



THE GROUND BENEATH JOYCE:

WHAT SCIENCE REVEALS ABOUT HER
CAPTIVITY AT SIX FLAGS

Executive Summary

For decades, Joyce has lived in captivity. Since 2010, she's been kept at Six Flags Wild Safari in New Jersey, in an enclosure alarmingly close to the park's roller coasters and heavy vehicle routes. That's especially troubling for an elephant, given how sensitive they are to even the faintest ground vibrations.

For example, elephants use low-frequency rumbles through the ground to communicate with one another across great distances. But at Six Flags, Joyce is constantly surrounded by man-made vibrations: rollercoasters, trucks and heavy machinery. So to better understand what she experiences, World Animal Protection partnered with Terrapin Sensing and the University of Maryland Department of Geology to measure the intensity and sources of ground shaking around Joyce's enclosure.

What the Data Shows

Between July 12 and August 12, 2025, sensitive seismometers were placed at eight sites around Six Flags' amusement and safari parks. After 30 days of collecting data, the results were clear: Joyce's environment is full of constant and powerful vibrations.

The seismology readings found three primary sources of ground motion:

- Rollercoasters producing vibrations between 5 and 20 Hz, which is the same range elephants naturally use to communicate.
- Safari trucks driving through the park, generating frequent vibrations between 20 and 200 Hz.
- A nearby water treatment plant, creating a steady mechanical hum around 7–10 Hz.

On the Mercalli Scale, these vibrations correspond to roughly a Level IV to V, which is similar to the tremors felt during a small earthquake. That means Joyce isn't just sensing these vibrations, she's living in a world where the ground is persistently shaking beneath her feet.

Why This Matters

While the seismology instruments were designed to measure vibrations as humans feel them, scientists still don't fully understand how elephants perceive or are affected by such constant ground motion. What we do know is that elephants are acutely sensitive to low-frequency vibrations and rely on them for comfort, communication, and safety. For Joyce, being exposed to these daily artificial vibrations likely disrupts her natural sensory world, compounding the stress of captivity.

"Elephants in the wild may choose to avoid such vibrations, but in captivity they have no such choice," Dr. Jan Schmidt-Burback, World Animal Protection's Director of Wildlife Research and Veterinary Expertise, said. "This adds to the long list of concerns for why a theme park in a cold climate environment, with truck-based observation on roads and rollercoasters nearby is clearly not the right environment for elephants such as Joyce."

What's Next

These findings underscore the urgent need to relocate Joyce to a sanctuary where she can finally live in peace, free from the constant mechanical noise and vibration she currently experiences at Six Flags. World Animal Protection will continue to work with experts and advocates to ensure her suffering is not ignored.

Report Contents

OVERVIEW.....	2
DEPLOYMENT	3
RESULTS.....	5
EVALUATION.....	6
SUPPLEMENTAL INFORMATION	7

Overview

An African elephant named Joyce has been in captivity since 1984 and has resided at Six Flags Wild Safari in New Jersey since 2010. Her small enclosure is near the roller coasters of Six Flags, where there is high concern about her proximity to the amusement park, as elephants are sensitive to vibrations. World Animal Protection requested the Terrapin Sensing team to evaluate the amount of ground shaking the elephants are subjected to daily. Here we present the primary sources of felt vibrations detected by the Terrapin Sensing instruments deployed near the elephant enclosure and around the park.

Key Results

- Observations of the vibrational (ground motion) environment were recorded at 8 sites around Six Flags Amusement and Safari Parks between July 12 and August 12, 2025. The site closest to the Park was ~180 meters away from the southern loop of the ride "Nitro". The site closest to the elephant enclosure was ~180 meters away from the southern enclosure fence. The other sites were chosen to better characterize specific noise sources.
- There are three primary sources of ground motion at detectable frequencies around Six Flags Amusement and Safari Parks: 1) Vehicle traffic (~20 to 200 Hz, close to the elephant enclosure it is mostly the park-run safari trucks); 2) The Six Flags Water Treatment Plant (a constant hum around 7-10 Hz); 3) The rollercoasters (mostly between 5 and 20 Hz).
- At the site closest to the elephant enclosure (site #6), the safari trucks produced an average ground motion with a spectral power of -30 dB (monthly average -55 dB) peaking at 0 dB, which corresponds to 0.61 m/s² ground acceleration (see Table 2). The roller coasters and water treatment plant had an average ground motion spectral power of -20 dB (monthly average -35 dB), which corresponds to ~0.12 m/s² ground acceleration (see Table 2). To a human, such ground motions can be felt quite noticeably and feel similar to those produced by a passing truck or large vehicle. The power peaks by the safari trucks are sufficient to slightly damage buildings.

Deployment

A total of 8 sites were strategically selected around Six Flags Amusement Park and Six Flags Safari Park for deployment of seismometer “nodes” sensitive to ground vibrations and motion (Fig. 1 and Table 1). Each site had a set of two nodes deployed (July 12, 2025); one node to record for ~ 24 hours, and the other to record data for ~ 30 days. The instruments were Fairfield Zland 3C Nodes (Fig. S1) that have onboard GPS timing and a self-contained power supply, allowing for the acquisition of up to 35 days worth of ground motion (seismic) data. The 24-hour nodes were collected on July 13, 2025, while the ~ 30 -day nodes were collected on August 12, 2025. The 24 hour nodes provided a quick first look at the park ground motion environment, while the 30 day nodes provided a complete month of observation.



Figure 1: Deployment map of node sites (pink) and the locations of the Nitro ride SW loop, the Six Flags Water Treatment Plant, and the elephant enclosure (yellow thumbtacks). North is up; see Table 1 for coordinates.

Site #1 is on a parcel of public land, located at the end of a forest road by Prospertown Lake. The road is accessible from Monmouth Rd. The lake is very popular for fishing on- and offshore with non-motorized boats. The roller coaster, Nitro, on the western edge of Six Flags Amusement Park, is visible and can be heard from this location.

Site #2 is on a parcel of public land, approximately 160 meters northwest of Site 1 and was chosen for supplemental data near the roller coasters minimizing the amount of road noise that could be picked up by the nodes. The roller coaster, Nitro, can be seen and heard from this location.

Site #3 is on a parcel of public land, just ~15 m from Monmouth Rd and is north-northwest of Six Flag. This site was chosen for its proximity to the vehicular entrance to Six Flags. Here, recording vehicular traffic and amusement park operations signals were the goal to give us a basis for other noise contributors besides the roller coasters.

Sites #4, #5, #6, and #7 are node deployment locations along the south boundary of Six Flags Wild Safari Park on Reed Rd. They were all placed on the opposite side of the road from the Safari Park on public, forest land. Site #5 is near the Savannah Sunset Resort and Spa, while Site #6 is the closest location to the elephant enclosure.

Site #8 is east of Six Flags and was chosen as an anchor point for noise detection. Heading west from Site #8 is a small road that leads to a park maintenance area and the Six Flags Water Treatment Plant.

Site #	Latitude (N)	Longitude (E)	Distance to Elephant Enclosure building (m)	Distance to Nitro Roller Coaster, centroid (m)
1	40.135	-74.451	1952	353
2	40.137	-74.452	2075	390
3	40.147	-74.444	2345	1125
4	40.122	-74.434	959	1903
5	40.125	-74.432	437	1830
6	40.127	-74.427	255	2003
7	40.128	-74.423	523	2231
8	40.141	-74.420	1618	2351

Table 1: Deployment site coordinates and distances to the center of the building in the elephant enclosure and the centroid of the "Nitro" roller coaster.

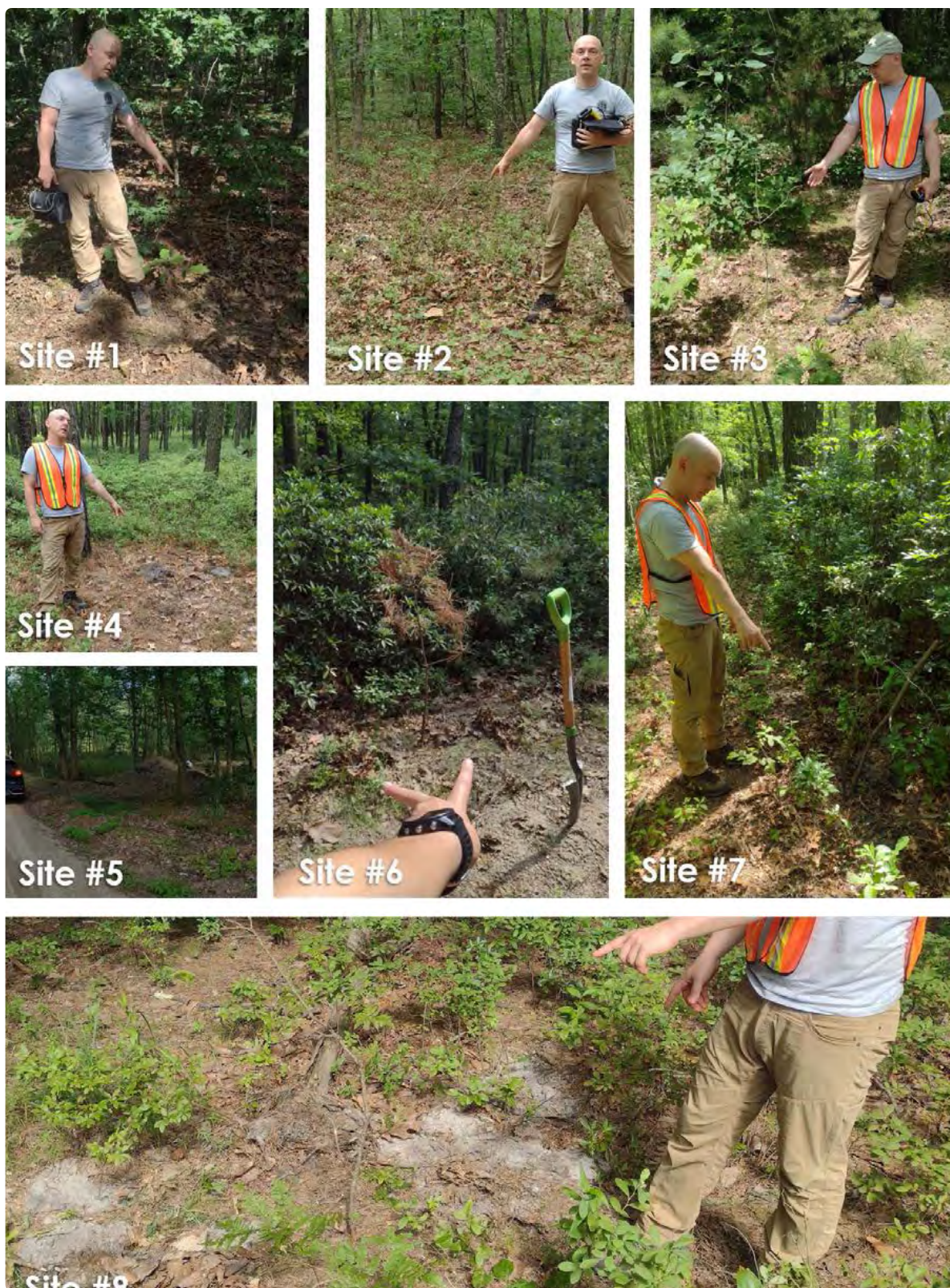


Figure 2: Individual site location photos. Geologist Dr. Hannes Bernhardt (pointing at deployment spots) for scale. The nodes were buried in the soil and lightly covered while recording to minimize coupling with atmospheric noise and detection by passerbys.

Results

Cumulating the daily noise over the entire 30 day span, the parks' operation time is detectable in the spectrograms in Fig. 3 as higher noise (dB) diurnal events (tan color pillars between 1 to 40 Hz). Other noise contributors have also been identified (Fig. 3) such as rain storms (A), the continuous Six Flag Water Treatment Plant hum, and the magnitude 8.8 Kamchatka earthquake that happened on July 30th, 2025 approximately 4000 km away (not locally felt).

Averaging the noise over the 30 day span gives us a better view as to how much vibration an area is being subjected to over time (Fig. 4). On a typical day, the vibrations from the first runs of the roller coasters start approximately 45 minutes before the amusement park opens at 10:30am. Closing times for Six Flags, when the vibrations from the park settle down, is variable depending on the day of the week, however, we observed that the park typically ends the rides around 10pm. The Wild Safari park opens at 10 am, but only runs until 4 pm. All of these patterns were readily observed in the data.

Scale level (for humans)	Peak ground acceleration (approx.)	Ground conditions
I. Not felt	$<0.0005 g_0$ (0.0049 m/s^2)	Not felt except by very few under especially favorable conditions.
II. Weak	$0.003 g_0$ (0.029 m/s^2)	Felt only by a few people at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III. Weak		Felt quite noticeably by people indoors, especially on upper floors of buildings. Many people do not recognise it as an earthquake. Standing vehicles may slightly rock. Vibrations are similar to the passing of a truck, with duration estimated.
IV. Light	$0.028 g_0$ (0.27 m/s^2)	Felt indoors by many, outdoors by few during the day. At night, some are awakened. Dishes, windows, and doors are disturbed; walls make cracking sounds. Sensations are like a heavy truck striking a building. Standing vehicles are rocked noticeably.
V. Moderate	$0.062 g_0$ (0.61 m/s^2)	Felt by nearly everyone; many awakened. Some dishes and windows are broken. Unstable objects are overturned. Pendulum clocks may stop.
VI. Strong	$0.12 g_0$ (1.2 m/s^2)	Felt by all, and many are frightened. Some heavy furniture is moved; a few instances of fallen plaster occur. Damage is slight.

Table 2: Relevant levels of the modified Mercalli scale used to explain the intensity of ground motion.

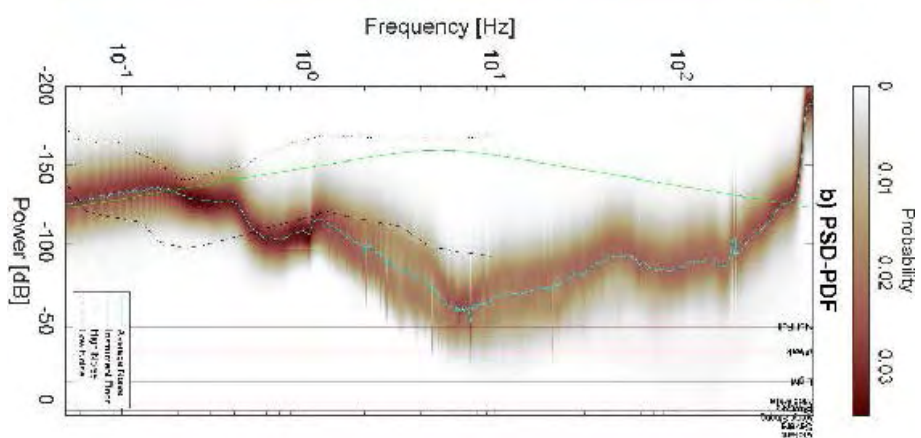
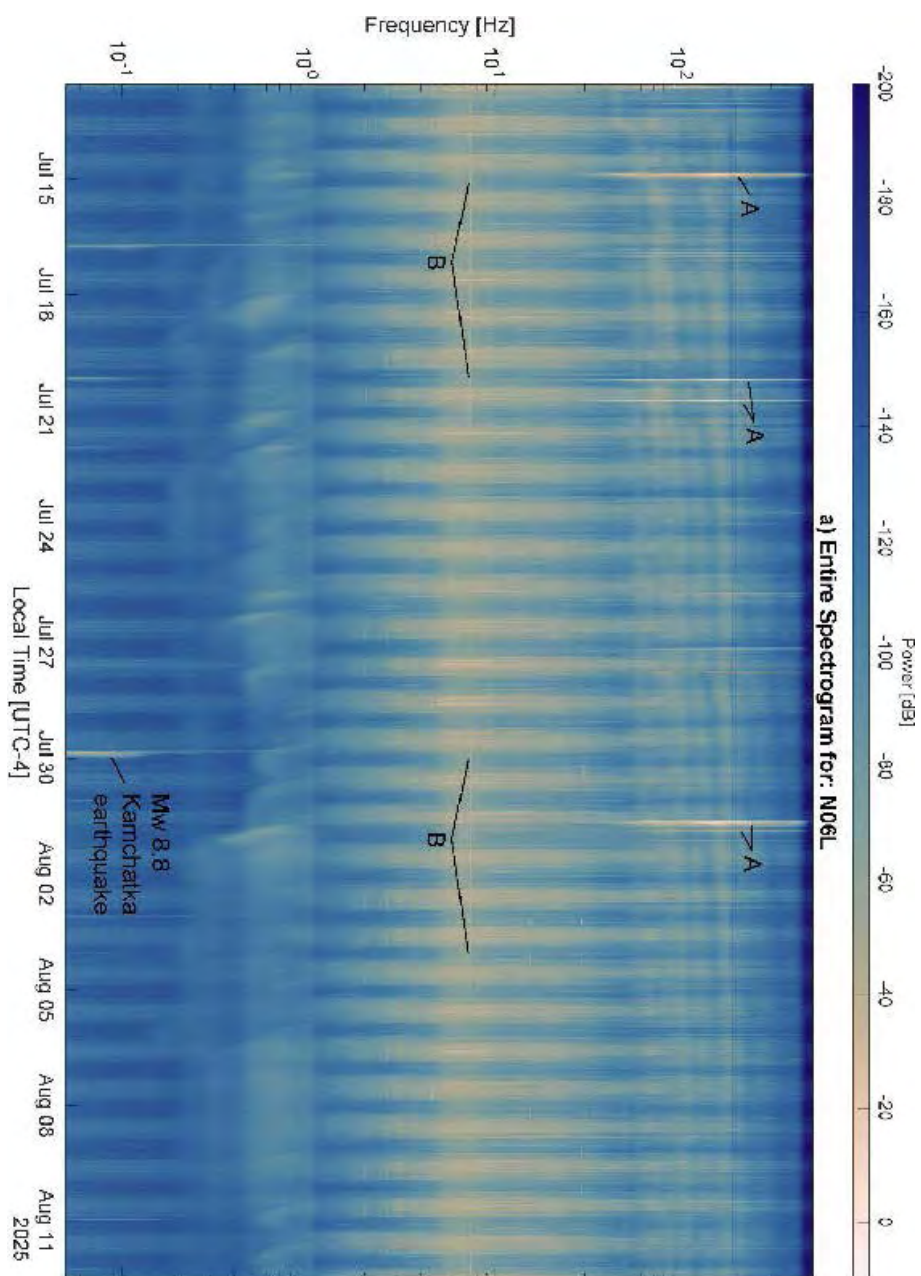


Figure 3 (previous page): a) Complete 31 days ground motion spectrogram for Site 6 by the elephant enclosure. Spectrograms are constructed in 15-minute time intervals and ground motion spectral density is measured in decibels (dB) referenced to $1 \text{ m/s}^2/\text{Hz}^{1/2}$. Label (A) are rain/wind events; label (B) are the $\sim 7\text{-}10 \text{ Hz}$ hum from Six Flags Water Treatment Plant at 702 Perrineville Road. Almost all other signals, mostly distributed in a striped, i.e. diurnal pattern, are from the rollercoasters at Six Flags Park ($\sim 5\text{-}20 \text{ Hz}$) and passing vehicles ($\sim 20\text{-}200 \text{ Hz}$), i.e., mostly the safari trucks but also some passing vehicles on Reed Road. b) Power spectral density probability function for the severity of shaking (see Table 2).

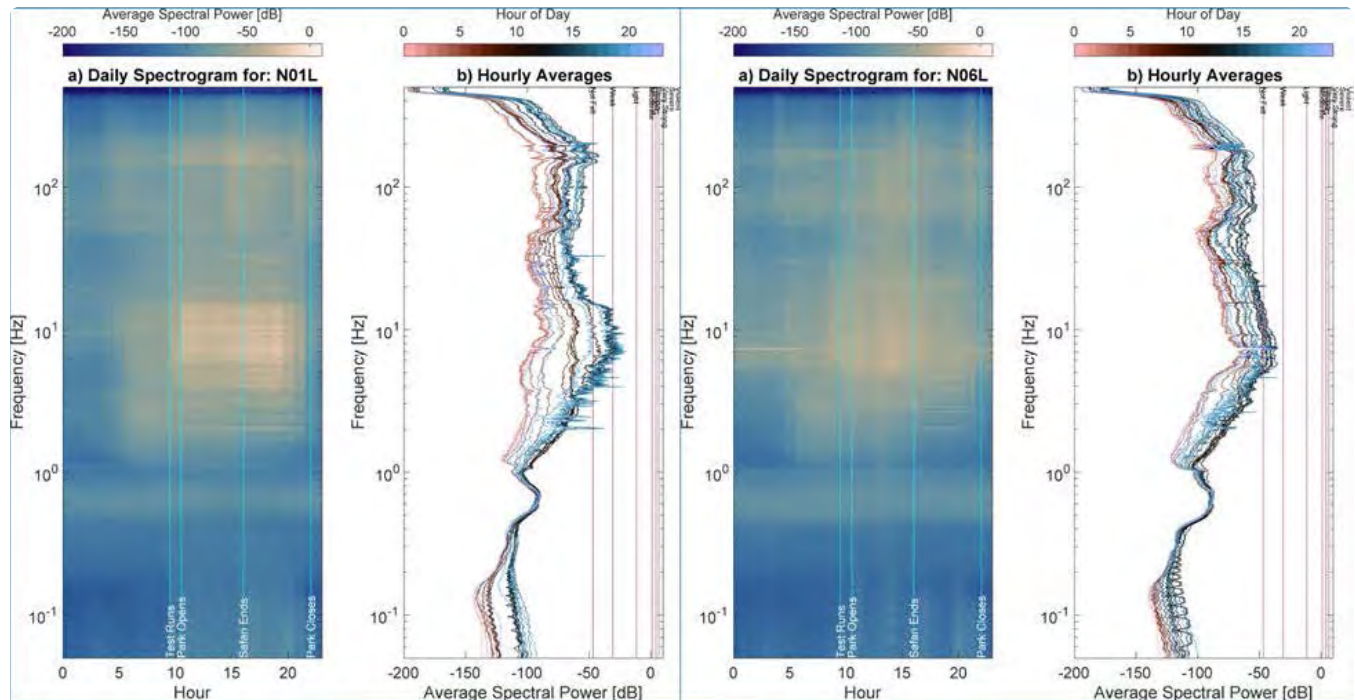


Figure 4: The average daily ground motion over the 31 day deployment, where the left image shows Site #1 (closest to the rollercoasters) and right image is Site #6 (closest to the elephant enclosure). Each image includes a spectrogram (a) and severity of shaking (see Table 2) over how many hours in a day (b). The light blue lines mark when the first roller coaster runs start, average operation time for Six Flags Amusement Park, and when the Wild Safari closes.

Evaluation

After examining the ground motion data, we identified three primary sources of felt vibrations around Six Flags Amusement and Safari Parks (Fig. 5 and 6): 1) Vehicle traffic (close to the elephant enclosure, this is mostly the safari trucks); 2) The Six Flags Water Treatment Plant (a constant hum and vibration from the plant); 3) The park rides, namely the rollercoasters. There is vehicle noise from nearby traffic on the roads and from the safari trucks, which is noticeable for a human standing nearby, registering as moderate to strong ground acceleration (see Table 2). The water treatment plant is producing continuous shaking (at the source this is even more severe than any vehicle traffic (Fig. S2)). The roller coasters are less severe than the vehicular traffic but comparable on the Mercalli scale shown in Table 2 (moderate to strong, Fig. 5).

The elephants are far enough away from the water treatment plant that the vibration from it is attenuated and spread out down into the weak to imperceptible range (for humans) (Fig. 6). The noise by the plant is monotonic

(resonant peak around 7-10 Hz). The plant is detectable at sites #4-7 nearby the elephants (N04, N05, N06, N07), but below detectable vibration levels for humans.

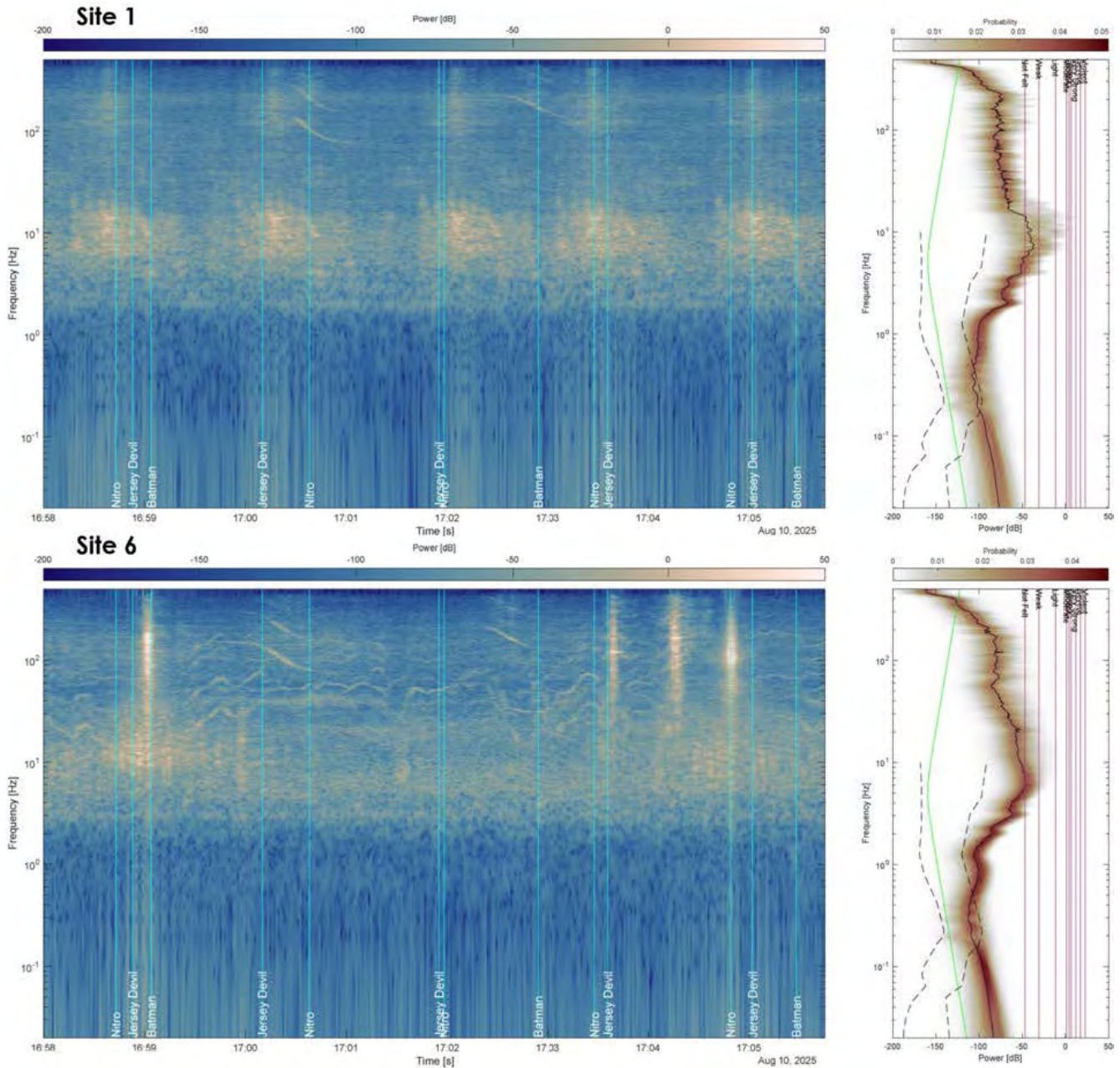


Figure 5: Start times of Nitro, Jersey Devil, and Batman are marked with thin light blue lines in both spectrograms of Site #1 (above) and Site #6 (below). The wispy lines above 10 Hz are audible noise. Due to the Doppler effect, passing vehicles and airplanes are visible as variable frequency lines.

Using the start and end times from the five largest roller coasters collected by the World Animal Protection crew inside the park, we are able to confidently observe Nitro on the nodes, while Jersey Devil and Batman are barely resolvable (Fig. 5). We could not confidently identify El Toro and Medusa roller coasters. Site #1, the closest to the park, best resolves Nitro (Fig. 5). Most of the roller coaster noise is around 5-20 Hz. At the elephant en-

closure, the roller coasters are around the threshold of detection (“not felt” to “weak” shaking for humans; Fig. 6), with pulses of individual roller coaster runs around the weak to light threshold near the elephant enclosure (see Table 2). The noise at Site #4 (N04L) and Site #5 (N05L) is about the same distance to the Nitro roller coaster as the elephant enclosure (Fig. 6 and S2).

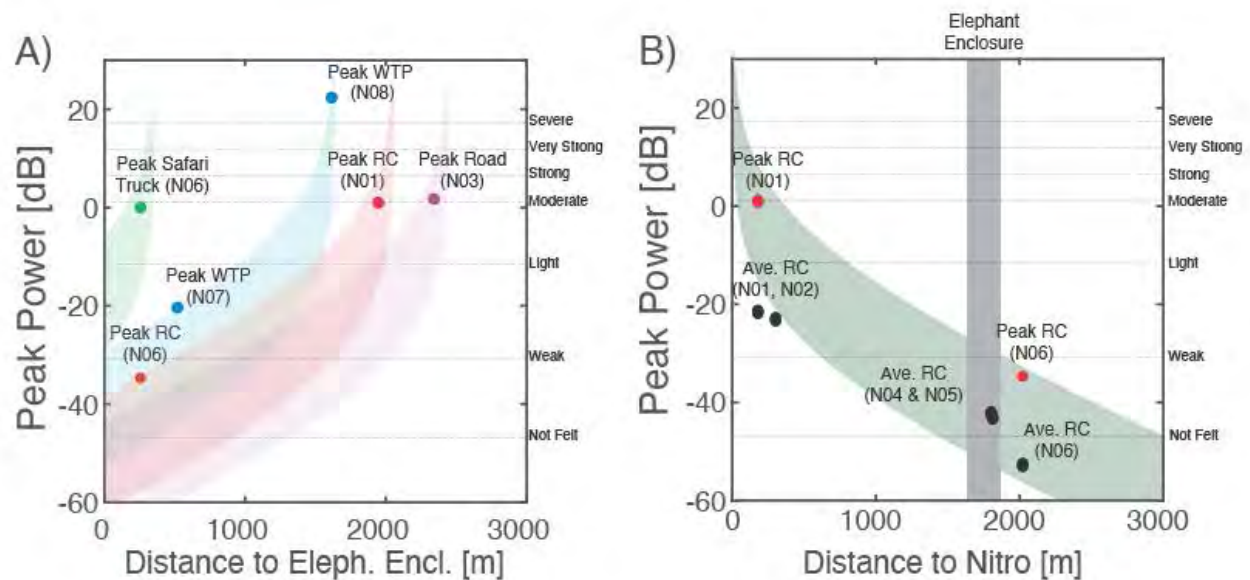


Figure 6: The sources of ground motion around the Six Flags park measured on node instruments. A) Peak ground motion of sources around the park arranged by distance from Joyce’s enclosure. The colored backgrounds are the expected attenuation decays from the source types back to the elephant enclosure. B) Peak ground motion and average ground motion arranged by distance from the Nitro roller coaster attraction. The attenuation decay envelope (green) used for part A are measured from the decay of the roller coaster signals. The location of the elephant enclosure is shaded in gray.

The dominant vibrational noise near the elephants is the Safari truck traffic (Fig. 6). These trucks register on the instruments as loud as heavy traffic 10 meters from a busy road (compare to Site #3, N03L, next to Monmouth Rd; moderate to strong ground motion). Unlike that station though, the Safari Trucks are more spread out in time (one truck every few minutes). The noise from these trucks is observable (Fig. S2) at Site #4 (N04L), Site #5 (N05L), and Site #6 (N06L) and comparable to the ground motion experienced by the elephants (depending on how close the truck approaches on the safari trail).

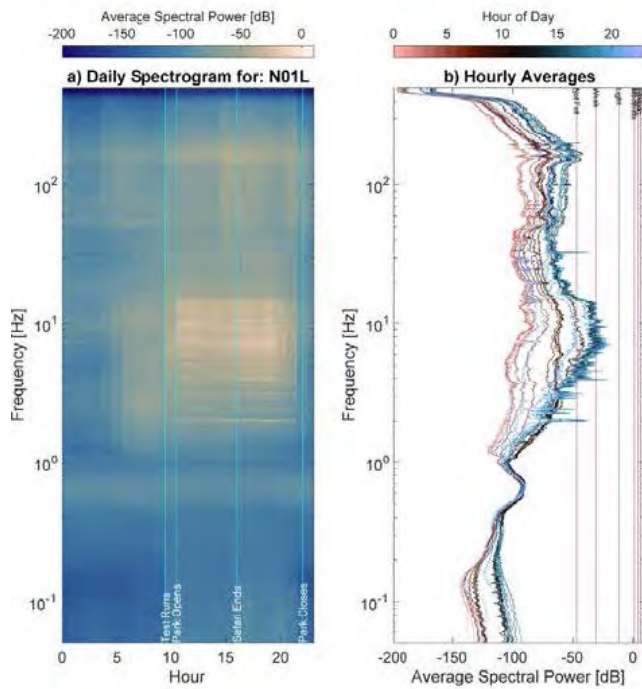
We note that the Mercalli scale (Table 2) used in this study is calibrated to human sensitivity to vibrations and largely based on its effects on structures and the constructed environment. It is unknown if the perceptible level for humans is equivalent to elephants, and what frequencies they are able to detect given their larger size and enhanced hearing acuity. Research on elephant communication suggests that these animals use low frequencies (~10 Hz or less) to detect and communicate with other herds, and that they are sensitive to ground vibrations passing through the ground. The majority of park-related vibrations in this study are felt in the 5-20 Hz or higher range and readily felt by humans.

Supplemental Information

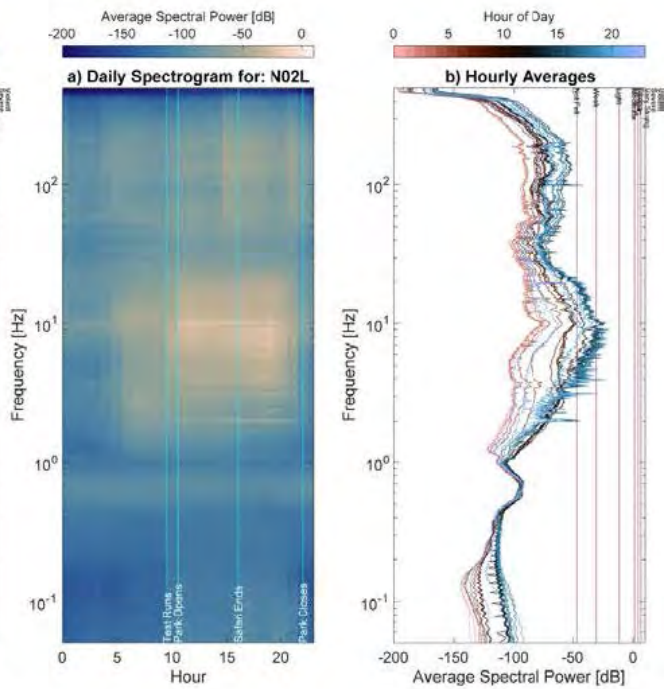


Figure S1: Fairfield ZLand 3C Nodes and deployment. In the larger photo is Hannes Bernhardt (foreground, deployment) and Miguel Endara (background). Ticks were rampant at stations, future studies should ensure participants use proper tick repellent.

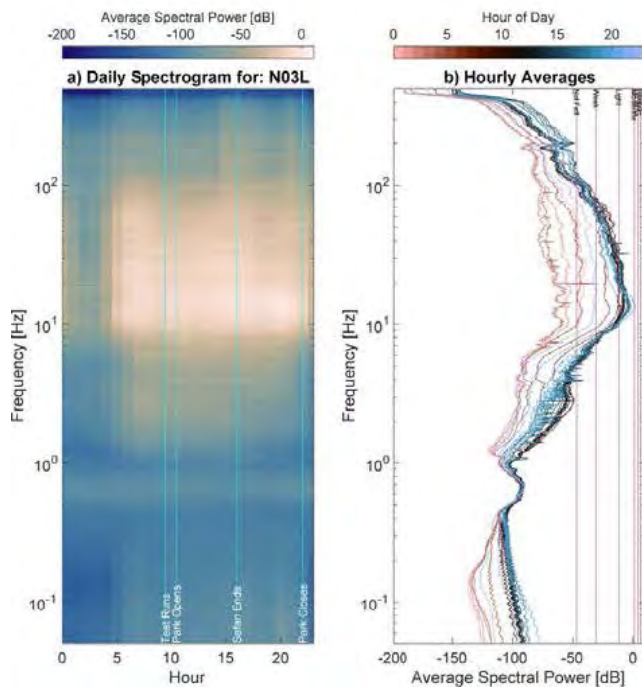
Site 1



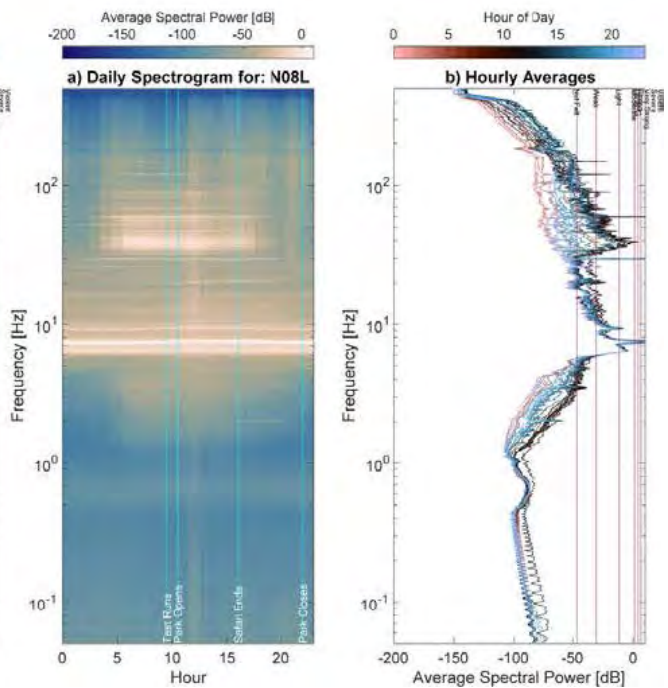
Site 2



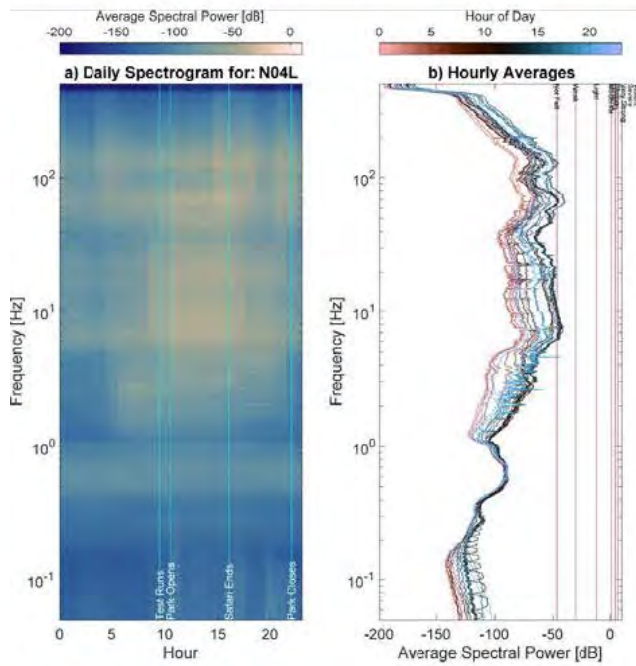
Site 3



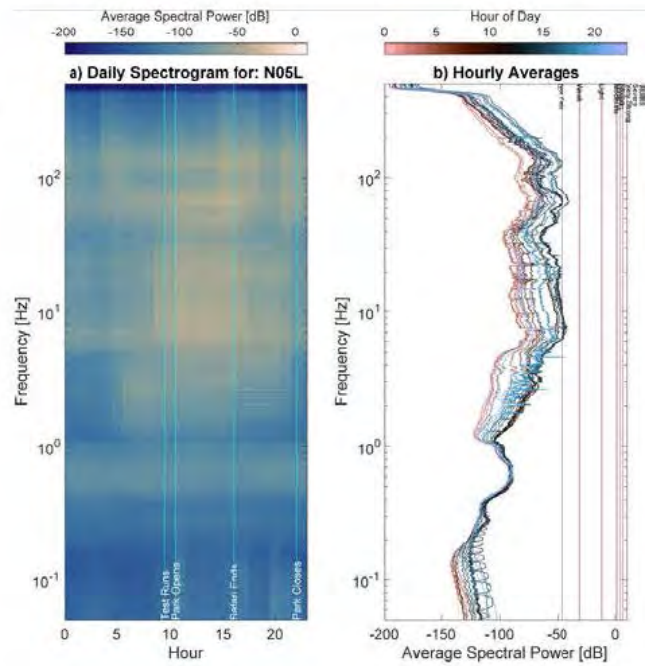
Site 8



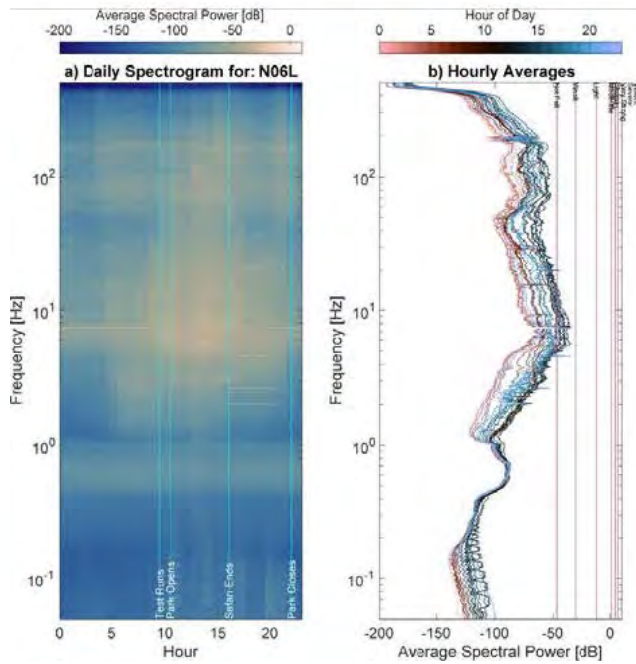
Site 4



Site 5



Site 6



Site 7

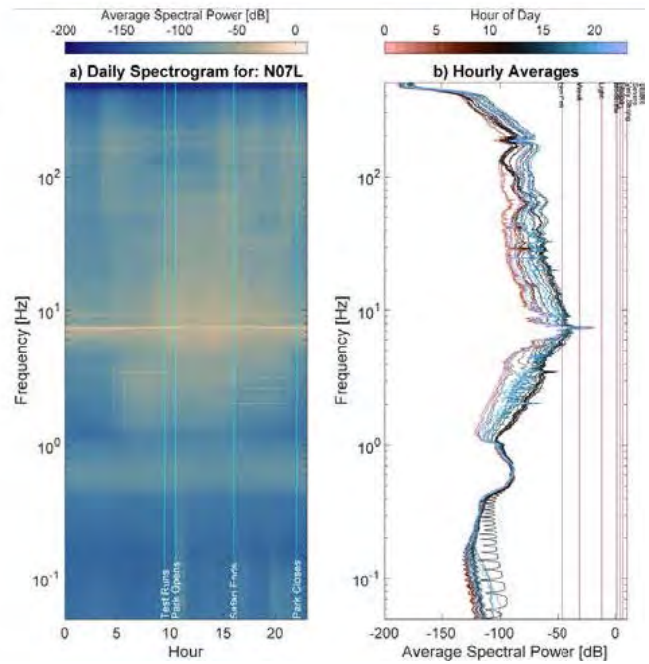


Figure S2: Average daily noise for Sites #1 - #8 during the entire deployment.