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TECHNICAL REPORT

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Sound at the zoo: Using animal monitoring, sound measurement, and noise reduction in zoo animal management

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A clear need for evidence-based animal management in zoos and aquariums has been expressed by industry leaders. Here, we show how individual animal welfare monitoring can be combined with measurement of environmental conditions to inform science-based animal management decisions. Over the last several years, Disney's Animal Kingdom® has been undergoing significant construction and exhibit renovation, warranting institution-wide animal welfare monitoring. Animal care and science staff developed a model that tracked animal keepers' daily assessments of an animal's physical health, behavior, and responses to husbandry activity; these data were matched to different external stimuli and environmental conditions, including sound levels. A case study of a female giant anteater and her environment is presented to illustrate how this process worked. Associated with this case, several sound-reducing barriers were tested for efficacy in mitigating sound. Integrating daily animal welfare assessment with environmental monitoring can lead to a better understanding of animals and their sensory environment and positively impact animal welfare.

KEYWORDS
animal welfare, noise reduction, sound measurement, welfare monitoring

1 | STATEMENT OF THE PROBLEM

One pressing task in the zoo and aquarium field is to develop and implement standardized tools to monitor individual animal welfare (Barber, 2009). Welfare can be assessed through behavioral, physiological, and health measures, each of which can indicate subjective experiences and affective states (Mellor & Beausoleil, 2015; Sandøe & Simonsen, 1992). Since welfare is unique to individual animals and contexts, the AZA Animal Welfare Committee recommended that zoo professionals develop tools for measuring zoo animal welfare on an individual animal-based level (Barber, 2009).

Multiple zoos and aquariums have developed their own assessment tools and programs. These include EthoTrak® (developed by the Chicago Zoological Society), EthoSearch (developed by Lincoln Park Zoo and partners), ZooMonitor (developed by Lincoln Park Zoo and partners) (Wark et al., 2016), WelfareTrak® (developed by the Chicago Zoological Society and partners) (Whitham and Wielebnowski, 2009), and the geriatric animal quality of life assessment process developed by San Francisco Zoo's Wellness and Conservation Center (Watters et al., 2015). Some species-specific welfare monitoring programs are also being designed based on multi-institutional studies that tested multiple parameters on a single species or taxa, such as the Elephant Welfare Initiative (Meehan, Mench, Carlstead, & Hogan, 2016) and C-Well® (Clegg, Borger-Turner, & Eskelinen, 2015).

An animal's sensory environment can have significant influence on its well-being. Specifically, anthropogenic "noise" can alter sound pressure levels and frequencies and elicit stress responses in animals (Kight & Swaddle, 2011; Morgan & Tromborg, 2007) both in the wild (e.g., Barber, Crooks, & Fristrup, 2010; Nowacek, Thorne, Johnston, & Tyack, 2007) and under managed care (e.g., Powell, Carlstead, Tarou, Brown, & Monfort, 2006; Shepherdson, Carlstead, & Wielebnowski, 2004; Westlund et al., 2012). By examining anthropogenic sound and welfare indicators simultaneously, zoos and aquariums can begin implementing mitigation strategies to enhance the sensory environment of animals and improve welfare.

Beginning in 2014, Disney's Animal Kingdom® began undergoing significant construction and exhibit renovation in preparation for new park attractions. In order to assure optimal welfare, Disney staff developed a process to monitor animal welfare and measure environmental variables that may impact animal welfare. This report demonstrates our animal welfare and sound monitoring approaches through discussion of a case study where integration of the two programs enhanced the welfare of a giant anteater (*Myrmecophaga tridactyla*).

2 | DESCRIPTION OF THE PROCESS

Disney's Animal Kingdom® animal care and science staff designed a welfare monitoring program that tracks animal-based measures (i.e., assessments from keepers, behavioral data, and endocrine data), and resource-based measures (i.e., husbandry events via checklists and environmental measures), a suggested strategy for holistic welfare assessment (Butterworth et al., 2011). This approach utilized aspects of various existing welfare assessment programs and tools and emphasized customization to individual animals and daily tracking of multiple welfare measures. Our goal was to better understand how specific events in our animals' environment influence their welfare and use that information to inform management decisions.

2.1 | Keeper checklists

Animal caretakers have a unique perspective of their animal's health, behavior, personality, and overall well-being and are therefore well-positioned to report on animal-based welfare parameters (Meagher, 2009; Wemelsfelder, 2007; Whitham & Wielebnowski, 2009, 2013). Beginning in May 2014, we began capturing this information from customized evaluations we termed "keeper checklists." Animal care and science staff most closely associated with an individual animal (validation by expert opinion) determined which parameters best indicated the welfare state of that individual animal. A mix of parameters in the physical, behavioral, and husbandry categories was chosen and objectively defined. Responses took various forms, including "yes/no," "typical/atypical," numeric scale, etc. Animal care staff identified whether responses for each parameter would contribute positively or negatively to the welfare state and quantitatively scored the responses (−1 for negative, 0 for neutral, +1 for positive). This coding is similar to the green flag/red flag system emphasized by Barber (2009). Response scores were summed within each category and displayed graphically to track trends in welfare over time (see Sandøe & Simonsen (1992) for discussion). Keeper checklists were to be filled out daily and by animal keepers with considerable experience working with those individual animals.

Furthermore, keeper checklists have placeholders to record "events" that staff postulated may impact the individual animal. Events included nearby construction, atypical activity (e.g., horticulture work, pressure washing, tour), and animal management changes (e.g., social group change, husbandry routine change, keeper staff changes). Dated events were graphed alongside daily welfare parameter changes. Every two weeks, data collected from "keeper checklists" were compiled, graphed, and distributed to animal care teams, so proper reflection and discussion of animal welfare could occur in relatively real-time and changes could be made as appropriate.

Centralized documentation is key to holistic welfare monitoring (Barber, 2009) and was instrumental in managing our long-term, multi-variable dataset of multiple animals. We utilized Fulcrum, a cloud-based data collection web platform (Fulcrum Mobile Solutions Inc., 2016). This service allowed for customized surveys, data submission from multiple users, and assignment of permission levels for data entry, editing, and downloading. This welfare tracking process proved to be a low cost, user-friendly tool for monitoring animal well-being.

2.2 | Sound monitoring

Since May 2014, 24-hr sound pressure level (SPL) data have been collected at selected sites within Disney's Animal Kingdom®. These measurements allowed for comparison of sound levels between normal operations and new or unusual events, such as construction or entertainment venues. Sound pressure levels (SPL re: 20 µP) were logged with a 3M™ Sound Examiner SE-400 Sound Level Meter (3M, St. Paul, MN) (frequency response: 10–20,000 Hz; weighting: C; response time: slow). A C-weighting, rather than an A-weighting, was chosen to capture low frequency sounds that many animals may be able to perceive. At intervals, the meters logged the mean (equivalent continuous sound level, L_{eq}), minimum (L_{min}), and maximum (L_{max}) SPL for the preceding interval. For long-term recordings in animal environments, a 1-min interval was used, and for experiments (see below) a 5-s interval was used. Meters were placed within or close to the animals' enclosures in order to accurately document the acoustic environment the animals experienced. Data were uploaded in 3M Detection Management Software (version 1.9.88) and later exported to spreadsheets for further analysis. To avoid taking averages of log-scale data (L_{eq}, L_{max}, L_{min}) during these analyses, the unlogged, raw dBC values were averaged and the resulting average was again log-transformed.

2.3 | Sound mitigation in animal areas: sound barrier tests

Sound level reduction for animals can be accomplished at the source (e.g., reducing emitted sound), during transmission (e.g., reflecting or absorbing sound), or at the receiver (e.g., moving animals). We tested a commercial sound-absorbing foam barrier (3.0 cm) and two relatively inexpensive barriers, a plastic polyethylene King Starboard® panel (0.6 cm) and a plywood panel (1.3 cm), for their ability to reduce sound levels during transmission. Each tested barrier (comprising multiple side-by-side panels) measured 1.7 m tall and 6.9 m long. The experimental setup is shown in Figure 1. Each trial of the experiment consisted of playing the same low, medium, and high frequency tones (30 s) through a speaker (MAXX4A [FBT, Recanati, Italy] or Mackie SWA 1501 [Loud Technologies, Woodinville, MN] and JBL EON 15G2 [JBL Professional, Northridge, CA]). Stimulus sound files were created in Adobe Audition (version 5.0): the low tones stimulus consisted of a 20, 40, 60, 80, and 100 Hz tones, the medium tones stimulus consisted of 200, 800, 1,600, and 2,400 Hz tones, and the high tones stimulus consisted of 3,000, 7,000, 11,000, 15,000 and 19,000 Hz tones. The three stimuli were played through a speaker and SPL was measured at two distances from

FIGURE 1 Schematic of experimental setup for sound-reducing barrier tests

the speaker (3M Sound Examiner SE-402; frequency response: 10–20,000 Hz; weighting: C; response time: slow). Before each test, the meters were calibrated (3M AC-300 calibrator 1,000 Hz, 114 dB) and post-calibrations were within ± 0.1 dB.

Each sound barrier was tested five times with each of the three tones, at a volume such that meter 1 read between 85 and 90 dBC. Nine control trials (without any barrier) were also conducted intermittently. The mean (equivalent continuous sound level, L_{eq}) for

TABLE 1 Keeper checklist for female giant anteater "Annie"

Parameter	Responses
Date	
Exhibit or holding	Exhibit; holding
Physical parameters	
Weight (lbs)	
Fecal form	Typical (soft); atypical (firm)
Location of feces	None; in water; anywhere but in water
Fur condition	Typical; atypical (over-groomed, hair missing)
Piloerection along spine	Yes; no
Scabby snout	Yes; no
Mucousy nose	Yes; no
Diet consumption	Typical; atypical
Request for veterinary assessment	Yes; no
Physical parameters comments	
Behavioral parameters	
Explore/investigate/dig	Yes; no
Amount of sleep	None observed; less than typical; typical amount; more than typical
Sleeping location	Typical; atypical
Side run (tripod walk with arched back)	Yes; no
Pacing	None; steady pace; speed walk; gallop
Behavioral parameters comments	
Husbandry parameters	
Asleep on keeper arrival in AM	Yes; no
Response to shower	No response; minimal use; fully engaged
Interaction with enrichment	Yes; no
AM shifting/feed cue	No response; awaken by keeper, then responds; responds to cue on own
PM shifting/feed cue	No response; awaken by keeper, then responds; responds to cue on own
New/other team staff member working area	Yes; no
Construction present (hear or see)	Yes; no
Construction comments	
Atypical activity present (hear or see)	Yes; no
Atypical activity comments	
Husbandry parameters comments	
Photos (optional):	
Keeper name(s):	

The checklist is divided between physical, behavioral, and husbandry parameters, and the responses for each parameter are given scores which factor into a daily welfare composite.

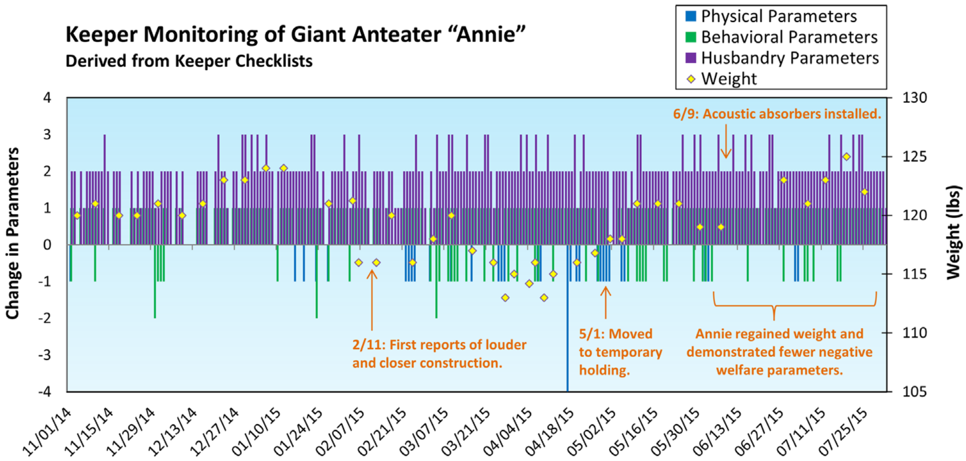

FIGURE 2 Welfare indicators and weight of giant anteater "Annie" from November 2014 to July 2015. Data were collected daily via the keeper checklist monitoring process

each meter was calculated during each 30-s stimulus at 5-s intervals. Noise reduction due to the barrier was calculated as the dBC loss observed between the 2 SPL meters during the sound barrier test minus the natural dBC loss observed during control trials without a barrier. For the in situ application to reduce sound, noise reduction due the barrier was calculated in the same manner.

3 | DEMONSTRATION OF EFFICACY

Animal care and science teams began using keeper checklists in May 2014 to monitor animal well-being of a cross-section of species at Disney's Animal Kingdom®, including a female giant anteater (*M. tridactyla*) named "Annie." Responses to 19 different parameters were documented daily to provide a portrayal of Annie's welfare state (Table 1). Beginning in February 2015, keeper checklist monitoring indicated that a higher proportion of negative welfare indicators were being reported (Figure 2). Specifically, the ratio of negative welfare indicators to data entries increased from 0.17 to 0.29 between two consecutive 3-month periods, and the ratio of positive welfare indicators to data entries decreased from 2.50 to 2.29. Furthermore, Annie's weight decreased during this time period. Staff postulated that these changes may have been due to increased construction-related activity and increased sound levels in the area (see Table 2), due to an increase in on-exhibit time, or due to a combination of both factors. With no reprieve in the near future, staff decided to relocate Annie to a temporary holding location in a perceived quieter environment on May 1, 2015. This transfer seemed to enhance Annie's comfort and well-being, as reflected by an increase in weight, a reduced ratio of negative welfare indicators to data entries (0.29 to 0.17), and an increased ratio of positive welfare indicators to data entries (2.29 to 2.35), for the 3-month period following her transfer.

We inadvertently moved a potentially sound-sensitive animal from an area that was exposed to increased construction noise, to an area that was exposed to noise from a nearby heating, ventilation, and air conditioning unit (HVAC). However, while the construction site's sound profile was so large that it would be very difficult to mitigate sound, the HVAC itself could be surrounded by a sound-reducing barrier. We tested three types of barriers (foam, plastic, and plywood) for their efficacy. For all three barriers, sound reduction was the greatest for higher frequencies compared to lower frequencies (Table 3). The foam acoustic absorber yielded the greatest reduction of high frequencies (12.2 dBC reduction), while the plywood barrier reduced low and medium frequencies more than the others (8.5 and 11.6 dBC reductions, respectively). Thus, species with different hearing sensitivities may benefit from different barriers.

To reduce sound from the HVAC, staff installed foam acoustic absorbers around the unit. A sound-absorbing barrier was chosen over a sound-reflecting barrier to avoid reflecting any road traffic sound in the area back to the animal. Before and after the barrier was installed, we measured SPL at the source of the HVAC and

TABLE 2 Daytime (8:00 am–4:00 pm) sound pressure levels collected over time inside giant anteater exhibit using 1 min recording intervals (see "Sound Monitoring" section)

	Aug 22, 2014	Feb 19–21, 2015 & Feb 24, 2015	Mar 25–26, 2015 & Apr 1, 2015	May 5–6, 2015 & May 13–14, 2015
Average mean (L_{eq}) dBC	69.1	72.0	71.3	70.4
Average max (L_{max}) dBC	71.8	74.5	74.0	72.6
Absolute max (L_{max}) dBC	80.4	90.7	88.4	86.6

TABLE 3 Average noise reduction due to each barrier type (*n* = 5 trials for each barrier)

		Noise reduction (dBC)		
Sound description	Sound frequency range	Foam	Plastic	Plywood
Low tones	20–100 Hz	−1.0	−2.2	−2.4
Medium tones	200–2,400 Hz	−5.1	−4.5	−7.3
High tones	3,000–19,000 Hz	−12.2	−11.6	−8.5

across the road at multiple points along the temporary holding location for the giant anteater. SPL along the temporary holding location post-barrier installation was reduced by 1–14 dBC, depending on proximity of the recording point to the HVAC unit. To put this SPL reduction in perspective, each 6 dB decrease is a halving of the SPL (Warren, 1973).

This case exemplifies how multiple teams can work together to maintain and improve animal welfare using a combination of animal-based and resource-based measures. In the case of Annie the anteater, the sound level environment in her exhibit was deemed to be the primary influence on her downward trend of welfare indicators. After her transfer to a temporary holding location, further effort was made to reduce the sound profile at that location. The end result was a return to a baseline indicators of positive welfare, and a successful demonstration of evidence-based management.

4 | OTHER CONSIDERATIONS FOR MEASURING SENSORY ENVIRONMENTS

- Note that each species and individual perceives their environment differently through unique sensory modalities (Burnett, 2012). For example, our recording equipment did not record into the ultrasonic range, which some species perceive.
- In addition to sound, other aspects of the sensory environment, such as light, olfactory stimuli, air quality, and ground vibration, may impact animal welfare.
- Qualitative aspects of environmental stimuli can be just as important as quantitative measures, including temporal scales (i.e., sudden vs. gradual onset, time of day), predictability, and averseness.
- There are no established guidelines for acceptable sound levels for animals in zoos and aquariums. Importantly, government workplace standards (e.g., NIOSH, 1998) are designed to reduce (but not eliminate) hearing loss in human workers and therefore are not appropriate guidelines for animals under managed care.
- Some of the loudest sources of noise result from the "normal" ambient environment, including pressure washing, door operation, fans, radios, and road traffic (Sales, Milligan, & Khirnykh, 1999; Voipio, Nevalainen, Halonen, Hakumäki, & Björk, 2006; personal observations).
- Phone applications that measure sound levels vary in accuracy and should be evaluated against calibrated scientific devices, but professional devices such as those used here can cost upwards of 1,000 USD, so there is a trade-off between accuracy and cost.

5 | CONCLUSIONS

1. Assessments from experienced animal caretakers, in conjunction with physiology and behavior monitoring, can be a valuable and efficient method for monitoring long-term animal well-being.
2. Assessing the 24-hr sensory environment should become an integrated part of animal care operations, as sound and other environmental variables can have influence on animal well-being.
3. Mitigating sound impact on animals' environment can occur by reducing the source of the noise or mitigating the sound's transmission through barriers.

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