviors can be rapidly identified. For example, the mapping process may rapidly identify locations where aggressive behaviors regularly occur. In turn, this knowledge could be used to make informed decisions on enclosure design.

* 1. ***Enclosure use indices***

While enclosure use indices remove many of the methodological issues in enclosure use research, and allow more objective analysis of space use, they remain rarely used in the literature (Hart et al., 2022). The omission of these indices can lead to erroneous conclusions drawn about space use, especially when zone sizes are of unequal size. It is important, therefore, that these indices are made more accessible to a wider research audience.

To facilitate objective enclosure use analysis, EMU has built-in functions to automatically analyze three common enclosure use indices; Entropy, modified SPI and Electivity Index. Furthermore, EMU allows the user to customize their analysis by increasing or decreasing the number of enclosure zones (Figure 2 and 3), and to generate enclosure use indices for each individual behavior (Figure 4). To the authors’ knowledge, this is the first time that enclosure use indices have been run on specific behaviors. This novel analysis method has several benefits. For example, use of SPI allows rapid evaluation as to which behaviors occur most evenly throughout an exhibit (Figure 5). Use of Electivity Index allows for identification of key, over-utilized resources that enable animals to engage in important behaviors (Figure 6).

A grid with a grid with a couple of dots

Description automatically generated with medium confidence

Figure 2. Two enclosure use maps, with an overlay grid of either A) 2x2 or B) 10x10. The number of grid points is adjustable, up to a maximum of a 10x10 grid (100 grid points). The use of a smaller or larger grid system can be used to alter the number of zones for enclosure use analysis.

A screenshot of a computer generated image

Description automatically generated

Figure 3. An enclosure use map, with a 6x6 grid, and 5 different ‘zones’ (as shown by the different shaded colors). EMU allows the user to self-select specific zones in an enclosure, up to a maximum of five different zones. These zones feed into all enclosure use analysis, such as Entropy, SPI and Electivity Index.

A graph with different colored bars

Description automatically generated with medium confidence

Figure 4. EMU outputs for A) Entropy at base 10, and B) Modified SPI. These values demonstrate that the evenness of space use for specific behaviors (for Entropy, values closer to 0 indicate even space use and for modified SPI, values vary between 0 and 1, with 1 demonstrating uneven space use).

A graph of a bar chart

Description automatically generated with medium confidence

Figure 5. EMU outputs for Electivity Index. Here. The index shows which zones are underutilized and overutilized (minimum and maximum values of -1 and 1 respectively) and can also break these values down by behavior. This allows researchers to identify zones that are overutilized for a specific purpose, such as courtship or rumination.

Historically, one of the main assumptions of enclosure use analysis was that animals should use their entire enclosure evenly. This premise is central to the calculation of Entropy, both SPI forms, and to a lesser extent, Electivity Index. This assumption is largely reflective of historic views that animals with good welfare are active and use the space that they are provided with; this is not reflective of many taxa, however. Reptiles, for example, are inactive for long periods, both in the wild and in captivity: high activity may conversely be a sign of inappropriate husbandry (Burghardt, 2013). It is important therefore that future enclosure use analysis tools can consider the importance of environmental resources whilst avoiding the trap of assuming that even space use is best.

The EMU app allows for enclosure use to be assessed in a more holistic manner, and the comparison of enclosure use indices for each behavior is particularly novel (Figure 6). These methods allow a researcher to identify which behaviors are likely to occur across much of an exhibit, versus those that only occur in a couple of select locations (Figure 7). This can aid in highlighting locations that are of special importance for behaviors such as displaying, breeding, or conversely, locations in which fights are most likely to occur.

A graph with different colored bars

Description automatically generated

Figure 6. An example of SPI outputs on a behavior-by-behavior basis. This shows which behaviors are spread most evenly around an animal’s enclosure, and which are most likely to occur in only one specific location.

A graph with different colored bars

Description automatically generated

Figure 7. Output of Electivity Index for an exhibit with three zones. Here, Electivity Index values are generated for each individual behavior.

1. **EMU: future applications**

EMU allows for several novel applications of space use, and further functionality may be added in future, with additional tools. Future tools for the app could include:

* Individual animal comparisons. There is sometimes a need to compare space use between individuals in a shared enclosure, especially aggression affects space use between individuals. Future iterations of the EMU app should allow comparison of individual animals in terms of both their behavior and space use.
* Behavioral diversity measures. Measures such as the Shannon Index have found their application in behavioral studies (Miller et al., 2020) There is the potential for future iterations of EMU to also allow behavioral diversity measures to be used in conjunction with zone use.
* Predictive modelling. The EMU app could be further developed to include predictive modelling, to determine what resources are of greatest value to animal enclosure inhabitants. Here, variables such as the proximity of a grid point to visitors, substrate type, or distance from important resources such as heat lamps can be inputted into the app. The inputting of these variables allows biologically meaningful questions to be posed, such as the impact of the ‘visitor effect’ on space use and behavior. These variables are inputted into predictive modelling that can quantify the impact of visitor viewing area proximity on animal location The ability of the app to take into account multiple variables simultaneously reduces the chance of erroneous conclusions being drawn, as has previously been demonstrated in the visitor effect literature (Goodenough et al., 2019; Rose et al., 2020).

1. **Conclusion**

Enclosure use analysis has historically suffered from somewhat technical indices that are not always easily used, and a tendency for enclosure use and behavioral data to be siloed from one another, even when both data types are collected simultaneously. The premise that animals should use their space evenly, which is built into enclosure use indices, has also limited evaluation of results. The development of the Enclosure MonitoR Use app facilitates future studies by reducing the challenges associated with generating enclosure use indices whilst also allowing space use to be analysed at the level of individual behavior types. The app also allows researchers to pose meaningful questions on where animals engage with specific behaviors, whilst also generating enclosure use indices, for the first time at the level of individual behaviors. It is hoped that this tool will encourage novel research questions on zoo animal behavior and enclosure use.

1. **Conflict of interest**

The author declare no conflict of interest.

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