An Epidemiological Approach to Welfare Research in Zoos: The Elephant Welfare Project

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Multi-institutional studies of welfare have proven to be valuable in zoos but are hampered by limited sample sizes and difficulty in evaluating more than just a few welfare indicators. To more clearly understand how interactions of husbandry factors influence the interrelationships among welfare outcomes, epidemiological approaches are needed as well as multifactorial assessments of welfare. Many questions have been raised about the housing and care of elephants in zoos and whether their environmental and social needs are being met in a manner that promotes good welfare. This article describes the background and rationale for a large-scale study of elephant welfare in North American zoos funded by the (U.S.) Institute of Museum and Library Services. The goals of this project are to document the prevalence of positive and negative welfare states in 291 elephants exhibited in 72 Association of Zoos and Aquariums zoos and then determine the environmental, management, and husbandry factors that impact elephant welfare. This research is the largest scale nonhuman animal welfare project ever undertaken by the zoo community, and the scope of environmental variables and welfare outcomes measured is unprecedented.

Keywords: elephant, welfare, husbandry, management, epidemiology

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Zoos present a challenging environment in which to study nonhuman animal welfare. Similar to other areas of applied animal welfare research, assessing how the captive zoo environment impacts individuals or populations of animals requires structured empirical methodology. However, zoos are unique among captive settings with respect to both the types of questions asked about animal welfare and the methods that can be used in pursuit of answers. Researchers studying animals in the zoo setting usually cannot rely solely on the standard experimental toolkit for investigative work but must instead think creatively about the application and integration of multidisciplinary techniques.

Zoo-based research can be problematic from a methodological perspective because the number of animals available to study at any one institution is usually limited. Small sample sizes do not preclude researchers from carrying out informative welfare research in zoos, but they do limit the types of questions that can be addressed and the utility of the resulting data. For example, Swaisgood and Shepherdson (2005) reviewed 41 studies investigating the impacts of environmental enrichment on stereotypy in various zoo animals. These studies had sample sizes of 1 to 17 (excluding a questionnaire study) and were generally experimental in nature; most often, each animal served as his or her own control. Although collectively these studies indicated that enrichments generally reduce stereotypic behavior, methodological challenges (see Kuhar, 2006; Swaisgood & Shepherdson, 2005) can prevent broader application of results to a population level. These include violation of statistical assumptions, failure to control for potential confounds, or use of specific methods tailored to the animals or site (see Kuhar, 2006; Swaisgood & Shepherdson, 2005).

One approach to dealing with small sample sizes in zoo settings is the use of multi-institutional studies. This approach has been promoted as a promising method for enhancing the utility of zoo-based animal welfare research (i.e., Hill & Broom, 2009; Swaisgood & Shepherdson, 2005; Watters & Wielebnowski, 2009). However, a controlled experimental approach is particularly difficult to apply in a multi-institutional design. Although there are standards of animal care that guide the practice of accredited zoos (Association of Zoos and Aquariums [AZA], British and Irish Association of Zoos and Aquariums, European Association of Zoos and Aquariums, etc.), modern zoos do not follow a formulaic approach to animal care. Zoo sites may vary considerably with respect to environmental, social, and management factors, and these may be difficult or impossible to sufficiently standardize. Therefore, it is essential that alternatives to controlled experimental methods be employed.

**EPIDEMIOLOGICAL STUDIES AND WELFARE**

Although opportunities to utilize multi-institutional experimental methodology in zoos are particularly scarce, zoos are not the only context in which nonexper-
imental approaches to data collection are important. The field of animal welfare science began in the 1960s, largely in response to concerns about the housing and management of animals on the farm. Initially, the approach was mainly experimental, involving mostly small-scale studies conducted under controlled conditions (see Appleby, Mench, Olsson, & Hughes, 2011). The goals of these studies varied, and the approaches ranged from very theoretical (e.g., studying animal cognition or mental states) to very applied (e.g., evaluating or redesigning flooring surfaces for cattle). An important goal of many studies, however, was to determine the factors contributing to welfare problems commonly observed in production settings, including abnormal and injurious behaviors, health problems, pain or distress, and excessive fearfulness.

As the field developed, it became apparent that experimental-scale studies needed to be complemented by research conducted in the field (e.g., on-farm) in order for practical improvements in animal welfare to be achieved. This is because the causes of welfare problems are often multifactorial. Lameness in meat-type poultry, for example, can be influenced by many factors, including genetics; husbandry practices related to lighting, nutrition, stocking density, and enclosure substrate quality; and the presence of infectious agents in the environment (Mench, 2004). It is virtually impossible to study all of these factors and the ways they interact using traditional experimental approaches. For this reason, Rushen (2003) argued for the adoption of more epidemiologically based approaches to animal welfare research and assessment.

Epidemiology is a term that describes the study of patterns in defined populations. The aim of an epidemiological study is to understand the prevalence of hazards and the risk factors associated with their occurrence. Once the factors are identified, effective strategies can be developed to minimize those risks and decrease the prevalence of the hazards (Noordhuizen & Frankena, 1999). This methodology has been employed for many years for zoo animal research in the areas of veterinary medicine and disease. However, only recently have veterinary epidemiologists and animal welfare scientists begun working together to apply epidemiological approaches to study animal welfare problems in captive environments (Duffield, Leslie, Lissemore, & Millman, 2009; Millman, Johnson, O’Connor, & Zanella, 2009) in a variety of settings and contexts, not just zoos and production agriculture.

There are many advantages to conducting epidemiological studies. Variability in facilities and management styles between zoos, farms, laboratories, and other settings in which animals are kept is considerable, and epidemiological approaches can “capture” that real-world variation in a way that experimental studies cannot. Epidemiological studies are a good way to identify the interactions of environmental and management factors that can lead to welfare problems and thus identify areas for improvement. Such approaches are also useful for evaluating welfare problems that may be serious but are of such low prevalence that they would be difficult to study otherwise.
Epidemiological Data Collection

Several approaches can be taken to collecting data for welfare epidemiological analysis, each of which has strengths and limitations. Although the method of data collection used depends upon the study question and goals, it is also influenced by technical, financial, and/or logistical constraints.

One method of data collection involves surveying people familiar with the subject population (i.e., animals). This method can be used to identify both risks and outcomes. For example, Pötzch, Lewis, Nicol, and Green (2001) surveyed laying-hen producers about their housing systems, lighting, feeding practices, and incidences and types of flock health problems. They then modeled the responses in order to determine risk factors for the occurrence of a serious injurious behavior, vent pecking. Survey methods like this allow the collection of large amounts of information at relatively low cost but introduce an element of unreliability because they depend upon the knowledge and skills of the individuals being surveyed, in particular their ability to accurately recognize and characterize the welfare outcomes that are of interest to the researchers.

Another method involves using preexisting data that were collected for a different purpose to identify risks and/or outcomes of interest (retrospective analysis). In a study of this type, Dewey et al. (2009) used production data collected by Ontario Pork as part of their producer payment records, in combination with weather data, to determine the temperature-related risk factors for pig mortality during transport. Historical data like these are useful for understanding changes in risk factors and prevalence, but their accuracy is difficult to validate and they may not accurately reflect current conditions across institutions or settings.

Data may also be collected directly from the population that has been selected for the study. Garner, Dufour, Gregg, Weisker, and Mench (2004) used this method to evaluate the relationships between cage design, social factors, genetics, and the incidence and severity of an abnormal behavior—barbering—in colonies of mice in the laboratory. Similarly, Lombard, Tucker, von Keyserlingk, Koprul, and Wear (2010) evaluated the relationships between cow hygiene, hock injuries, and free stall usage on U.S. dairy farms using data collected from those farms during visits by trained assessors. These kinds of data are more easily validated, but historical data that may be important to understanding prevalence are not taken into account (Lombard et al., 2010).

MULTI-INSTITUTIONAL STUDIES OF ZOO ANIMAL WELFARE

Early multi-institutional studies in zoos focused primarily on evaluating care and husbandry methods for a particular species. These generally involved surveys to
determine what zoos were doing for a species to establish husbandry guidelines by consensus. However, these only identified what was traditional, with little or no empirical evidence of welfare implications (Melfi, 2009).

In the late 1970s, zoo researchers began evaluating welfare by investigating links between environmental or management factors that varied between institutions and behavioral indicators of welfare. For example, an early study of stereotypy in zoo-housed bear species found that cage size and topography were associated with levels of stereotypic pacing (Van Keulen-Kromhout, 1978). Multi-institutional studies of red pandas (Roberts, 1989) and gorillas (Miller-Schroeder & Paterson, 1989) identified cage features that were important for reproductive success and good maternal behavior. Mellen (1991) found that institutional differences in the quality of animal caretaking partially explained individual differences in reproductive success for small felid species; Carlstead, Mellen, and Kleiman (1999) and Carlstead, Fraser, Bennett, and Kleiman (1999) identified environmental predictors of reproductive success for black rhinos.

For optimizing breeding in captivity of Humboldt penguins, large population size and sand or gravel nesting material were two of the recommendations resulting from a study of 16 British zoos (Blay & Côté, 2001). Finally, Bashaw, T arou, Maki, and Maple (2001) conducted a multi-institutional survey in giraffes and found that time spent indoors and feeding methods were associated with stereotypic licking, whereas stereotypic pacing was predicted by birth history, indoor enclosure size, and type of food.

With the advent of noninvasive techniques for analyzing glucocorticoid hormones in feces and urine, a new tool was available to more directly investigate the environmental impacts on welfare. Wielebnowski, Fletchall, Carlstead, Busso, and Brown (2002) evaluated fecal glucocorticoids in 73 clouded leopards (an arboreal species) at 12 zoos and found evidence of lower stress levels associated with housing in taller cages and higher levels if they were on public display or housed in proximity to other large predators. These findings were confirmed in subsequent experiments where fecal glucocorticoids were found to be reduced when enclosures were modified to allow animals to access higher areas or hide from visitors or large predators (Butterworth, Mench, & Wielebnowski, 2011; Shepherdson, Carlstead, & Wielebnowski, 2004). In another study, Carlstead and Brown (2005) collected fecal samples from 26 black rhinos and 19 white rhinos for 1 year at 10 and 6 zoos, respectively. They found that black rhinos living in enclosures surrounded to a greater extent by the public had higher mean glucocorticoid levels, whereas for white rhinos, individual mean glucocorticoid levels were negatively correlated with how easily each rhino approached his or her caretaker.

These studies all identified potential causes of stress in zoo species and were valuable contributions to our knowledge of zoo husbandry. For exam-
ple, the *Clouded Leopard* (*Neofelis nebulosa*) *Husbandry Guidelines* (originally published in 2000) now includes recommendations on the need to maximize available enclosure height by providing climbing and hiding spaces and avoiding placing animals in close proximity to other large cats (Butterworth et al., 2011). However, despite being multi-institutional, these studies were conducted with relatively small sample sizes, and opportunities to investigate a wide range of potentially influential factors that vary across institutions were limited.

**MULTI-INSTITUTIONAL STUDIES OF ZOO ELEPHANT WELFARE**

Multiple factors are driving the need for a large-scale, coordinated, multi-institutional approach to studying the welfare of zoo elephants. Significant public attention has been directed toward the housing and care of elephants in zoos, and many questions have been raised about whether zoos can meet elephants’ environmental and social needs in a manner that promotes good welfare. Additionally, animal protection organizations have initiated campaigns designed to garner public support or spur legal action with the express purpose of removing elephants from zoo collections.

Clearly, addressing questions regarding zoo elephant welfare is timely and relevant, and the prioritization of a coordinated effort among elephant-holding institutions has been recommended (Hutchins & Thompson, 2008) from within the North American zoo community. To be effective, this effort must address questions in the public discourse that apply to the entire population of captive elephants in North American zoos, and it must also provide meaningful results that can inform interventions aimed at improving the welfare of individual elephants at specific institutions. To gain access to all the data needed to be effective, the elephant-holding zoo community must itself conduct this study and be willing to implement the results.

The first comprehensive study of zoo elephant welfare was conducted by Clubb and Mason (2002). Through a review of published literature, secondary source materials, and interviews with experts, the authors identified the prevalence rates of important welfare problems in the European Zoo elephant population, including arthritis, aggression-related deaths, foot problems, and stereotypy. Because they had limited access to current information on elephant husbandry and management, the authors were unable to link these welfare outcomes with specific risk factors. However, their review of the literature on elephant populations in the wild and in captivity led them to propose several potential independent variables that they predicted would be correlated with elephant welfare, including social groupings, physical environment, handling, diet, and climate.
In addition, upon further analysis of Asian elephant survivorship data, they determined that being captive-born (vs. wild-born/imported) and experiencing interzoo transfer were predictive of diminished life span (Clubb et al., 2008; Clubb et al., 2009). Also worth noting was a trend in these data linking early removal from mother and reduced survivorship of calves later in life (Clubb et al., 2008; Clubb et al., 2009). The fact that the management practice of moving elephants between zoos (and potentially removing calves from dams) ultimately increases the risk of early death raises concern that these experiences elicit stress responses that negatively impact welfare in both the short term and long term (Clubb et al., 2009).

A second comprehensive study of elephant welfare was conducted by Harris, Sherwin, and Harris (2008). They surveyed physical and husbandry conditions of elephants in United Kingdom zoos and gathered physiological and behavioral data to identify indicators of welfare. They determined the prevalence of several welfare outcomes, including foot health, body condition, stereotypy, and gait. The authors attempted to identify risk factors related to husbandry or housing for each of these welfare outcomes, although the small sample size (77 elephants in 13 zoos) limited the types of analyses that could be conducted.

Although no risk factors were identified for foot health, the amount of outdoor space available was found to be important for both gait and stereotypy prevalence, with more space associated with better gait and less stereotypy performance during the day. Although the statistical methods used in this study did not allow for the identification of potentially confounding variables or determination of the relative contribution of different risk factors to welfare outcomes, it was very informative with respect to guiding continued analysis of the factors that contribute to elephant welfare.

Reproductive potential can be a welfare indicator (Mason & Veasey, 2010a, 2010b), and there is also a substantial amount of data available from multi-institutional reproductive studies of elephants in North America. In a 2008 survey of 109 Asian and 136 African elephants at 75 of 76 AZA zoos with elephants, over a third of the elephants did not exhibit normal ovarian cycles, based on serum progestagen analyses (Dow, Holásková, & Brown, 2011). Without increased reproduction, zoo elephants are predicted to face “captive extinction” within a few decades because death rates exceed birth rates (Faust, Thompson, & Ernhardt, 2006; Wiese & Willis, 2006). A majority (53%) of acyclic females have been classified as socially dominant, with the remaining 47% being split evenly among middle and subordinate groups (Freeman, Guagnano, Olson, Keele, & Brown, 2009). In facilities with multiple noncycling elephants, one is always the dominant individual.

By contrast, reproductive suppression of elephants in the wild generally is not observed unless resources are severely limited, in which case dominant females use social aggression to suppress reproduction in subordinates (Dublin, 1983;
Thus, the situation in zoos is a contradiction and could be a type of social stress (Freeman et al., 2009). In support of stress-induced reproductive suppression is the finding of elevated prolactin in the vast majority of noncycling elephants (Dow & Brown, 2012). Hyperprolactinemia is a pathologic condition and primary cause of amenorrhea and anovulation in many species, including women (Bachelot & Binart, 2007). It has been linked to psychological variables, such as maladaptation and passive responses to stress (Sobrinho, 2003). Thus, a large-scale, epidemiological study collecting data on stress, social management, social relationships, and hormone levels is warranted.

Although these studies of elephants show how valuable multi-institutional studies can be, limited sample sizes and difficulty in evaluating more than just a few factors have hampered efforts to more clearly understand how interactions of husbandry factors influence the interrelationships among welfare outcomes. The project we describe in the remainder of this article was developed to gain a better understanding of those interactions and interrelationships of elephants in North American zoos.

THE INSTITUTE OF MUSEUM AND LIBRARY SERVICES (IMLS) ELEPHANT PROJECT

Despite the significant public interest in elephant welfare, there has not yet been a comprehensive, multidisciplinary, scientific assessment of the welfare status of elephants in North American zoos. In December 2010, the IMLS—an independent, U.S., federal, grant-making agency that supports libraries, museums, and zoos—awarded an $816,000 grant to a group of researchers to study the welfare of elephants in North American zoos accredited by the AZA. The grant responded to a substantial need for objective, science-based information on the environmental factors impacting zoo elephant welfare and is unprecedented in scope and scale in the zoo community. Of the 73 AZA zoos exhibiting elephants, 72 committed to participate in the project. These zoos collectively care for 166 African and 125 Asian elephants, all under a single accrediting body. Thus, rather than studying a small sample of zoo elephants, we are assessing the welfare of nearly the entire population.

Partners on the IMLS grant included the Honolulu Zoo, Oregon Zoo, Toledo Zoo, Chicago Zoological Society, Smithsonian’s National Zoo, AZA, and the Center for Animal Welfare at the University of California Davis. The primary goal of this study was to produce scientific data that would aid in decision making with regard to best practices in elephant management. The study assessed elephant welfare using a broad array of animal-based measures, and it evaluated how those measures were affected by factors such as enclosure design, exercise
and training programs, social group composition, climate, and management. In the remainder of this article, we discuss the structure of this project and some anticipated outcomes.

A Framework for Elephant Welfare

In structuring the Elephant Welfare Project, a yearlong planning phase was supported by an IMLS Planning Grant awarded to the group of collaborators in 2009. The goals of the planning phase were to solicit commitments from elephant-holding zoos, identify concerns about elephant welfare, design the research project to assess those concerns, develop the necessary welfare assessment tools, and plan data collection methods. To achieve these goals, we convened a highly diverse panel of scientists with expertise in behavior, veterinary medicine, physiology, and zoo animal welfare; academics specializing in farm animal welfare science; and experienced elephant managers.

The panel included a zoo director familiar with the public concerns about elephant welfare and scientists with extensive experience conducting multi-institutional studies in zoos. Convening such a broad assortment of individuals provided scientific, management, and social/ethical input into gathering knowledge and opinions about zoo elephant welfare issues and their potential resolutions. Ultimately, the process led to the identification of a variety of indicators of positive and negative welfare in zoo elephants and facility-based input variables that potentially impact welfare.

Our panel developed a framework that defined a range of welfare outcomes by adapting criteria established by the European Union Welfare Quality (WQ) project. The WQ project had the goal of developing practical and validated animal-based methods for assessing the welfare of poultry, pigs, and cattle on commercial farms and was organized into four principles of animal well being: good feeding, good housing, good health, and appropriate behavior. Within these principles, 12 different, but complementary, criteria were identified (see Blokhuis, Miele, Veissier, & Jones, 2013). Our panel of experts modified these criteria by eliminating those that were not relevant to elephant management and adapting the others to better fit the situation of zoo elephants, resulting in seven welfare criteria. For example, whereas farm animals are frequently deprived of food to control body weight or for other management reasons, elephants are well fed but are at risk of obesity. Therefore, the WQ criterion “Animals should not suffer from prolonged hunger” was changed to “Feeding and avoiding obesity.”

The WQ criteria also include language pertaining to animal emotions: “Negative emotions such as fear, distress, frustration or apathy should be avoided whereas positive emotions such as security or contentment should be promoted.” There has recently been much interest in expanding the assessment of ani-
mal welfare to include more positive emotional states, essentially determining whether the quality of animals’ lives is good rather than being merely “not bad” (Yeates & Main, 2008).

Historically, most inferences about the welfare status of elephants (as well as farm and other zoo animals) have been based mainly on factors associated with negative or chronic stress responses, such as stereotypies, aggression, poor maternal care and infanticide, and morbidity and mortality (Brown, 2000; Chatkupt & Sollod, 1999; Clubb et al., 2008; Clubb & Mason, 2002; Elzanowski & Sergiel, 2006; Laws et al., 2007; Mason & Veasey, 2010a; Ramanathan & Mallapur, 2008). The United Kingdom study of Harris et al. (2008) also focused primarily on indicators of poor welfare. It is obviously critical to evaluate the risk factors for these kinds of negative outcomes in any comprehensive study of welfare, but an emphasis on only negative indicators might miss cases in which welfare is good or in which aspects of good welfare can compensate for negative experiences (Yeates & Main, 2008).

With positive welfare in mind, we formulated three welfare principles for zoo elephants encompassing our seven welfare criteria using the positive psychology model of human happiness developed by Seligman and colleagues (“the pleasant life,” “the engaged life,” and “the meaningful life”; Seligman & Csikszentmihalyi, 2000; Seligman, Steen, Park, & Peterson, 2005) and adapted for use with animals by Boissy et al. (2007). We loosely reinterpreted these three principles of happiness into more animal-based welfare principles: physical well being and comfort, engagement with the environment, and positive psychological state. Overall, therefore, our framework emphasizes not only the absence of poor welfare but also the presence of good welfare. The resulting three principles and seven welfare criteria are given in Table 1.

Overview of Project Methods

The purpose of the IMLS elephant welfare study is to determine the environmental and husbandry factors that are most important for enhancing elephant welfare. The seven-criteria framework we developed for elephant welfare was used to select a range of known, “gold standard” welfare indicators (welfare outcomes) for elephants as well as to determine new measures that needed to be developed and validated. This multifactorial approach to assessing elephant welfare was intended to provide a more holistic approach to identifying best management practices for elephants. All welfare indicators were animal based and were statistically analyzed in relation to a broad range of facility-based measures, or input variables. We provide a summary of the general methods of data collection and the rationale for choosing them, leaving specifics of the indicators measured to later publications.
TABLE 1
Framework of Welfare Outcomes for Elephants, Types of Indicators, and Their Data Collection Methods

<table>
<thead>
<tr>
<th>Welfare Principles and Criteria</th>
<th>Welfare Indicators</th>
<th>Data Collection Methods</th>
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<tbody>
<tr>
<td>Physical well being and comfort</td>
<td></td>
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<tr>
<td>1. Feeding and avoiding obesity</td>
<td>Body condition score</td>
<td>Photographic survey</td>
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<td></td>
<td>Nutritional physiology</td>
<td>Blood sampling, veterinary exams, fecal form assessments</td>
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<tr>
<td>2. Freedom of movement to seek physical comfort</td>
<td>Comfort behavior frequencies</td>
<td>Keeper survey assessments, video recordings</td>
</tr>
<tr>
<td>3. Optimal health</td>
<td>Health and injury status</td>
<td>Veterinary exam, veterinary records, blood parameters</td>
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<tr>
<td></td>
<td>Reproductive status</td>
<td>Hormone analysis, breeding history</td>
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<tr>
<td>Engagement with environment</td>
<td></td>
<td></td>
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<tr>
<td>4. Species-appropriate social behaviors</td>
<td>Social behavior</td>
<td>Keeper survey assessments, video recordings</td>
</tr>
<tr>
<td></td>
<td>Group cohesion</td>
<td>Keeper survey assessments, video recordings</td>
</tr>
<tr>
<td>5. Species-appropriate nonsocial behaviors</td>
<td>Activity budgets</td>
<td>Keeper survey assessments, video recordings</td>
</tr>
<tr>
<td></td>
<td>Sleep</td>
<td>Keeper assessments, video recordings, lateral recumbency measurement</td>
</tr>
<tr>
<td>6. Good human-elephant relationships</td>
<td>Keeper-directed behaviors</td>
<td>Keeper survey assessments</td>
</tr>
<tr>
<td>Positive psychological state</td>
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<tr>
<td>7. Avoidance of negative emotions (e.g., fear, frustration, apathy) and experience of positive emotions (security, contentment)</td>
<td>Glucocorticoid excretion profiles</td>
<td>Blood and fecal hormone analysis</td>
</tr>
<tr>
<td></td>
<td>Play and exploratory behavior</td>
<td>Keeper survey assessments, video recordings</td>
</tr>
<tr>
<td></td>
<td>Quality of life</td>
<td>Keeper survey assessments</td>
</tr>
<tr>
<td></td>
<td>Temperament</td>
<td>Keeper survey assessments</td>
</tr>
</tbody>
</table>

Collecting Data to Measure Elephant Welfare

Many physiological and behavioral welfare indicators were assessed for each elephant. Table 1 lists the welfare criteria and provides examples of welfare indicators covered by each criterion and the general data collection methods.

Multi-institutional and epidemiological studies often make use of more than one form of data collection (e.g., Garner, Kiess, Mench, Newberry, & Hester,
but our study was unusual in that it utilized and integrated all three of the data collection methods described earlier. Direct measures of individual elephants were taken by on-site zoo personnel. These included photographs, videos, blood samples, veterinary examinations, and technology-assisted behavioral observations (GPS combined with accelerometry; Leighty, Soltis, & Savage, 2010). Historical data were garnered from the studbooks, veterinary records, and other sources.

For example, 10 years of medical records for each elephant were reviewed, and specific health events were identified and scored for clinical signs, body system involved, diagnosis, treatment, and category of disease, which was similar to the process used by Mikota, Sargent, and Ranglack (1994). Retrospective data were also used to collect information about each elephant’s rearing experiences (e.g., birthplace, age at which he or she was moved from his or her mother/natal group, and number of years spent in different types of institutions) from the elephant studbooks.

The project also made extensive use of survey data obtained from staff members at each zoo who had knowledge of and experience with their elephants. Elephant managers were surveyed to obtain detailed descriptions of facilities and management practices. Data included information on environmental (e.g., enclosure size and complexity, social groupings, flooring, and feeding methods) and husbandry factors (e.g., training and handling procedures, veterinary care program, enrichment program, and feeding) at each zoo for each elephant because not all individuals at a zoo experience the same housing and/or procedures.

Also using surveys, keepers rated individual elephants on relative frequencies of specific behaviors, temperament, and quality of life. Three keepers rated each elephant so that his or her responses could be tested for concordance. Integrated assessments of animal well being by keepers, based on a whole-animal approach, are becoming an accepted and valued means of assessing the relative welfare status of different individuals (reviewed by Whitman & Wielebnowski, 2009). Animal care professionals are constantly engaged in informal, qualitative welfare assessments whereby they synthesize and filter accumulated knowledge of an animal over time in a variety of contexts to arrive at a holistic evaluation of his or her behavior and well being (Wemelsfelder & Lawrence, 2001).

The validity and reliability of these kinds of ratings of behavior have been demonstrated for a variety of mammal species (see review by Gosling, 2001). Carlstead, Fraser, et al. (1999) found good agreement between the behaviors performed by black rhinos in standardized tests of responses to novel objects and the ratings of keepers on the frequencies of certain behaviors. In zoo African elephants, Freeman, Schulte, and Brown (2010a) found that keeper assessments of social relationships among females were similar to those found by direct behavioral observations, and they further showed that a socially dominant status was related to ovarian cycle problems (Freeman, Schulte, & Brown, 2010b).
A recent example of the value of caretaker assessments of well-being was provided by Weiss, Adams, and King (2011), who found that orangutans in zoos that were rated as “happy” 7 years prior had a lower mortality rate. We validated keeper assessments of elephant behavior in our study by comparing their assessments with technology-assisted and video observations made at a subset of zoos as well as by correlating keeper assessments with the various outcome measures we assessed.

Keepers’ assessments of elephant temperament/personality were also employed. Temperament influences welfare because it is the filter that shapes an animal’s responses to the social and physical environment and his or her ability to cope with change and other potential stressors (Henry, 1986). Surveys asking caretakers to rate animals on temperament traits have been shown to be valid tools for assessing individual differences (Gosling, 2001; Weiss, King, & Perkins, 2006; Wemelsfelder & Lawrence, 2001). In a study of individual behavioral variation among 44 captive adult cheetahs, Wielenowski (1999) found high interrater agreement between keeper ratings of individuals on a questionnaire comprising 18 behavioral adjectives (e.g., calm, excitable) and ratings by a researcher directly observing the behavior of those individuals.

Data Management and Analysis

This project required the collection of a large volume of data and the investigation of a wide array of potentially important relationships among multiple variables. Therefore, a web-based data management and integration infrastructure that would streamline data entry, organization, and analysis was employed. The base-product software was developed to manage large amounts of data within the health care, social services, and education sectors and was customized by our technology consultants to create a user-friendly data-entry interface to collect data efficiently and improve data quality. All data were coded at the time of collection, and all project analyses were performed blind to animal or zoo identity.

Data analysis took several forms, including prevalence calculations (population-level rates of welfare outcomes), census-level descriptive statistics such as population-level means and distributions of input and outcome factors, longitudinal analyses (e.g., reproductive hormones, fecal form scores), survey validation (keeper assessments of behavior using video data), and the epidemiological analyses.

The epidemiological analyses involved several phases (Garner et al., 2012). The first phase involved data processing and indexing. Each data type (survey, hormone analysis results, and medical health history) needed to be represented as one or more discrete values for inclusion in the multivariate models, which for some types of data (e.g., survey data) required developing indices to generate
“scores.” Once all of the input and outcome variables were defined and indexed, we used a hypothesis-led approach to building associations by pairing each outcome variable with a hierarchical list of input variables based on the strength of the predicted correlation. Inclusion of variables in the models was prioritized based on these lists, but the variables suitable for inclusion in the final models depended significantly on factors related to data quantity and quality.

An example of how the information we collected could be used to better understand one welfare outcome is obesity. Obesity is a potential health problem (Fowler & Mikota, 2006) that has been reported to be of high prevalence in zoo elephants. In their study of United Kingdom zoos, Harris et al. (2008) found that 75% of elephants were overweight or very overweight based on ratings of photographs taken from one perspective using a body condition scale. To assess the prevalence of obesity in North American zoos, we used a 5-point whole body condition scoring system that was developed and validated by ultrasound analyses of actual bodily fat deposition (Morfeld, 2013). Additionally, physiological parameters of nutritional status (leptin and insulin to glucose ratio; Considine et al., 1996; Leon, Hernandez-Ceron, Keislert, & Gutierrez, 2004) and thyroid activity (TSH, T3, and T4; Brown, Walker, & Moeller, 2004) were assessed concurrently.

Once prevalence data for obesity and altered nutritional biomarkers indicative of metabolic syndrome are obtained, we will evaluate the relationships between these outcomes and a range of input variables that we have identified as possible contributors to obesity, including (a) keeper-directed exercise (reported through surveys); (b) food quantity, quality, and presentation methods (also reported through surveys); (c) available space (reported monthly by managers); (d) time spent indoors (reported by managers); and (e) amount and type of training (following Harris et al., 2008; reported by managers). Blocking factors in this model may include individual animal characteristics like sex, species, and age obtained from retrospective data. Assuming we are able to fit a model that includes each of the possible risk factors, the outcome of the analysis will reveal which factors contribute significantly to body condition and the relative importance of each significant factor in predicting obesity.

Limitations of Epidemiological Studies

Epidemiological studies like the current elephant study do have limitations. Epidemiological data are correlational. As such, this kind of analysis cannot definitively establish causation but instead can only show which of the factors that were evaluated are associated with positive or negative welfare outcomes.

In addition, there can be sources of error in the data that are difficult to correct; this is particularly true of retrospective data that have been collected for purposes not related to the study and requires that questionable data be validated.
or excluded from the analysis (Dewey et al., 2009). In fact, fitting models for epidemiological data often results in a significant amount of data reduction due to various issues inherent to this kind of study, including that data are often not independent and that large data sets can result in spurious correlations (Dewey et al., 2009).

For example, Lombard et al. (2010) evaluated 16 variables that could potentially affect hock injuries in dairy cows, but only 8 of these could actually be included in the final model. Information may also have to be eliminated from the analysis because there is simply too little variation across institutions. Conversely, data may have to be eliminated or combined if there is too much variation. For example, in a study of the effects of house and cage design on laying-hen production and welfare (Garner et al., 2012), many of the house design variables of interest could not be analyzed because they were unique to specific egg farmers.

Anticipated Outcomes

Although it is impossible to predict in advance how much of the data collected for the project can be used in the final epidemiological data models, new information will be gained. First, the project will yield a comprehensive database that includes detailed information on housing and husbandry practices at the level of the individual elephant. This is a departure from the typical zoo-based approach to characterizing husbandry and housing and accounts for the variation in experiences individual elephants at the same institution may have with respect to space, social opportunities, and handling. In addition, the project will be able for the first time to assess the prevalence and distribution across North American zoos of a variety of important elephant welfare indicators, including frequency of affiliative and abnormal behaviors, body condition, hyperprolactinemia, and stress. Each zoo can then use that information to benchmark where their elephants fall within the zoo population for each specific welfare outcome.

The project should also identify some of the major housing and management risk factors for welfare outcomes and identify their relative importance (e.g., Garner et al., 2012). This information will allow zoos to determine the extent to which those risk factors are present at their institutions and help them prioritize modifications to their facilities and animal management programs in order to make measurable improvements in elephant welfare. Ideally, the results of the epidemiological analysis will be followed up with experimental studies to confirm the causal relationship between specific inputs and welfare outcomes, but this is not always possible with zoo-housed species where environments cannot be manipulated. However, specific hypotheses can be tested by conducting pre- and postoccupancy studies of new exhibits or by examining other longitudinal changes, such as changes to social groupings or management practices.
We anticipate that this project will create a model welfare assessment process for zoo elephants. If two or more outcomes are found to be highly correlated for elephants and they are found to have the same contributing factors, then the one that is most straightforward and reliable to measure in the zoo setting can be used as a “proxy” for the others, streamlining ongoing assessments. This model can also be adapted and applied to other managed species. Of course, proxy measures have to be validated for each species studied because factors important for an outcome in one species may not be as important for another, but a validated welfare assessment process for elephants will help identify the inputs and outcomes to consider for other species, thus reducing the costs associated with conducting similar studies of those species. In particular, the elephant model could demonstrate the utility of using surveys and historical data for developing welfare assessments for other zoo-managed species.

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