The Zone Overlap Index: a new measure of shared resource use in the zoo

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Abstract

It is important that the environment provided in the zoo is relevant to the species being housed and its suitability be easily assessed by personnel. As shared space and resources can overlap in a zoo's enclosure a tool is required to measure the effects of such overlap between individual animals in a shared enclosure. This paper outlines the Pianka Index (PI), a tool used in ecology to quantify niche overlap, that has value in quantifying the amount of time that animals spend in shared enclosure zones. One limitation to this method, however, is that the established method of determining the PI requires division of the enclosure into equally sized zones, something that is not always relevant to a zoo enclosure. To combat this, we created a modified index, entitled the Zone Overlap Index (ZOI). This modified index is the exact mathematical equivalent of the original index when zone sizes are equal. When zone sizes are unequal, the ZOI generates higher values when animals share smaller, as opposed to larger, zones. This is because animals are more likely to share larger enclosure zones simply by chance, and shared use of smaller zones brings individuals into closer proximity with the potential for

competition. To illustrate the application of the ZOI, a series of hypothetical situations were generated to reflect real-world scenarios, demonstrating how this index could be used to better understand zone occupancy overlap in the zoo.

Keywords: compatibility, enclosure design, mixed-species enclosure, Pianka Niche Overlap Index, proximity

Research highlights:

1. *The Pianka Index can be used to quantify space use overlap in exhibits with equal-sized zones.*
2. *The Zone Overlap Index quantifies space use overlap in exhibits with unequal-sized zones.*
3. *The Zone Overlap Index places higher weightings on small zones which animals are unlikely to shareby chance.*

Introduction

The managed environment of the zoo, with its finite space, often results in increased density and social housing for animals (Mason, 2010). This can often present challenges for animal management (Clubb & Mason, 2007; Kroshko et al., 2016). Inappropriate combinations of individuals could result in extreme competition with welfare impacts (Mason, 2010). As such, it is important that animal care staff can assess animal compatibility to reduce the risk of future welfare problems. Although a species' wild social behavior may appear to be a good predictor of their suitability for multi-animal enclosures, research has demonstrated that the creation of mixed-species display is not so clear cut. Some solitary species can be housed in pairs or groups with no identified welfare impact (Macri & Patterson-Kane, 2011), whereas social species regularly pose compatibility challenges in captivity (Hosey et al., 2016). At maturity, species often naturally disperse away from natal groups, but the zoo's finite captive environment hampers these attempts (Price & Stoinski, 2007l; Morgan & Tromborg, 2007). A clear understanding of animal compatibility and space use is therefore useful for practitioners to promote animal welfare, ensure appropriate animal management and evidence the ecological relevance of enclosure sizes.

In the wild, aggression is often triggered by competition over valued and/or limited resources (Tran et al., 2014) such as food or access to potential mates (Stamps, 1977). In the wild, individuals that fit a similar demographic (e.g. similar body size or same sex) (Ward et al., 2006), or species that share similar ecological niches (Tran et al., 2014) are more likely to compete, and this may also stand true in the zoo. Knowledge of the perceived value of an area or resource within an enclosure could be used to reduce competition in captive animals. Understanding how sympatric species avoid competition, and selection of these species for mixed species exhibits, may be appropriate but any usage of shared resources still needs to be measured and interpreted.

Valid identification of how and where zoo-housed animals overlap in their space use may be of use to the further development of species-appropriate housing and husbandry. Any valued resources, that are finite in nature, could become the focal point for competition or aggression between the occupants of an enclosure. By highlighting resources that encourage animals to congregate, the distribution and pattern of such valued resources within an enclosure can be evidenced to promote species-typical behavior. There are already a range of tools available to aid researchers in the field of animal space use and welfare (Macri & Patterson-Kane, 2011), and the use of several tools in combination can help to unpick a complex scenario. Behavioral measures and enclosure use analysis are particularly synergistic as they can identify both where and how an animal uses its space (Ross & Lukas, 2008). However, there are currently no tools available that quantify any overlap in space use between individual animals.

To aid ecologists in quantifying niche overlap in free-living populations, the Pianka (1973) Niche Overlap Index was developed. Traditionally, this index is used to quantify the dietary overlap between two sympatric species. These Pianka Index (PI) values are useful in that they provide a numerical value for the dietary competition between two animal species (Glen & Dickman, 2008). The Pianka Index assumes that individuals/species with similar diets are likely to compete over ecological niche. This index could be useful if adapted to a new role in the zoo due to its abilities in assessing usage of shared resources, something common to practically all zoo enclosures. Here, the assumption is that animals that spend long periods of time in shared zones are more likely to compete over resources.

Consequently, this paper describes the evolution of the PI to enable quantification of enclosure zone overlap in a zoo or aquarium (hereafter "zoo") context. Literature relating to Pianka's (1973) Niche Overlap Index was consulted and then a modified version, the Zone Overlap Index (ZOI), was tested on simulated data to assess its practical application.

Methods

Pianka's index

The equation for Pianka's Niche Overlap Index is:

$$O_{jk} = \left(\frac{\sum P_{ij}\, P_{ik}}{\sum {P_{ij}}^{2} \sum {P_{ik}}^{2}}\right)^{1/2}$$

Traditionally, P_i is the frequency of occurrence of prey item *i* in the diet of species *j* and *k* (Pianka, 1973). The values generated vary between 0 (no overlap) and 1 (total overlap). For the purposes of animal space use research, P^i represents the use of enclosure zone *i* by animals *j* and *k*. Here, animals *j* and *k* can be animals from two different species, or two individuals of the same species that share an exhibit. The equation assumes that all zones are of equal size. In practice, this is rarely the case, so there was a need to develop an index that could factor in unequal zone sizes.

Developing the Zone Overlap Index

A new index, entitled the ZOI, was developed using by adapting the PI. The equation for the index is:

$$ZO_{jk} = \left(\frac{\sum Zi(P_{ij}\ P_{ik})}{\sum ZiP_{ij}{}^{2}\ \sum ZiP_{ik}{}^{2}}\right)^{1/2}$$

In this index, P^i is the amount of time that animals *j* and *k* spend in zone *i* in a given study period.

Zi represents the total enclosure size (e.g. m^2, cm^3), divided by the size of zone *i*.

As per the PI, this index generates a value between 0 (total separation) and 1 (total overlap) for animals *j* and *k*. When all zones are of equal size, the PI and the ZOI produce identical values. The more time that animals *j* and *k* spend in shared zones, the higher the generated values. However, when zones are unequal in size, the two indices differ. The more time that animals *j* and *k* spend in shared, smaller zones, the higher the index values become in contrast to results generated by the PI in the same situation. Simulation data were developed and expressed graphically to illustrate the workings of both Indices under different conditions (Supplementary material for Excel file).

Scenario 1

A highly simplified enclosure was generated that consisted of only two zones: Zone A and Zone B. Two animals: Alpha and Beta, occupied this enclosure. Alpha and Beta were observed simultaneously for sixty sets of one-hour observation periods, using instantaneous focal sampling at one-minute intervals. For each observation, 60 data points were generated per animal per hour. Regardless of the observation, Beta always stayed in zone A. Alpha, by contrast, spent 60 minutes in zone A in the first observation. For the second observation, Alpha spent 59 minutes in zone A, and one minute in zone B. For the third hour, Alpha spent 58 minutes in zone A and 2 minutes in zone B. This pattern is repeated until Alpha spent only 1 minute in zone A, and 59 minutes in zone B. Both PI and ZOI were applied to these data generated.

Scenario 2

The zone sizes for the basic, two-zone exhibit introduced in scenario 1 were altered to demonstrate the effect of unequal zones on ZOI values. Three sets of zone sizes were used. For the first simulation, the two zones were equal in size ($50m^2$ for each zone). For the second and third simulations, zone A was made larger ($90m^2$) or smaller ($10m^2$) than zone B ($10m^2$ or $90m^2$). The animal space use patterns were identical to those described in Scenario 1.

Scenario 3

A more complex situation, in which three animals (Alpha, Beta and Omega) shared an enclosure that contained four zones (zones A to D). As per the first two scenarios, all three animals were observed for one-hour sessions, during which instantaneous focal samples of location are taken every minute. This resulted in 60 data points per animal per hour.

In this scenario, Beta stayed in zone A for the entirety of all observations. For the first observation, Alpha and Omega were also observed for all 60 minutes in this zone. However, over the course of the study, both Alpha and Omega slowly dispersed to new zones (in the second hour, Alpha spent 59 minutes in zone A and 1 minute in zone C, whereas Omega spent 59 minutes in zone A and 1 minute in zone B). This pattern continued for 60 hours, up until the point that Omega and Alpha spend only one minute in zone A, and the remaining 59 minutes in zone B and C, respectively.

Initially, all zone sizes were set to be equal for this scenario. For example, all zone sizes were 25m^2. PI values were generated between all animal pairs.

To demonstrate the effect of unequal zone size on index values, the four zone sizes were then altered for a second simulation. This time, zone A was set to 30m^2, zone B to 60m^2, zone C to 5m^{2,} and zone D to 5m^2. The simulation was rerun, using the ZOI for all three pairwise comparisons (Beta-Alpha, Beta-Omega and Omega-Alpha).

Results

Scenario 1

Simulations were developed for a simple, two-zone enclosure, to compare the values generated by PI and ZOI for two animals, Alpha and Beta. When both animals spent all their time in zone A, both the PI and ZOI value were 1. As Alpha spent progressively more time in zone B, PI and ZOI values dropped. PI and ZOI values were identical to one another (Table 1).

Table 1. PI and ZOI values generated from a simulated two-zone exhibit. The table is abridged to show every tenth hour.

Number of minutes spent by Alpha in zone A	PI	ZOI
60	1.000	1.000
50	0.981	0.981
40	0.894	0.894
30	0.707	0.707
20	0.447	0.447
10	0.196	0.196

Scenario 2

In this scenario, Beta always occupied zone A for the full hour, but Alpha spent progressively less time in this zone. In all scenarios, ZOI values dropped as the two animals spent less time in the same zone. However, the drop was much steeper for the simulation where zone A was larger in size (90m^2). By contrast, ZOI values remained high for longer in the simulation where zone A was smaller (10m^2) (Figure 1).

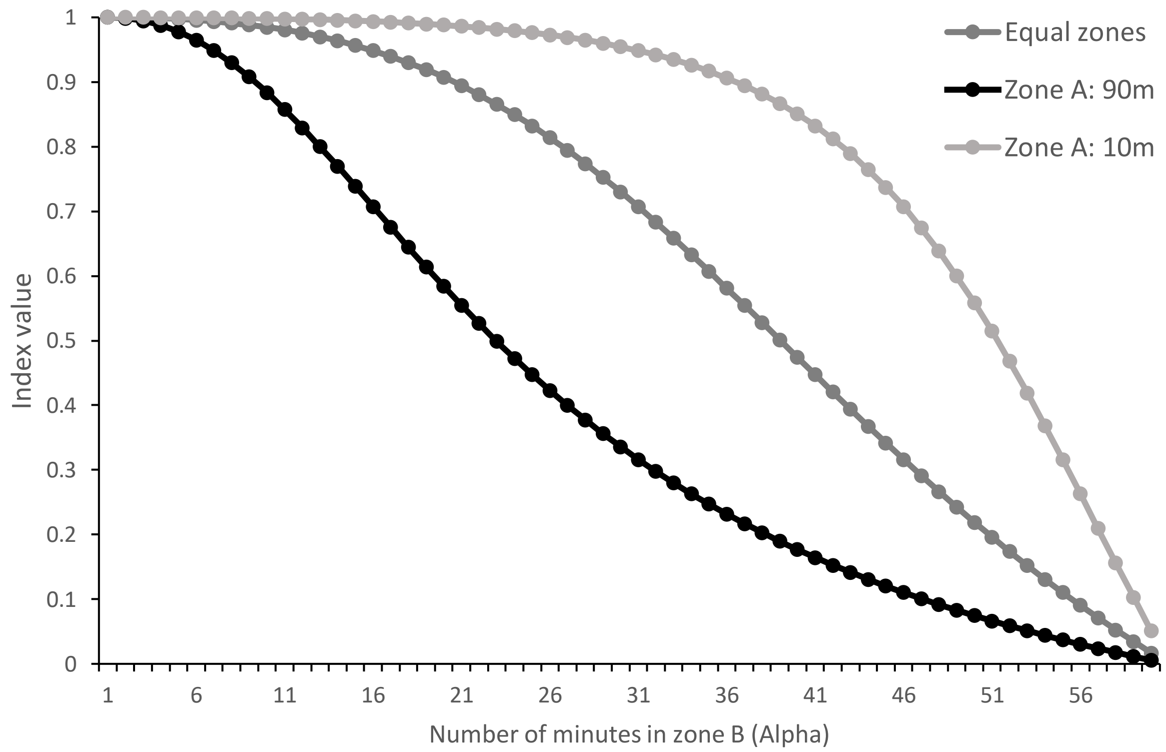

Figure 1. Effect of unequal zone size on ZOI. The grey line shows the index values when both zones are of equal size, and the black and light grey line demonstrate ZOI values when zone A is set to be larger (90m^2) or smaller (10m^2).

Scenario 3

For this scenario, three animals (Alpha, Beta and Omega) spent time in a four-zone enclosure. Beta spent the entire study period in zone A, whereas Alpha and Omega transition from spending all their time in zone A, to spending their time in zone C and B, respectively. Simulations were generated for this scenario when all zones are of equal size (Figure 2), and when zones were of unequal size (Figure 3). The PI was used for the equal-size zone simulation, and ZOI was used for the unequal-size zone simulation. The values for Beta-Omega stayed higher for longer than the values for Beta-Alpha.

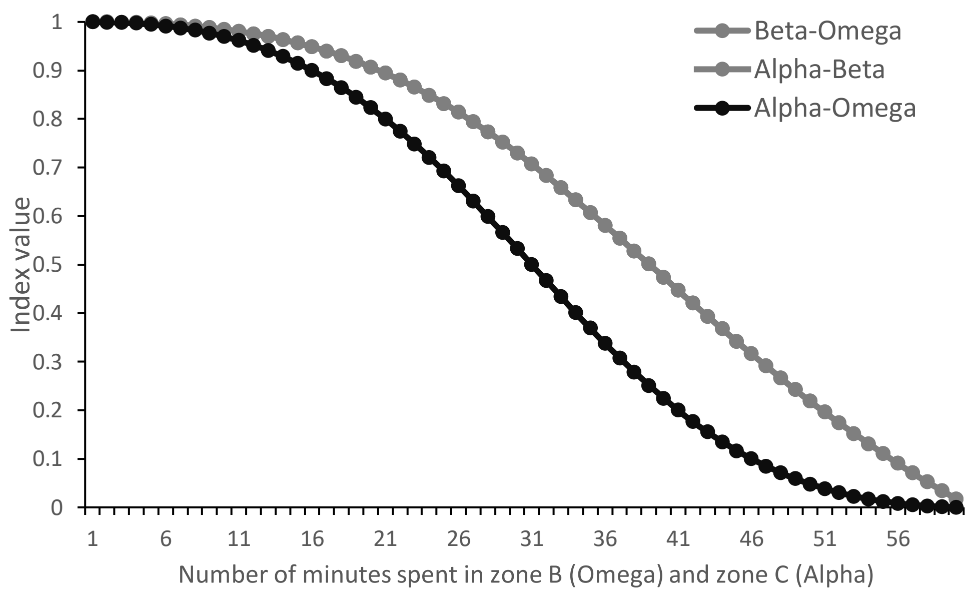

Figure 2. PI values for a simulated four-zone enclosure containing three animals. Here, two animals (Omega and Alpha) spend progressively less time in zone A (shared with Beta) as the study progresses. The lines show the PI values for Beta-Omega, Beta-Alpha, and Alpha-Omega combinations. The Beta-Omega line is invisible because it is hidden behind the Alpha-Beta line, which it is identical to.

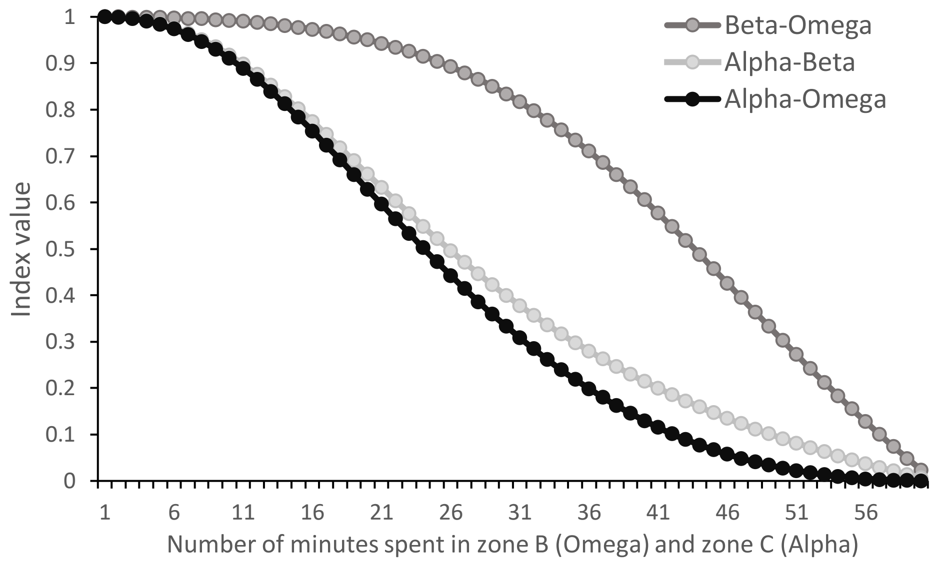

Figure 3. ZOI values for a simulated unequal-sized four-zone enclosure containing three animals. Here, two animals (Omega and Alpha) spend progressively less time in zone A (shared with Beta) as the study progresses. The lines show the ZOI values for Beta-Omega, Beta-Alpha, and Alpha-Omega combinations.

Discussion

The PI and ZOI were used to quantify enclosure zone overlap in a range of simulated scenarios. First, the results demonstrated that PI and ZOI generate identical values when applied to an enclosure containing equally sized zones. Second, the ZOI generated values closer to 1 when animals spent time together in smaller zones, and slightly lower values when animals spent time together in the larger zones (e.g. Table 3). The reason for this is that animals spending time together in smaller areas is less likely to arise by chance than animals spending time in larger enclosure areas. The PI is therefore valuable for use in exhibits which can be clearly delineated into equal-sized zones, whereas the ZOI has merit when assessing exhibits with unequal-sized areas.

The PI and ZOI fit a new niche in assessing space overlap (Vieira & Port, 2007), and these methods could be applied to compare different individuals from the same species, in a shared enclosure. While there are several existing methods of assessing enclosure use, such as Spread of Participation Index

(Plowman, 2003), Electivity Index (Vanderploeg and Scavia, 1979) and Entropy, these methods do not directly compare how individual animals use space. Of the four indices, three assess enclosure use holistically, providing only a single value of evenness of space use. The ZOI therefore is much more appropriate for direct comparisons of zone overlap between animals, as it generates pairwise comparisons which can be quantified between group members.

While PI and ZOI incorporate some enclosure use theory, they are not traditional measures of enclosure use. Unlike existing indices, the PI and ZOI do not automatically assume that animals should be using all areas. In fact, a value of 1 (total overlap) can be generated even if animals are using a single zone (e.g. Figure 2). For both indices, this maximum value is generated only when the two animals are using the same zones in the same proportion to one another. Similarly, a value of 0 (no overlap) can be generated for animals provided they never use the same zones. This is useful because it demonstrates that the indices are not sensitive to variation in the size of unused zones.

Unlike PI, the ZOI weights zones based on their respective size. This weighting is inverted, so that proportionally smaller enclosure spaces are weighted more heavily. Animals are less likely to spend time together in small enclosure spaces due to chance (Matthiopoulos, 2003; Smith et al., 2021). Smaller spaces that are being shared are therefore more likely to contain highly valued resources, thus increasing the chances of competition.

While the PI and ZOI share some similarities with measures of animal sociality and social networks, they fit a different role. Social networks are built on proximity or interaction-information between animals (Wey et al., 2008), neither of which are factored into these indices. The ZOI may generate high values for animals that associate together because they spend time in the same zones. However, the indices will also generate high values for animals that regularly compete for shared, valued exhibits resources. The index therefore generates a measure of overlap, rather than an index of association or competition.

Future applications

Given their versatility, there are many scenarios in which the PI and new ZOI could be used to investigate. Three examples of practical application are as follows:

1. Mixed species enclosures. The ZOI could be applied to existing mixed-species enclosures to quantify the level of overlap between species. Where several species are maintained in the same enclosure, pairwise comparisons could be made to determine which species overlap most in space use. It is theorized that animals that share a similar ecological niche will use similar resources and zones, resulting in higher competition and therefore higher ZOI values. Future studies, using the Zone Overlap Index in combination with behavioral measures (e.g. of aggression) would have value in testing this, especially in scenarios where compatibility may be challenging, such as canids and ursids (Dorman & Bourne, 2010).

2. Compatibility in single species exhibits. Management of endangered species normally sees animals paired for breeding via studbook recommendations that incorporate genetic and demographic information (Ayala-Burbano et al., 2020). However, animals within a pair may not be behaviorally compatible, resulting either in aggression or avoidance (Kozlowski et al., 2015). When used with other measures, such as behavioral observation, the ZOI can quantify use of shared enclosure areas (and this may be indicative of affiliation between individuals in a breeding pair) or for identification of animals that are beginning to split from an existing social group (Hosey et al., 2016), and therefore are ready for movement to a new facility.

3. Introductions. Introductions of new animals into established groups can be risky, and competition may cause injury (Berg et al., 2019). As the ZOI defined the degree of overlap in space use (and therefore potential for competition between individual animals) it has an application in assessing where conflict may appear. The ZOI could also aid in identification of potential aggression flashpoints at small but valuable resources.

Conclusion

The new ZOI can assess space overlap in co-habiting zoo animals. Several scenarios have been demonstrated to support its usage as a tool to assist in zoo management. The index represents an opportunity to quantify and compare overlapping space use between animals. This identification of valuable resources helps practitioners make informed decisions on enclosure development to ensure resource availability is appropriate for all species being housed.

Conflict of Interest

The authors declare no conflict of interest.

Ethical statement

No ethical approval was required as the work is a theoretical paper.

Data Sharing and Data Accessibility

The simulated data generated for this project are available from the authors upon reasonable request. Additionally, a Pianka Index and Zone Overlap Index generator spreadsheet is available as a supplementary file.

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