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The use of biofloors in great ape zoo exhibits

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Abstract

The past several decades have seen significant progress in zoo exhibit design, with naturalistic spaces replacing many of the traditional concrete enclosures. Furthermore, research studying the impact of such exhibit design in terms of animal welfare and zoo visitor experience has increased. While this has been especially true for studies of zoo-housed great apes, the effect of the floor type that apes reside on—whether concrete or a softer/organic substrate—has received relatively little attention. To better understand zoos' motivations for, and experiences with, different flooring substrates, a survey was administered to all 89 zoos accredited by the Association of Zoos and Aquariums that house great apes. Here, the results of the survey are presented and interpreted in the context of the knowledge gained from the four biofloor exhibits housing chimpanzees and gorillas at the Lincoln Park Zoo in Chicago, USA. Of the 62 zoos that responded, 45 reported having indoor exhibit spaces in which visitors could view great apes, but only 13 had exhibits that provide a biofloor as the exhibit substrate. Zoos indicated that animal welfare was a key motivator for installing biofloors, while facility constraints were most often cited as the primary impediment to having a biofloor. Pest control and cleaning protocols only varied slightly across institutions and floor types, with many zoos following similar maintenance procedures. Overall, survey responses and experiences at Lincoln Park Zoo suggest biofloors promote positive welfare without compromising husbandry efforts and are a worthwhile investment.

Introduction

Husbandry practices are constantly evolving and being refined at zoological parks, sanctuaries and laboratories housing non-human primates (hereafter primates). At zoos, exhibit design has moved beyond the 'hygiene' model of old that prioritised cleaning, feeding and viewing animals to more naturalistic designs that also emphasise the animals' needs while promoting public awareness of wildlife conservation (Coe and Dykstra 2010). Given both the intelligence and activity levels of primates, much of the research that has been conducted to date has evaluated the efficacy of great ape exhibits in promoting species-typical behaviours and welfare (e.g., Maple and Finlay 1986, 1987; Ogden et al. 1990; Hoff and Maple 1995; Stoinski et al. 2002; Ross et al. 2009, 2011; Earl et al. 2020). While considerable research has explored the effects of various components of great ape exhibits, the substrate on which the animals sit, stand, walk and sleep has received far less empirical attention.

Moving beyond simply providing supplemental bedding materials such as hay or wood wool (also known as excelsior) on top of a concrete floor, biofloors provide a more expansive and permanent naturalistic substrate for indoor enclosures made up of a deep layer of natural materials such as bark chips or shredded wood. For the purposes of this study, a biofloor is defined according to several practical considerations that distinguish them from primarily hardscape floors: 50% of the indoor floor surface area contains a natural substrate (or deep litter) that is at least 15 cm in depth and this substrate remains in place (excluding routine maintenance) for at least six months.

Although the term biofloor is used here, other facilities use terms such as mulch, woodchip or deep-litter bedding (Chamove et al. 1982; Ludes and Anderson 1996; Morrison et al. 2003; Fuller et al. 2010), particularly with laboratory-housed animals where bedding materials may be regularly rotated as opposed to permanent fixtures of enclosures (Janavaris et al. 2019).

Provisioning a biofloor in primate enclosures has been suggested to have positive impacts on primate welfare and behaviour, resulting in activity budgets that more accurately reflect their wild counterparts (Ludes and Anderson 1996; Blois-Heulin and Jubin 2004; Beisner and Isbell 2008). Moreover, most studies have found that the addition of a biofloor promotes naturalistic, species-typical behaviours while reducing abnormal behaviours in several primate species housed in both zoos and laboratories (*Pan troglodytes*, Clarke et al. 1982; Brent 1992; Baker 1997; Ross et al. 2009, 2011; *Gorilla gorilla gorilla*, Ross et al. 2009, 2011; *Macaca* spp., Chamove and Anderson 1979; Chamove et al. 1982; Bayne et al. 1992; Boccia and Hijazi 1998; Beisner and Isbell 2008; Doane et al. 2013; but see Byrne and Suomi 1991; *Cebus* spp., Chamove et al. 1982; Westergaard and Fragaszy 1985; Ludes and Anderson 1996; Jacobsen et al. 2010; *Cercocebus torquatus*, Blois-Heulin and Jubin 2004; *Cercopithecus* spp., Chamove et al. 1982; Fuller et al. 2010; *Lemur catta, Saimiri sciureus, Saguinus labiatus* and *Callithrix jacchus*, Chamove et al. 1982). For example, primates provided with a manipulatable substrate can use the material for nesting and play, thus promoting typical behavioural repertoires (Chamove and Anderson 1979; Chamove et al. 1982; Boccia 1989; Brent 1992; Ludes and Anderson 1996; Baker 1997; Ross et al. 2011). It is also likely that biofloors improve the naturalistic aesthetics of an exhibit, as compared to concrete floors (Jacobson et al. 2017), while also potentially reducing ambient noise levels (Janavaris et al. 2019), although these potential benefits have not been studied extensively.

Importantly, adding a substrate to primate enclosures does not appear to pose a health hazard and may even have benefits. Chamove et al. (1982) found that as woodchips remained in enclosures, they increasingly acted as a deterrent to bacterial survival, resulting in lower bacterial counts on cage floors covered with litter than on bare cage floors. This self-sterilising process suggests that the presence of an absorbent substrate greatly reduces the likelihood of disease transmission from faecal contamination (Chamove et al. 1982). Indeed, Brent (1992) found that regularly adding and removing woodchips to chimpanzee enclosures kept the enclosures cleaner and drier. An additional benefit of this type of flooring is that it may also positively contribute to the physical health of primates; minimising the impact on joints during locomotion is commonly cited as a motivator for installing a biofloor. As health and sanitation concerns are common when considering installing a biofloor, these findings should help alleviate those fears.

Despite the apparent health and welfare benefits that result from the provision of a biofloor, they have yet to be universally adopted by zoos housing primates. Given this, the present study sought to better assess motivations for, and experiences with, biofloors housing great apes. To do so, a survey was administered to all Association of Zoos and Aquarium (AZA) accredited zoos housing great apes. Furthermore, and in contrast to many previously published reports, the study aimed to gain perspectives across multiple facilities and across more than just a single species. As biofloors are gradually becoming more common in great ape exhibits in zoos accredited by the AZA, this study focused on these exhibits. Lincoln Park Zoo, for example, regularly receives inquiries about how the four biofloors in our chimpanzee and gorilla habitats are installed and maintained. Such attention highlights the general interest in learning about the advantages of these systems, as well as the lack of information on these topics. Furthermore, while biofloors are increasingly viewed as the gold standard when designing and constructing new primate enclosures at zoos, variation exists in terms of the species they house, the type of biofloor substrate, husbandry and cleaning methods, and pest control. By surveying AZA institutions, the study aimed to better describe these experiences.

There were two key aims with the study: first, to determine the number of indoor exhibits within AZA-zoos that provided biofloors for great apes, what motivated these institutions to provide biofloors, and how they managed and maintained their biofloors; and, second, to evaluate whether zoos' management and maintenance protocols differed across exhibits with biofloors and those without biofloors. It was predicted that, similar to experiences at Lincoln Park Zoo, welfare would be a primary motivating factor for installing biofloors. Overall, it was also expected that zoos with great apes living on biofloors would primarily describe positive and relatively similar experiences to each other with cleaning, pest control and animal welfare. In addition to presenting the results of the survey, this paper also discusses these findings in the context of experiences with the four biofloor great ape exhibits at Lincoln Park Zoo.

Methods

To address the study aims, a survey was sent to all 89 AZA-accredited zoos housing great apes (chimpanzees, gorillas, bonobos *Pan paniscus*, orangutans *Pongo* spp.), including the home institution, Lincoln Park Zoo, via a web-based survey tool (www.SurveyMonkey.com) (a copy of the survey can be found in supplementary materials). Each zoo was asked to complete one survey per exhibit housing great apes at their institution. For example, if a zoo only housed one group of orangutans, they would only answer the survey once, whereas if a zoo housed both orangutans and chimpanzees they would answer the survey twice, once per exhibit. All survey responses were received between 31 December 2018 and 4 July 2019.

All respondents were asked to answer questions relating to three core topics: 1) exhibit size and design, 2) exhibit cleaning and pest control protocols, and 3) great ape behaviour, health and husbandry protocols. Additionally, all respondents were asked whether or not their exhibit had a biofloor. Those that responded 'no' were asked whether their exhibit had previously contained a biofloor and, if so, what had motivated its removal. Conversely, for exhibits that never contained a biofloor, respondents were asked to indicate why a biofloor had never been considered.

For those institutions that had an indoor exhibit with a biofloor, a number of follow-up questions related to the biofloor were asked. Specifically, the survey asked what motivated the zoo to install a biofloor (animal welfare, public perception, husbandry needs, aesthetics and/or another motivator) and what measures they had taken to install the biofloor (e.g., if an exhibit was retrofitted with a biofloor or designed from scratch to accommodate one). Other questions aconcerned the apes' perceived comfort levels on the biofloor as well as whether or not they are prophylactically treated for parasitic diseases, and if this treatment began when the biofloor was installed. The survey also asked for information relating to the biofloor itself, such as the depth, what substrate was used (bark chips, shredded wood, soil, straw, pine straw, or another material), how the zoo obtained the material, and whether the apes consumed these materials. Lastly, zoos were asked how long they had used a biofloor in the exhibit, how frequently the substrate is replaced, and how the biofloor is maintained. It is noted that respondents could select all applicable options for certain questions, while several other questions included an open-ended 'other' response option.

Table 1. Breakdown by species and permanent floor material of the 86 completed surveys received for non-holding indoor exhibits from 42 AZA-accredited zoos.

Floor material						
Species	Biofloor	Concrete	Concrete and gunnite	Concrete and wood shavings	Gunnite	No Response
Bonobo	0	3	1	0	2	1
Chimpanzee	7	8	0	1	2	0
Gorilla	11	17	4	1	1	0
Orangutan	2	17	4	2	0	0
Rotate gorillas and chimpanzees	0	1	0	0	0	0
Rotate gorillas and orangutans	0	0	0	0	0	1
Total	20	46	9	4	5	2

Ethics statement

This study was reviewed and approved by the Lincoln Park Zoo Research Committee (approval number: 2018-013), which provides oversight for all research conducted by zoo staff. Additionally, all four great ape Species Survival Plans (SSPs) reviewed and endorsed this study.

Data preparation

Responses were received from 62 of the 89 (69.66%) institutions that were sent the survey. Of these 62 zoos, 45 (72.58%) provided information pertaining to 128 distinct exhibit spaces housing great apes, although surveys pertaining to 39 of these exhibits, located at 17 zoos, were excluded from further consideration due to them being outdoor exhibits or managed as an off-exhibit holding space, resulting in 89 total indoor exhibits. A further three surveys submitted by three of these zoos were excluded due to insufficient information provided. Thus, the results are based on the survey responses received from 42 zoos comprising 86 exhibits (Table 1).

As many zoos did not respond to all questions, percentages are presented in terms of total responses received for that question rather than as a percentage of the total number of exhibits or zoos. Moreover, as some zoos with multiple exhibits provided different responses for each exhibit, some results are reported in terms of number of exhibits rather than number of zoos. It is also noted that surveys were received from three zoos that indicated that they utilise biofloors in off-exhibit indoor holding areas (housing bonobos, chimpanzees and orangutans, respectively). Given that these were the only zoos that responded that they have biofloors in their holding areas, for comparative purposes these surveys were excluded as outliers from the remaining results as well.

Results

Overall, of the 42 zoos that responded with information about indoor ape exhibits, biofloors were present in 20 (23.26%) exhibits at 13 (30.95%) zoos, predominantly housing chimpanzees and gorillas (Table 1). It was found that six (14.29%) zoos had both biofloor and hardscape ape exhibits, while seven (16.67%) exclusively housed their apes on biofloors and 29 (69.05%) exclusively housed their apes on hardscape floors. Thirteen (65.00%) of the biofloor exhibits, spread across seven zoos, were specifically designed for biofloors, with the remaining exhibits retrofitted to accommodate a biofloor. There was a broad range in terms of how long biofloors had been in use by the zoos surveyed, with two zoos utilising a biofloor for their apes for over 15 years in five exhibits (Table 2).

All 13 zoos with biofloor exhibits provided information about the materials they use in their biofloor substrate. Materials included bark chips or nuggets (61.54%), chipped or shredded wood (30.77%), and a mix of soil and mulch (7.69%). These zoos reported that they primarily received these materials individually bagged from an external company. Of the 20 biofloor great ape exhibits, 12 (60.00%) had complete coverage of the floor with substrate, while the others had between 65% and 95% coverage. The depth of these biofloors varied considerably across exhibits as well, from 30 cm or less to approximately 150 cm of substrate in some exhibits (Table 3).

Table 2. Responses to the question: Approximately how long have you had a biofloor in this exhibit? Note: One zoo did not respond to this question while another zoo noted that they have had soil for 28 years but bark mulch for just three years and so are included here in the 1–5 years category. Responses were open-ended and thus were grouped in approximately five year increments. Two zoos had multiple biofloor exhibits that had been in use for different durations.

Duration	Number of exhibits (n=19)	Percent of exhibits
<6 months	2	10.53
1–5 years	5	26.32
6–10 years	3	15.79
11–15 years	4	21.05
>15 years	5	26.32

Table 3. Responses to the question: What is the depth of your biofloor? Please provide a range if necessary. Note: Two zoos reported multiple biofloor exhibits with different depths.

Depth (cm)	Number of exhibits (n=19)	Percent of exhibits
0–30	5	26.32
30–60	4	21.05
60–90	5	26.32
>90	5	26.32

Table 4. Responses to the question: What motivated your institution to provide a biofloor in this exhibit? Please check all that apply.

Motivation	Number of zoos (n=13)	Percent of zoos
Animal welfare	13	100.00
Husbandry benefits	12	92.31
Aesthetics	11	84.62
Public perception	9	69.23
Other	3	23.08

Motivations for providing or avoiding biofloors

The zoos' stated motivations for installing a biofloor were relatively consistent, and all 13 zoos included animal welfare among their motivators. When asked to rate how strong of a motivator animal welfare was on a scale of 0 to 100 for each of the 20 biofloor exhibits, the mean rating was 89.65 (SD=17.82) and no zoo entered a rating below 50. Other motivators included public perception, aesthetics and other practical benefits such as heat retention, noise reduction, drainage and a softer surface for aging and arthritic apes (Table 4).

The 35 zoos that reported that they do not have a biofloor exhibit were asked why this was the case, and if their institution had previously utilised a biofloor in at least one ape exhibit. For both questions, a response was obtained from all but one of these zoos, with six (17.65%) reporting that their zoo previously had a biofloor exhibit but no longer does. Facility constraints and pest control were the most commonly reported reasons for not having a biofloor, while the cost of substrate materials was the least commonly reported reason (Table 5). Open-ended responses given for other reasons for not having a biofloor included zoos whose animals are able to occupy outdoor areas with natural substrates throughout the majority of the year, concerns about animals breaking glass with rocks found in biofloor substrates, wanting to encourage apes (orangutans specifically) to be elevated, and poor experiences with previous dirt floors retaining the smell of urine or being overly dusty. When these 35 zoos were asked if they provide their apes with bedding materials, every zoo that responded (n=34) indicated that they provide wood wool, hay, wood shavings, straw, sheets and/or blankets, or a combination of these materials. Similarly, the nine zoos with biofloors that responded to this question all also reported that they provide their apes with bedding materials.

Maintenance of exhibits with and without biofloors

Maintenance of biofloors was relatively consistent across institutions; zoos indicated that they rake as needed, turn or rotate the substrate monthly, mist or hose the substrate, and replace or add more substrate as needed. When provided with an open-ended opportunity to describe cleaning protocols, the frequency of cleaning varied widely across institutions, from daily, to twice a month, to simply 'as needed'. The materials zoos used to clean their biofloor exhibits overlapped considerably, with zoos generally using a mix of diluted bleach or other disinfectant based on the label guidelines for that product, either standard or biodegradable detergent, and vinegar.

Twelve zoos provided feedback regarding whether or not they had ever completely replaced the exhibit substrate, with four (25.00%) reporting that they had previously done so. Three of these four zoos indicated they had replaced their biofloors at least once and one zoo indicated they do a partial replacement every two years. The remaining eight zoos (75.00%) reported that they had never completely replaced their biofloors, though one zoo had only recently installed biofloors and another indicated that such a replacement was forthcoming following three years of use.

Zoos without biofloors primarily used bleach or another disinfectant, standard detergent and vinegar to clean their exhibits. The frequency of cleaning non-biofloor exhibits with disinfectants also varied considerably, with some zoos cleaning as often as four to five times a week and others only using disinfectants every one to three months. Regardless of exhibit floor type, zoos reported their cleaning protocols in varying levels of detail, with some zoos describing daily, weekly and monthly protocols, while others simply provided information regarding their 'full clean' protocols that involve the use of disinfectants.

Table 5. Responses to the question: Which of the following explains why this exhibit space does not have a biofloor? Please check all that apply.

Reason	Number of zoos (n=34)	Percent of zoos
Facility constraints	17	50.00
Pest control concerns	11	32.35
Never considered a biofloor	9	26.47
Keeper time/husbandry concerns	7	20.59
Don't know	6	17.65
Biofloor would be too costly	5	14.71
Animal medical concerns	5	14.71
Substrate materials would be too costly	1	2.94
Other	19	55.88

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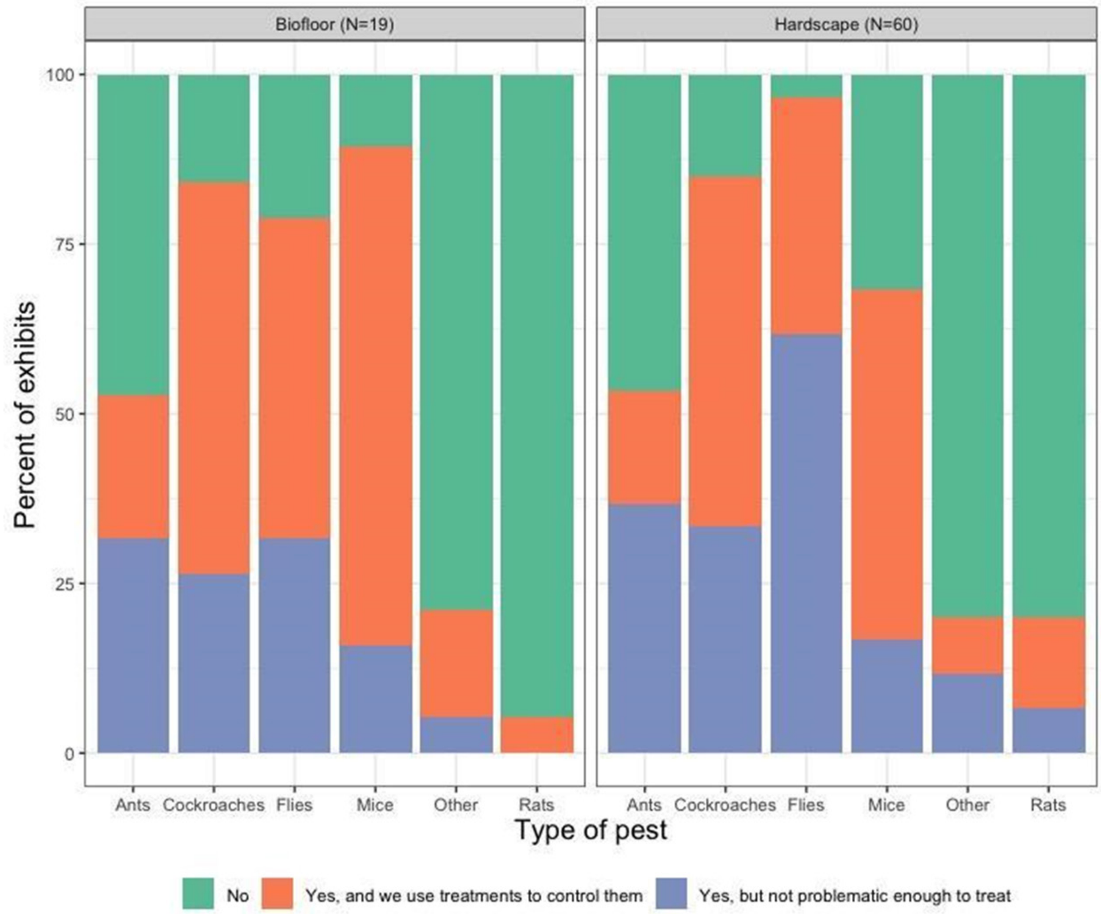

Figure 1. Responses to the question: Do you ever see pests in your exhibit, and if so, do you treat for them? Note: Other pests included sparrows, chipmunks, basilisks, gophers, rat snakes and earwigs.

Each zoo was also asked about their experiences with pest control, specifically if they ever see cockroaches, flies, ants, mice, rats, or any other pests, and how they treat them. As many zoos house multiple ape species, sometimes in separate buildings, their responses often varied from one exhibit to another. Accordingly, pest control results are presented in the context of exhibits rather than zoos. Irrespective of floor type, patterns of responses for whether treatment was required were relatively consistent for all pests (Figure 1). Likewise, the treatment protocols zoos reported for exhibits with hardscape floors consisted of equivalent treatments as used by zoos with biofloors, though as would be expected, there was variation in terms of the specific products or traps used.

Floor material and ape health

Zoos were asked whether they prophylactically treat their apes to address concerns with parasites. A response was received from 12 zoos with biofloor exhibits, five (41.67%) of which reported that they prophylactically treat their apes, although no zoos indicated that such treatments were specifically implemented when the biofloor was installed. In zoos with traditional hardscape floors, 47.62% prophylactically treated their apes.

Zoos with biofloors were also asked whether their apes ever eat the biofloor materials, with responses received from 12 zoos. The apes never did so in nine (47.37%) exhibits, while they rarely ate the substrate in six (31.58%) exhibits and sometimes ate it in four (21.01%) exhibits. Not a single zoo with a biofloor exhibit reported any gut impactions requiring veterinary intervention resulting from apes consuming the organic material that comprises the biofloor. Additionally, no zoos reported that their resident apes showed discomfort on the biofloor substrate, although one zoo commented that their gorillas initially did not like the 'squishy' texture of the floor, but now all walk and nest comfortably on it.

Discussion

The responses to the survey about great ape exhibits in AZA-accredited zoos revealed that only 16.67% of the zoos that responded house their apes exclusively in exhibits with biofloors, while another 14.29% of the responding zoos provide biofloors in some but not all of their ape exhibits. Although hardscape floors remain most common, the number of ape exhibits using biofloors in AZA-accredited zoos has nonetheless steadily grown over the

Figure 2. A) Indoor biofloor great ape exhibit at Lincoln Park Zoo. B) Full substrate replacement at Lincoln Park Zoo.

last two decades. Survey responses indicated that the zoos with biofloor exhibits were motivated to install their biofloors for a variety of reasons, but all cited animal welfare as a motivator. Although fewer than half of the responding zoos provided biofloors, the length of time that zoos reported having had biofloors suggests that zoos are continuing to add such substrates to their exhibits (i.e. across zoos biofloors had been in place for as little as a few months to over 15 years). Using the definition of a biofloor given above, variation was still found among zoos with regards to the percentage of exhibit floor covered with a biofloor, the depth of the biofloor and the material of the biofloor used. Critically, regardless of this variation, biofloors do not appear to pose any challenges to great ape health, with not a single gut impaction reported in the survey responses despite five zoos noting that their apes rarely or sometimes eat the floor materials. Some zoos even subjectively reported that they think their apes spend more time on the ground because of their biofloors, though that has not been the case with the chimpanzees and gorillas at Lincoln Park Zoo (Ross et al. 2009; Earl et al. 2020).

Although ape health and comfort are not negatively impacted by biofloors, and apes may in fact benefit from their provision, it is notable that relatively few AZA-accredited zoos house great apes in exhibits with them. This is particularly true for orangutans and bonobos as, excluding any biofloor holding areas, 18 of the 20 great ape exhibits with biofloors house chimpanzees or gorillas. The other two exhibits house orangutans, with no indoor, on-display bonobo exhibits utilising a biofloor, resulting in a clear skew in survey responses towards just two of the great ape species. However, examining the total number of AZA-accredited institutions housing each ape species at the time the survey was completed provides additional context. Survey responses indicate that there were seven on-display indoor chimpanzee exhibits with biofloors located at six zoos, or 20% of the 30 zoos housing chimpanzees at the time the survey was administered (it is noted that not all zoos completed a survey for each of their exhibits and 27 (30.34%) zoos who received the survey never replied at all). Similarly, there were 11 gorilla exhibits with biofloors located at nine zoos, or 18.75% of the 48 zoos housing gorillas at the time of the survey, resulting in similar proportions of biofloor exhibits to zoos for those species. However, despite just two on-display indoor orangutan exhibits with biofloors, this species can be found in 52 zoos. One zoo commented that they believe the absence of orangutan exhibits with biofloors could be the result of a desire for zoo-housed orangutans to remain in elevated positions, as their arboreal counterparts in the wild would do. Meanwhile, bonobos are only housed at eight accredited institutions, some of which only have outdoor exhibits in addition to their holding areas. As such, if the one bonobo holding area with a biofloor were included in the analysis, once could say that that 12.5% of zoos housing bonobos utilise a biofloor, slightly lower than the proportion of biofloor chimpanzee and gorilla exhibits. Nonetheless, as the majority of survey responses and experiences with biofloors at Lincoln Park Zoo pertain solely to chimpanzees and gorillas, generalising these findings to other species should be done with care.

For context on the results of this AZA-wide survey, first hand experiences with biofloor exhibits housing apes at Lincoln Park Zoo are discussed next. It is intended for these details to provide a more complete picture of the process of providing and maintaining a biofloor and help to answer the common questions that are received from colleagues who are considering implementing a biofloor at their own institution. At Lincoln Park Zoo, the Regenstein Center for African Apes (RCAA) opened in 2004 with four indoor/outdoor enclosures to house chimpanzees and gorillas (Ross et al. 2009, 2011). These naturalistic enclosures (one of which is not viewable to the public) were strategically designed to promote species-specific behaviours, containing moveable vines and hammocks, climbable structures, artificial termite mounds and providing floor-to-ceiling windows for the public to view the apes (Ross et al. 2011). The previous ape facility was considered innovative for its time, but was primarily constructed using hardscape materials such as metal and concrete. One of the major improvements in the design of RCAA was to replace the traditional concrete floor of the previous facility and to utilise a biofloor composed of pine-bark mulch chips, approximately 1 m in depth, throughout each exhibit (Figure 2).

From the survey responses, animal welfare was a primary motivator for installing biofloors when RCAA was built (Ross et al. 2011). The chimpanzees and gorillas at Lincoln Park Zoo, like the other apes housed on biofloors at AZA-accredited institutions, seem extremely comfortable walking on the biofloor substrate, foraging through the wood chips for food, playing with supplementary nesting materials such as wood wool and hay, and frequently using these materials to build nests at ground level atop the wood chips (Ross et al. 2009, 2011). However, zoos considering biofloors must also consider the financial impact of a biofloor as well as potential effects on husbandry routines. Some researchers have noted that introducing a substrate to a primate enclosure did not negatively affect husbandry efforts (Baker 1997; Bennett et al. 2010), or the costs in terms of labour (time). However, no change (Doane et al. 2013) or a slight increase (Chamove and Anderson 1979; Brent 1992) in husbandry time following the introduction of a woodchip substrate has also been documented. Bennett et al. (2010) conducted a comprehensive cost-benefit analysis of providing wood shavings as a substrate for pen housed bonnet macaques *Macaca radiate* and concluded that the provisioning of wood shavings resulted in overall cost savings of approximately 14% annually. Specifically, the increased cost for initial materials and the ongoing cost of wood shavings were negated by the savings associated with reduced husbandry labour, water and cleaning chemicals use. While a similar analysis has not been conducted at Lincoln Park Zoo, it can be anecdotally reported that installing biofloors has resulted in a reallocation of time spent cleaning and maintaining the exhibits rather than an increase in husbandry efforts.

The way in which the biofloor exhibits at Lincoln Park Zoo are cleaned and maintained is similar to other zoos, as reported by respondents to the survey. Leftover food, faecal matter and soiled bedding are removed daily and windows are spot-cleaned with vinegar, while a full clean of the exhibits is carried out weekly. The full clean consists of scrubbing the windows with Rochester Midland Corporation Lime Sol, rinsing and spot-scrubbing concrete structures and platforms and hosing everything off, including rinsing the top layer of substrate if it is too dry. A pitchfork is used to turn the top 15 to 30 cm of our substrate monthly, and to add in a thin top layer of substrate every one to two months, at which time disinfectant is also used to clean all non-porous surfaces. Finally, on a quarterly basis, approximately 50 3-ft^3 bags of bark chips are added to each indoor exhibit (M=101.38 m^2, SD=21.87 m^2) after turning the top layer of substrate. As noted from the survey responses, these cleaning methods appear in line with those of other zoos, though exact schedules and cleaning products vary slightly. However, common cleaning products used by AZA-accredited zoos with biofloor exhibits included disinfectants such as diluted bleach, both standard and biodegradable detergents, vinegar and dishwashing soap. Under Lincoln Park Zoo's cleaning protocols, there has only been a mold problem once, which followed a full substrate replacement, and it was eliminated using vinegar and by turning the substrate every couple of days for a few weeks. Furthermore, aside from one minor issue soon after the building opened, there have been any drainage issues.

In 2007–2008, all of the substrate in each of the four exhibits was systematically replaced, though the survey responses show that the majority of zoos have never replaced their biofloors. However, this finding may also be partially explained by their relatively short tenures at the time the survey was administered (Table 2). Given the design of the Lincoln Park Zoo facility, the process of fully replacing the biofloor was extremely time consuming, taking two to three days to remove all the substrate from a single exhibit. Moreover, the process was found to be unnecessary as when all of the substrate was removed, it was found that the very bottom layer was clean, peat-like soil on top of a dry floor. This indicated that the biofloor had functioned as a natural composting system, exactly as it was designed to do. As the biofloor is between 75 and 90 cm deep, it has been found that simple maintenance is more effective and practical than full replacement; however, it is possible that zoos with shallower biofloors may indeed require more frequent replacement. A small hole is dug in each exhibit once a year to check the condition of the substrate layers, though, to date, the bottom layer has always been a clean, semi-moist and fine peat-like soil.

Perhaps the most common questions received regarding the biofloors at Lincoln Park Zoo have to do with pest control. Fortunately, there is a pest control manager on staff who treats the building regularly, with most treatments being relatively effective. As with all but one zoo with biofloors, rats have not been a problem here, but like several zoos, it is necessary to periodically treat for mice. Flies were also a common pest among AZA-accredited zoos that house apes in biofloor exhibits according to the survey, though just five zoos found them problematic enough to treat and the degree to which this problem differs compares to exhibits with traditional substrates is unconfirmed. Zoos reported that they primarily treat flies with various types of sticky traps. At Lincoln Park Zoo, Spalding Laboratories Fly Predators, Alpine WSG, various sticky traps and several types of electronic insect killers are used in staff areas. Only one zoo responded that they find ants problematic enough to treat, relying on zoo pest control to treat them. All zoos with biofloors that responded to the pest control survey questions indicated that they saw cockroaches, though four of them did not find them problematic enough to treat. At Lincoln Park Zoo, Bayer Maxforce FC gel is used to treat cockroaches, and has been relatively effective, with few cockroaches seen, considering the expectations for this type of environment. Considering the survey responses, experiences with and treatments for pests appear approximately equivalent for exhibits with biofloors and hardscape floors. Accordingly, from these experiences with biofloors and the survey responses, it appears that pests are commonplace regardless of floor type, and with treatment they should not be an impediment to having a biofloor. This is important to emphasise given that a primary reason that zoos gave for not providing biofloors was a concern about pests. Thus, the conclusion reached is that floor substrate does not seem to influence pest prevalence, which might help to ameliorate the concerns of zoos installing a biofloor in their ape exhibit.

Overall, Lincoln Park zoo is broadly satisfied with the use of biofloors for the chimpanzees and gorillas living at RCAA. The decision to install biofloors at RCAA when the building was constructed in 2004 was made after considerable research and deliberation, and as part of the facility's pre- and post-occupancy evaluation process (Ross et al. 2011). Like other zoos, the potential to enhance animal welfare was the primary motivator, but there is reason to believe the biofloors have also played a role in positively influencing the visitor experience by creating a more naturalistic aesthetic (Jacobson et al. 2017). To the authors' knowledge, no

AZA-accredited institution utilised a permanent biofloor for their ape exhibit prior to 2002, so the rapid growth of this design feature is substantial. Despite variation in terms of biofloor materials, depths, cleaning procedures and pest control, survey responses revealed widespread satisfaction with biofloors by both apes and their caretakers and managers across AZA institutions. Survey results suggest there is no single correct method for installing and maintaining a biofloor, but rather the physical and financial constraints of zoos may influence the exhibit design, while pest control and cleaning protocols do not vary considerably. Accordingly, survey responses as well as the knowledge gained from evaluations at Lincoln Park Zoo have bolstered the suggestion that biofloors are a worthwhile investment and that further research examining their potential impacts on apes, managers and visitors will help guide their future implementation in great ape housing.

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