Relationship of Airborne Particulate Matter and Daily Temperature to Serum Glucocorticoid Concentrations and Cyclicity Status in Zoo Elephants

A Thesis submitted to the Faculty of the Graduate School of Arts and Sciences at Georgetown University in partial fulfillment of the requirements of the degree of Master of Public Policy

By:

Dessa Marie Dal Porto, B.A., B.S

Washington, D.C.
April 13, 2007
Abstract

Elephants are at the center of a highly intense debate over whether it is ethical to maintain them in western zoos for purposes of research, education or entertainment and zoos are charged with gathering data to identify the best practices for the animals. Some believe it is inhumane to keep elephants in small enclosures, in unrelated groups that are socially unstimulating, and in climates that are unnatural and harsh (Clubb and Mason, 2002). Others argue it is essential to have elephants in zoos because they play a crucial role in educating the public, as a research resource and as a hedge against extinction. One reason this debate is so polarized is that the criteria used for identifying poor animal welfare are usually subjective, based on anecdotes and lacking in scientific evidence. Scientists need to define objective methods to assess psychological states in animals, including elephants, and develop better tools to measure stress, pain and suffering (Brown et al., in press).

This thesis is an attempt to provide scientific backing for elephant management decision making. Using fixed effects and dprobit statistical modeling, this thesis investigates the impact of two potential stressors, air pollution and average daily temperature, on indicators of elephant well-being – reproductive ovarian activity and adrenal cortisol secretion. The data was compiled for this analysis and includes biological...
information obtained from the Smithsonian’s Conservation and Research Center, and air pollution and temperature data from the Environmental Protection Agency and Resources for the Future. This fixed effects results reveals that daily PM2.5 and daily temperature impact daily cortisol concentrations and the dprobit results reveal that average daily temperature and cortisol concentrations impact the likelihood that an elephant is cyclic of not. While few realistic policy implications can come from these results, as it is highly unlikely that animals will be relocated, zoos must take these biological and environmental factors into consideration when managing domestic elephants. Extensive further research is necessary to understand the complex mechanisms of stress, cyclicity and how they are impacted by the natural environment.
This Thesis is dedicated to Bella, an elephant that was born to the Houston Zoological Park and died at the young age of 1.

May the work of elephant conversationalists worldwide improve wild elephant protection and captive elephant breeding and research.

Special thanks go to Winston Harrington, Yatziri Medina, Christine Duce, Jeff Mayer, Dr. Charlie Gaskins and Dr. Janine Brown for their academic and emotional support.

And to Victor Dumas and my parents for their everlasting faith.
# Table of Contents

Introduction .................................................................................................................. 1

Chapter 1: Literature Review ..................................................................................... 2
  Stress and Distress .................................................................................................. 2
  Measuring Stress .................................................................................................... 3
  Stress and Reproduction ......................................................................................... 4
  Air Pollution ........................................................................................................... 5
  Temperature ............................................................................................................ 7

Chapter 2: Theoretical Model .................................................................................... 8
  Hypothesis ............................................................................................................... 8
  Research Design ..................................................................................................... 8
  Data Set .................................................................................................................. 10

Chapter 3: Data Analysis ......................................................................................... 15
  Fixed Effect Model ................................................................................................. 16
  Unexpected Results ................................................................................................. 17
  Dprobit Model ........................................................................................................ 18

Chapter 4: Policy Recommendations ...................................................................... 23
  Daily PM2.5 ............................................................................................................ 23
  Temperature ........................................................................................................... 25

Tables ....................................................................................................................... 27

References .................................................................................................................. 29
Introduction

Elephants are at the center of a highly intense debate over whether it is ethical to maintain them in western zoos for purposes of research, education or entertainment.

Some believe it is inhumane to keep elephants in small enclosures, in unrelated groups that are socially unstimulating, and in climates that are unnatural and harsh (Clubb and Mason, 2002). Others argue it is essential to have elephants in zoos because they play a crucial role: 1) in educating the public about the need for species and habitat preservation; 2) as a research resource to understand biological mechanisms not easily studied in nature; and 3) as a hedge against extinction in case a catastrophe affects the wild population. One reason this debate is so polarized is that the criteria used for identifying poor animal welfare are usually subjective, based on anecdotes and lacking in scientific evidence. Scientists need to define objective methods to assess psychological states in animals, including elephants, and develop better tools to measure stress, pain and suffering (Brown et al., in press).

While the effects of PM2.5 have been extensively researched in humans, there has been no research on the effects of air pollution on the quality of life of zoo animals. Because elephants are exposed to daily air pollution both in and out of doors, it is reasonable to assume that varying levels of air pollution as well as average daily temperature would affect their health and well being. This paper investigates the impact of two potential stressors, air pollution and average daily temperature, on indicators of elephant well-being – reproductive ovarian activity and adrenal cortisol secretion.
Chapter 1. Literature Review

Stress and Distress

Stress has emerged a key indicator of animal well-being, yet there is no one definition for animal stress. Some observers follow intuition and believe stress to be a negative aspect of life. Others believe that stress is merely the “biological response elicited when an individual perceives a threat to its homeostasis” and that it may be, but is not necessarily negative (Moberg, 2000). My thesis adopts the later view – that stress is not necessarily a negative influence. The problem lies in distinguishing distress from stress.

Compounding this problem is the fact that the biological cost of a stress response cannot be used as a litmus test, as it is subjective, and varies by animal, and situation. Each elephant shifts biological functions away from some facilities towards areas where the animal needs more functionality in order to react to the stressor and this adjustment is unique to each animal. Equally subjective is the manner in which each animal is equipped, both behaviorally and genetically, to cope with stress. Just as some humans are most stressed by spiders or high places, elephants may have equally high sensitivities with certain stressors, and there is no way to know which elephants have higher thresholds (Hutchins, 2006).
Measuring Stress

Exposure to a stressor can produce a cascade of psychological and physiological changes. Thus, some researchers contend that stress levels can be measured via behavioral observations or by serum glucorticoid concentrations (cortisol). Currently, the measurement of psychological responses is subjective and relies on non-quantifiable
information. But it is also easily obtained and at a relatively low cost. Behavioral
observations are treated as proxies for animal well-being yet there is no robust evidence
that there is a correlation between the two (Von Holst, 1998; Rushen, 2000). In addition,
serum glucorticoid concentrations (in the case of this paper, cortisol) are an indicator of a
physiological response to a stressor and have been measured in wild and captive elephant
populations (Brown et al., 1995).

Although cortisol is a quantifiable index of stress, there are limitations to
measuring and interpreting the hormone. Collecting blood from an animal is a stressful
act, and can itself induce a rise in serum cortisol levels (Reinhardt et al., 1990; Cook et al.,
2000). Also serum cortisol levels, while quantifiable do not provide any evidence about
cause. Additionally, cortisol is released in a circadian manner with higher concentrations
in the morning hours, and lower concentrations in the evening and variation in timing of
blood tests may result in inaccurate estimations (Weitzman, Fukushima, 1970; Carnes et
al., 1988; Bettinger et al., 1998; Suzuki et al., 1998).

Thus, physiological changes alone are not conclusive stress indicators. To better
comprehend the stress and distress effect on an elephant’s well-being researchers will need
to investigate both psychological and physiological factors. However, due to the lack of
psychological data, this paper will investigate only elephant’s physiological responses.

**Stress and Reproduction**

Studies have found that increased levels of stress lead to decreased levels of
fecundity in many animals, including humans, and that by reducing stress, reproductive
rates may increase. The mechanisms by which stress suppresses reproduction are complex and are not fully understood. However, evidence shows that chronic stress can lead to decreased gonadotropin secretion and reproductive failure (Matteri et al., 2000).

Cortisol has been proven to have a negative correlation with lutenizing hormone, the hormone necessary for ovulation to occur. Thus animals with high levels of stress may not ovulate. If scientists can identify the factors that decrease negative stress and increase quality of life, elephant fecundity may increase. Currently 18% of reproductive age elephants in U.S. zoos that are being hormonally monitored exhibit some form of ovarian dysfunction. The prevalence of flatliners, elephants exhibiting no progesterone cycle, presents a substantial roadblock to the goal of having a self-sustaining zoo elephant population (Brown et al., 2004). Recent evidence indicates that some flatliner elephants fluctuate between periods of cyclicity and non-cyclicity for no known reason. Stress may be a factor in this variation and extensive research is necessary to understand the relationship between stressors and fluctuating cyclicity. This study does not include elephants that fluctuate between cycling and non-cycling and not does attempt to imply cortisol concentrations are the cause of an animal’s cyclicity status. Instead this analysis investigates the cortisol concentrations of elephants, both cycling and flatlining animals, to see if there is an overall trend between the two groups.

**Air Pollution**

This section considers the possible effects of varying concentrations of air pollution on elephant cortisol levels by looking at the effects of air pollution on humans.
It will discuss specifically the effects of fine particulate matter, or liquid droplets, in the air that are 2.5 micrometers in diameter or smaller (PM2.5) or “approximately 1/30 the size of a human hair. High concentrations of airborne particulate matter are proven to be detrimental to human health, specifically in regard to upper respiratory health, heart disease and premature deaths (EPA). Harvard School of Public Health found that, controlling for temperature, humidity, barometric pressure, day of the week and seasonal patterns, an increase in exposure to air pollution (PM2.5) led to a statistically significant increase in deaths in 10 US cities (Schwartz, 2000). Another study found that there is a 4% increase in the risk of dying with each annual 10 microgram per cubic meter increase in PM2.5 (Kaiser, 2005). Yet, another study, funded by the American Cancer Society, found that chronic exposure to PM2.5 causes as much lung cancer as exposure to secondhand smoke. Additional research indicated that children who are reared in areas of California with high levels of PM2.5 have higher incidences of underdeveloped lungs (Gauderman et al., 2004). And a 2004 study reported in Science found that mice exposed to exhaust particles exhibited DNA mutations that were passed on to their young (Somers et al., 2004).

Although studies have not been able to separate the effect of PM2.5 from the effects of other pollutants, a large number of researchers believe the PM2.5-death link to be robust. Daniel Greenbaum, President of the Health Effects Institution in Cambridge, Massachusetts argues that, “there’s an association with particles that doesn’t go away,” and that additional research is needed to identify the relationship between PM2.5 levels and
quality of life (Kaiser, 2005). While this research does not go so far as to correlate PM2.5 levels with elephant death, it does strive to take the first step towards correlating ambient air pollution with animal well-being.

**Temperature**

In contrast to the relative absence of research on air pollution and animal well-being, there has been some investigation of the effects of temperature on animal well-being. But it is unknown how outdoor daily temperature affects elephants around the U.S. (Becker et al., 2005). After investigating four female African elephants from Wildlife Safari in Winston, Oregon, researchers found no correlation between seasonal temperature variations and elephant serum cortisol concentrations. But this study only looked at one facility and was unable to compare between two or more climates (Bechert, et al., 1999). Also since air pollution levels vary with the season and temperature fluctuation, it is highly probable that there will be a strong correlation between the two variables. The present study expands upon Bechert’s work and looks at 62 animals from 22 locations, allowing for comparisons between zoos and animals, resulting in more robust conclusions.

Research into the affects of environmental temperature on domestic animals has resulted in conclusive evidence that “chronic exposure to elevated temperatures... diminished the ability of the hypothalamo-hypophyseal axis to secrete FSH and LH, which (has) physiological consequences on follicular growth” and can greatly decrease animal fecundity (Flowers, 1990). Mature swine are known to have transient periods of
infertility as a result of high temperatures (Wettermann, 1985). A statistically significant correlation has also been found linking high temperatures with female swine not reaching puberty at a normal age (Flowers, 1989). While “the manner by which elevated environmental temperature retards the sexual maturation...is not known” a strong correlation does exist.

Chapter 2: Theoretical Model

Hypothesis

This study hypothesizes that cortisol concentrations and cyclicity status will be impacted by PM2.5 and average daily temperature; high average daily temperature and high levels of PM2.5, independently, will result in increased levels of cortisol and decreased likelihood of ovarian cyclicity.

In order to test this hypothesis, this study will incorporate two separate dependent variables representing well-being (cortisol) and cyclicity status (ovarian cyclicity). Cortisol is used as a proxy for elephant well-being, while cyclicity status is a direct representation of ovarian cyclicity.

Research Design

The key independent variables in this study will be daily PM2.5 levels and average daily temperature. In addition a number of explanatory variables will be included to control for elephant management style, daily temperature variation, animal dominant status, yearly variations and the age of the animal.
**Fixed Effect Model**

Using a two-way demeaned estimation fixed effect model the impact of PM2.5 and average daily temperature on cortisol were examined. Moberg states that “the greatest problem in measuring stress (cortisol) is inter-animal variations in the stress response,” and the fixed effect model overcomes this difficulty by controlling for individual animal cortisol variation (2000, p. 6). The explanatory variables in the model include average daily temperature variation, animal age and year dummy variables - 6 in total - were created to account for yearly differences in cortisol, with 1999 serving as the baseline.

\[
\text{Well-being (cortisol)} = \beta_0 + \beta_1 \text{average daily temperature} + \beta_2 \text{daily PM2.5 level} + \beta_3 \text{age} + \beta_4 \text{daily temperature variation} + 2000\text{dummy} + 2001\text{dummy} + 2002\text{dummy} + 2003\text{dummy} + 2004\text{dummy} + \varepsilon
\]

The coefficients of interest are $\beta_1$ and $\beta_2$.

**Dprobit Model**

Using a dprobit model the impact of PM2.5 and average daily temperature on cyclicity status were examined. The coefficients from this model can be interpreted as the marginal effects on the probability of an elephant cycling for an elephant that has the mean values of each independent variable. A drawback to using the dprobit model is that it is unlikely to have an individual, or a group of individuals, with mean values of the independent variables, but as this model is not for predictive purposes it is acceptable.
Because cyclicity status does not vary within the time period this analysis investigates it was necessary to collapse the data set and create a new data set with mean values of each variable for each animal. The dprobit model uses the collapsed dataset and due to missing data points for some animals the n for the dprobit analysis is 48.

Ovarian cyclicity (cyclicity status) = $\beta_0 + \beta_1 \text{cortisol concentration} + \beta_2 \text{dominance status} + \beta_3 \text{management style} + \beta_4 \text{age} + \beta_5 \text{average daily temperature} + \beta_6 \text{PM2.5}$

The coefficients of interest are $\beta_1$ and $\beta_6$.

**Data Set**

This study is based on a data set compiled specifically for this analysis. The data set is an uneven panel containing weekly data points for 62 elephants from 22 zoos for the years 1999 – 2004. The elephants represent all geographic regions of the continental US and Hawaii as shown in Table 1 and Figure 2.
Well-Being and Cyclicity Measurements

The data for the dependent variables, cortisol, and cyclicity status, are from an elephant database maintained at the Smithsonian Institution National Zoological Park’s

---

1 The 22 Elephant facilities included in this study are: Rio Grande Zoo, Albuquerque, New Mexico; The Maryland Zoo in Baltimore; Elephants of African Rescue Society, Wild Things Animal Rentals, Inc., Salinas, California; Honolulu Zoo, Honolulu, Hawaii; Indianapolis Zoo, Indianapolis, Indiana; Jacksonville Zoo and Garden, Jacksonville, Florida; Kansas City Zoo, Kansas City, Missouri; Knoxville Zoo, Knoxville, Tennessee; Memphis Zoo, Memphis Tennessee; Miami Metro Zoo, Miami, Florida; Nashville Zoo as Grassmere, Nashville, Tennessee; National Zoological Park, Washington, D.C.; Oakland Zoo, Oakland, California; Pittsburgh Zoo, Pittsburgh, Pennsylvania; Riverbanks Zoo and Garden, Columbia, South Carolina; Roger Williams Park Zoo, Providence, Rhode Island; Sedgwick County Zoo, Wichita, Kansas; Seneca Park Zoo, Rochester, New York; Toledo Zoo, Toledo, Ohio; Utah’s Hogle Zoo, Salt Lake City, Utah; Virginia Zoological Park, Norfolk, Virginia; Wildlife Safari, Winston, Oregon).
Conservation and Research Center (CRC) in Front Royal, VA. Serum were acquired from zoos that submitted samples to the CRC laboratory for diagnostic evaluation of ovarian cyclicity. All serum cortisol and progesterone analyses were conducted at the CRC laboratory; thus, there was no inter-laboratory variation.

Animals and Sample Collection

Serum samples, collected approximately weekly for elephants housed at 22 facilities in North America were utilized in this study. In general, blood was collected from a vein on the caudal aspect of the ear while in lateral recumbency, or from the saphenous vein in the leg. Samples were collected in the morning in conjunction with the daily bath routine. All elephants were well-conditioned to blood sampling procedures, which were part of the management routine. Blood was maintained at ~4°C and centrifuged (~1500 g) within a few hours of collection, and the serum stored at ~20°C until analysis. Age ranged from 14 to 56 years with a mean of 26.79 and a standard deviation of 8.58 (Table 4). Elephants were managed under a free (n = 42) or protected (n = 20) contact system.

Radioimmunoassays

Each sample was analyzed for concentrations of cortisol and progesterone using solid-phase I\textsuperscript{125} radioimmunoassays (RIA) (Count-A-Count; Diagnostic Products Corporation, Los Angeles, CA) previously validated for elephants (Brown and Lehnhardt, 1995, 1997; Brown et al., 1991, 1999a,b). Each assay was modified by halving amounts of reagents and sample (25 µl sample or standard, 500 µl tracer). Additional low standards
(2.5 and 5 ng/ml) also were prepared by diluting the provided 10 ng/ml standard. Assay sensitivity was 2.5 ng/ml at 90% binding. For all assays, intra- and inter-assay coefficients of variation were <10% and <15%, respectively.

**Temperature and Pollution Measurements**

The data for air pollution and temperature were acquired from the Environmental Protection Agency National Air Data Group with the assistance of Resources of the Future. Average daily temperature, maximum daily temperature and daily PM2.5 levels were extracted for all zoos, and minimum daily temperature was extracted for 14 of the 22 zoos. The control variable of daily temperature variation was created from subtracting the minimum daily temperature from the maximum daily temperature.

**Control Variables**

Control variables in the dataset include dominance status, management style and age. Data for all three of these variables was obtained from the CRC database, in accordance with American Zoological Association information.

In total, the sample size is 6801.\(^2\) The size of the data set will enable me to generate precise estimators due to the significant degrees of freedom. The data set also contains all of the variables of interest and an adequate number of control variables. Descriptive statistics for the variables in this analysis are included in Tables 4 and 5.

While the dataset is robust, several potential problems exist.

---

\(^2\) The fixed effect model utilizes a sample size of 3231, as some zoos do not have data for minimum temperature, thus temperature variation could not be calculated and the observations were dropped from the analysis.
First, the data set is not evenly distributed across the country, and certain areas, such as Kentucky and the mid west, are over represented.

Table 1
Geographical Distribution of Elephants

<table>
<thead>
<tr>
<th>Region</th>
<th>States in region</th>
<th>Number of elephants in Region</th>
<th>% of total population in study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific States</td>
<td>WA, OR, HI, CA, AK</td>
<td>9</td>
<td>15%</td>
</tr>
<tr>
<td>Mountain States</td>
<td>CO, ID, MT, NV, UT, WY</td>
<td>2</td>
<td>3%</td>
</tr>
<tr>
<td>Midwest States</td>
<td>IL, IN, IA, KS, MI, MN, MO, NE, ND, OH, SD, WI</td>
<td>14</td>
<td>23%</td>
</tr>
<tr>
<td>Southwest States</td>
<td>AZ, NM, OK, TX</td>
<td>3</td>
<td>4%</td>
</tr>
<tr>
<td>South States</td>
<td>AL, AR, FL, GA, KY, LA, MD, MS, NC, SC, TN, VA, WV</td>
<td>26</td>
<td>42%</td>
</tr>
<tr>
<td>Atlantic States</td>
<td>CT, DE, ME, MA, NH, NJ, NY, PA, RI, VT</td>
<td>8</td>
<td>13%</td>
</tr>
</tbody>
</table>

Second, if stress induced by air pollution is chronic, rather than acute, cortisol levels may be elevated or suppressed above or below normal levels, due to desensitization or sensitization of the stimuli following repeated exposure. J.L. Brown et al. describes the perplexing situation of “...chronically-stressed individuals can produce paradoxically low corticoid (cortisol) concentrations that are indistinguishable from unstressed subjects” as a challenge to interpretation of stress hormone data (in press, p. 10). J. Ladewig found that repeated exposure to a stressor can result in sensitization, desensitization or no alternation of the stress response and there is no way to know how an animal reacts to chronic stress.
other than individual investigation. Ladewig (2000) found that “there are indicators that exposure to a stressor of low intensity (which PM2.5 or temperature are categorized as) will cause desensitization to that particular stressor...” (p. 165). If chronic air pollution is the case cortisol concentrations might be skewed as a result and the analysis will not reflect the influence of air pollution on an animal well-being.

Third, while all zoos attempt to take blood draws at the same time each day it is highly unlikely that there is no time variation in the blood draws. The variations in timing of blood draws could result in fluctuations of cortisol due to normal circadian rhythms of cortisol secretion. J. Brown (2000) found that urinary concentrations of cortisol in three Asian elephants varied throughout the day with highest cortisol concentrations in the morning and decreasing concentrations throughout the day. Brown concluded, “...when designing ‘stress monitoring studies,’ timing of (medium) collection should be standardized for accurate data interpretations (p. 362).

Chapter 3: Data Analysis

The following discussion will first focus on the results of the fixed effects model, emphasizing the unexpected results. Second, the dprobit model analysis will be discussed. Each model’s results will be examined as they relate to the hypothesis and the impact daily PM2.5 and average daily temperature can have on elephant well-being and cyclicity.
The fixed effect model results provide some support to the hypothesis that there is a correlation between daily PM2.5 values and cortisol concentrations. Daily PM2.5 levels did have a statistically significant effect, at the .05 level, on elephant cortisol concentrations; with a one-unit increase in daily PM2.5 levels resulting in a .0045 ng/dl increase in cortisol. The concern that chronically high cortisol levels would result in suppressed cortisol, and a negative relationship between cortisol and daily PM2.5, is not validated by these results. It is either the case that elevated cortisol is not chronic, and does not initiate the negative feedback mechanism that suppresses cortisol, or the instances of chronic elevated cortisol resulting in cortisol suppression are less frequent than acute elevated cortisol as a result of elevated daily PM2.5.

Average daily temperature did not have a statistically significant effect on cortisol concentrations as predicted in the hypothesis. These results coincide with the finding of Bechert et al. in which no relationship between serum cortisol concentrations and temperature was found to be significant (1999). The only statistically significant explanatory variable was daily temperature variation, which is discussed in the next section.

The explanatory power, F-test and R-squared, of this analysis indicate that, while we can reject the null hypothesis that all of the coefficients are equal to zero, there is still a great deal of uncertainty in the model as the predicted values to not correlate that highly.

---

3 The n for this model (3231) was smaller than the entire dataset due to the fact that not all zoos had data for daily temperature variation.
with the actual. This is an acceptable discrepancy, as the model is not to be used as a predictive model.

Table 2
Fixed Effect Model Results

| Dependent Variable | P>|t| | Coefficient | Standard error |
|--------------------|-----|----------------|---------------|
| Cortisol (ng/dl)   |     |                |               |
| Average Daily Temperature | 0.182 | -0.001 | 0.001 |
| Daily PM2.5        | 0.051** | 0.004 | 0.002 |
| Age                | 0.455 | -0.045 | 0.06 |
| Daily Temperature Variation | 0.037** | -0.005 | 0.002 |
| Year Dummy - 2000  | 0.202 | 0.429 | 0.336 |
| Year Dummy - 2001  | 0.750 | 0.110 | 0.346 |
| Year Dummy - 2002  | 0.529 | 0.233 | 0.37 |
| Year Dummy - 2003  | 0.326 | 0.397 | 0.404 |
| Year Dummy - 2004  | 0.235 | 0.528 | 0.445 |
| Constant           | 0.065* | 2.56 | 1.386 |
| Number of Obs.     | 3231 |                 |               |
| Prob>F             | 0.0000*** |             |               |
| R Squared Within   | 0.014 |                |               |
| R Squared Between  | 0.011 |                |               |
| R Squared Overall  | 0.003 |                |               |

significance: *, p< .10 level; **, p< .05 level; *** p< .01 level.
n = 3231, 38 elephants represented

Unexpected Results

The most curious discrepancy between the original hypothesis and the analysis results is the statistical significance of the daily temperature variation and the lack of statistical significance of average daily temperature. Daily temperature variation was originally included in the model as an explanatory variable and is significant at the 0.05 level. The findings illustrate that animals that reside in zoos where the daily temperature
variation is larger have lower cortisol concentrations than zoos residing in locations where
the temperature does not vary greatly throughout the day. Because daily temperature
variation and average daily temperature are positively, though mildly, correlated, omitting
daily temperature variation would have resulted in omitted variables bias. Because daily
temperature would have been upwardly biased, and appear more to have more of an
influence that it truly does, if daily temperature variable had been omitted from the
analysis.

**Dprobit Model**

The results from the dprobit analysis are convincing that there is a statistically
significance relationship between cortisol and cyclicity status and average daily
temperature and cyclicity status. The relationships are robust, as they are significant at the
.10 level with a small sample size of 48 elephants.

The relationship between cortisol and cyclicity status was not accounted for in the
hypothesis and thus this does not support or refute the hypothesis. The evidence shows
that the higher an elephants cortisol concentrations the less likelihood the animal is to be
cycling, and thus reducing cortisol concentrations, stress levels, is important for an
elephants’ fecundity. It cannot be concluded that all stimuli that elicit a stress response
should be eliminated from elephant contact, as “stress represents an important part of life
and should not be considered as inherently bad” (Wielebnowski, 2003, p. 973).

\(^4\) Correlation of + 0.1807
In regard to the magnitude of the relationship between cortisol and cyclicity status, we must exercise caution as the wide confidence interval (−.594, .019) suggests the magnitude of the relationship is inconclusive. The analysis indicates that a one unit increase in cortisol resulting in a 33 percentage point decrease in the probability of an elephant cycling, yet the large confidence interval indicates that the magnitude of the coefficient should not be interpreted literally. These are marginal effects on the probability of cycling for the individual with the mean values of each independent variable and it is highly unlikely to have an individual or a group of individuals with mean values of the independent variables. Like the fixed effects model, this is not a predictive model and is should only be analyzed to estimate significant relationships.

In an effort to increase the sample size, the dprobit model was analyzed using imputed data for the 12 elephants with missing data for dominance status. The results were inconclusive; the dummy variable for the imputed data indicated that the imputed values were statistically significant, rending the model biased. Further research, with larger sample sizes, is necessary to illustrate the magnitude of the relationship between cortisol and cyclicity status.

---

5 The inclusion of imputed dominance status data increased the n from 48 to 60, an increase of 20%.
While it would increase the size of the sample set to exclude dominance status, it cannot be excluded because without it, cortisol would be biased towards zero as a result of omitted variable bias. The affect of cortisol on cyclicity status is masked when dominance status is excluded from the relationship because cortisol and dominance status are negatively correlated. Dominant animals exhibit lower concentrations of cortisol, and it is necessary to control for this relationship in the model. There may be other relationships between the independent variables that are not accounted for in this model and further
research in necessary to investigate the possibilities. Further research might look into the amount of exposure elephants have to the public, the length of time elephants are enclosed indoors, construction near their enclosure and elephant health condition. Because this analysis is one of the first examining the relationship between elephant cortisol concentrations and environmental and physiological factors additional research should be conducted to validate the results.

The dprobit results support the hypothesis that average daily temperature will impact cyclicity status, and, as predicted, high average daily temperature results in decreased likelihood of cyclicity. A one-unit increase in average daily temperature resulting in a 2 percentage point decrease in the probability of an elephant cycling. The confidence interval for this relationship is narrow, thus indicating that the magnitude of the relationship estimated by this model is close to the true magnitude.\(^6\) Though this analysis provides evidence that there is a statistically significant relationship between average daily temperature and cyclicity status, the evidence is not definitive and further research is necessary.

The explanatory variables dominance status, management style and age have no statistically significant relationship to the probability of whether an elephant is cycling of not, nor was the variable of interest, daily PM2.5. This does not support the hypothesis that daily PM2.5 would impact cyclicity status; higher levels of daily PM2.5 do not influence elephant ovarian cyclicity.

\(^6\) The confidence interval for average daily temperature is (-.041, .00070).
The explanatory power of the equation, the likelihood ratio chi-square of 10.81 and a Prob>chi2 of 0.0943, indicate that the model as a whole is statistically significant at the 0.1 level. It is highly unlikely, below the 90% level, to obtain a chi-square statistic of this value if at least one of the coefficients is not equal to zero. The pseudo R-squared is provided in the dprobit model (.1814) but is not a true equivalent to the OLS R-squared and should be interpreted with great caution, with little emphasis placed on the value.

Table 3
Dprobit Model Results

| Dependent Variable | P>|z| | dF/dx | Standard error |
|--------------------|------|-------|-----------|
| Cyclicity Status (0 = not cycling; 1 = cycling) | | |
| Independent variables: | | |
| Cortisol (ng/dl) | 0.067* | -0.288 | 0.156 |
| Dominance Status | 0.454 | -0.043 | -0.043 |
| Management Style^ | 0.946 | 0.010 | 0.145 |
| Daily PM2.5 | 0.219 | 0.036 | 0.029 |
| Age | 0.26 | -0.013 | 0.012 |
| Average Daily Temperature | 0.060* | -0.020 | 0.02 |
| Number of Obs. | 48 | | |
| Prob>chi2 | 0.0943* | | |
| Pseudo R2 | 0.181 | | |

Significance: *, p< .10 level; **, p< .05 level; *** p< .01 level.
^ dF/dx is for discrete change of dummy variable from 0 to 1
n = 48, 48 elephants represented

7 Prob>chi2 is equivalent to a P value.
Chapter 4: Policy Recommendations

The questions facing zoos include how best to create an environment for an elephant that reduces distress, has an adequate amount of positive stimuli, is conducive to reproduction and is within the financial capacity and spatial boundaries of the facility. The policy implications for these findings are complex and one must take into consideration not only the findings of this research, but also the natural restrictions of finances, space, and practicality before making a recommendation.

To review, fixed effects model results indicate that PM2.5 and daily temperature variation have are a statistically significant impact on cortisol concentrations and the dprobit model results indicate that cortisol levels and average daily temperature have a statistically significant impact on cyclicity status. There is overlap in these findings, in that daily PM2.5 impacts cortisol levels and cortisol levels impact cyclicity status yet daily PM2.5 is not significant in regards to cyclicity status, and additional research is necessary to further investigate the interwoven relationships between the factors influencing cortisol concentrations and cyclicity status.

**PM2.5**

Increasing the fecundity and well-being of zoo elephants are the two highest priorities within the elephant research community, and are essential to maintain a sustainable elephants population within US zoos. The above results indicate that environmental factors do influence well-being and zoos should take this into consideration when making decisions. Yet it is highly unlikely that zoos will relocate to
areas with lower PM2.5 levels and small ranges of daily temperature variation. The costs of relocation and new facility construction in addition to the high stress imparted on the elephants as a result of the move do not out weigh the benefit of the reduced stress because of lower daily PM2.5 and temperature variation.

Even if zoos were to move locations it is not necessarily the case that a zoo could relocate to a more rural area and be in an environment with lower daily PM2.5. As Pope II et al. concluded, Huntington, West Virginia, a rural location, had higher levels of daily PM2.5 that New York City, an obviously urban location, due to its proximity to coal-fired power plants (2002). Extensive research would need to be conducted to identify locations suitable for elephant facilities and this would add to the costs of the move, reducing the practicality.

To further complicate the situation, PM2.5, due to the small size of the material, is known to travel long distances and affect areas other than near the origin of the pollution. As the EPA website confirms, “...one-third of the haze seen over the Grand Canyon comes from Southern California” and is not produced nearby. In conclusion, a policy recommendation that requires zoo relocation is impractical and expensive.

While zoos cannot change their location they can change zoo policies. PM2.5 is a result of “fuel combustion from automobiles, power plants, wood burning, industrial processes and diesel powered vehicles such as buses and trucks” and zoos can enact policies to reduce emissions (EPA, Laboratory). The small change of using electrical or natural gas powered vehicles and machinery instead of diesel or gas powered equipment,
though this would not affect transitory PM2.5 from other facilities, could reduce zoo PM2.5 levels.

Zoo management could also enact policies of how long elephants remain indoor or outdoor during the day. Just as humans are notified of days when pollution is abnormally high, elephants could be required to remain indoors when PM2.5 reached a certain level.8

**Temperature**

Animal rights activists have long argued that housing elephants in colder climates is inhumane and cruel. They argue, as the organization Save Elephants In Zoos does, that, “Zoos in cold climates pose additional health threats to elephants, who originate from the warm, temperate regions of Africa and Asia. Cold winters force elephants indoors for months at a time, into cramped enclosures...” The results from this analysis indicate exactly the opposite. Elephants housed in colder climates in fact are more likely to be cycling. These finding correlate with Matteri et al., who states that “The sensitivity of the (hormones controlling ovulation) to environmental temperature is well recognized” and “Heat stress has repeatedly been shown to exert inhibitory effect on (cyclicity)” (2000, p. 54). There is little evidence as to the effects of colder temperatures on cyclicity.

If temperature is to play a role in deciding elephant management, these findings conclude that for improved elephant fecundity, animals should not be housed in warmed climates as animal rights advocates believe, but in colder climates with less temperature

---

8 This is assuming indoor air pollution is lower than outdoor air pollution.
variation. But, just as it is unlikely that zoos will relocate, it is also unlikely that animals will be relocated as a result of the finding that elephants are more likely to cycle in colder temperatures. While few elephant management policy recommendations will come as a result of these findings, this thesis is step towards analytically investigating the animal rights issues of elephant management. The American Zoological Association and elephant rights organizations can begin to discuss the matters to elephant well-being with anecdotal evidence.

Overall, this study recommends that zoos work to decrease the levels of PM2.5 and, while it is impractical to relocate animals, to consider the effects of average daily temperature and temperature variation on elephant fecundity and well-being. Additional research is necessary to further investigate the impact of environmental and physiological stressors on elephant well-being and cyclicity.
### Tables

**Table 4**

Descriptive Statistics

Fixed Effects Model

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>6978</td>
<td>26.79</td>
<td>8.58</td>
<td>14</td>
<td>56</td>
</tr>
<tr>
<td>Cortisol (ng/dl)</td>
<td>6976</td>
<td>1.6</td>
<td>1.11</td>
<td>0.25</td>
<td>20.8</td>
</tr>
<tr>
<td>Cyclicity Status*</td>
<td>6801</td>
<td>0.76</td>
<td>0.43</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Dominance Status</td>
<td>5387</td>
<td>3.22</td>
<td>1.37</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Management Style*</td>
<td>6917</td>
<td>0.73</td>
<td>0.44</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>PM2.5 Daily Value</td>
<td>5965</td>
<td>13.08</td>
<td>8.1</td>
<td>0.85</td>
<td>67.8</td>
</tr>
<tr>
<td>Minimum Daily Temperature</td>
<td>3243</td>
<td>51.45</td>
<td>17.03</td>
<td>-6.3</td>
<td>80.24</td>
</tr>
<tr>
<td>Maximum Daily Temperature</td>
<td>6104</td>
<td>69.55</td>
<td>18.35</td>
<td>13</td>
<td>109.6</td>
</tr>
<tr>
<td>Average Daily Temperature</td>
<td>6103</td>
<td>59.71</td>
<td>16.93</td>
<td>6.35</td>
<td>93.2</td>
</tr>
<tr>
<td>Daily Temperature Variation</td>
<td>3243</td>
<td>20.61</td>
<td>7.49</td>
<td>-11.43</td>
<td>45.45</td>
</tr>
</tbody>
</table>

* is a dichotomous variable, 0 or 1
### Table 5
**Descriptive Statistics Dprobit Model**

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortisol (ng/dl)</td>
<td>62</td>
<td>1.643</td>
<td>0.645</td>
<td>0.814</td>
<td>4.906</td>
</tr>
<tr>
<td>Cyclitiy Status*</td>
<td>61</td>
<td>0.721</td>
<td>0.452</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Dominance Status</td>
<td>49</td>
<td>3.224</td>
<td>1.388</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Management Style*</td>
<td>61</td>
<td>0.672</td>
<td>0.473</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>PM2.5 Daily Value</td>
<td>62</td>
<td>12.424</td>
<td>3.53</td>
<td>3.792</td>
<td>17.638</td>
</tr>
<tr>
<td>Age</td>
<td>62</td>
<td>26.55</td>
<td>7.827</td>
<td>15.545</td>
<td>53.298</td>
</tr>
<tr>
<td>Average Daily Temperature</td>
<td>62</td>
<td>59.854</td>
<td>7.53</td>
<td>44.829</td>
<td>76.991</td>
</tr>
</tbody>
</table>

* is a dichotomous variable, 0 or 1
References


