Hill, S.P. and Broom, D.M. 2009. Measuring zoo animal welfare: theory and practice. *Zoo Biol.*, 28, 531-544. DOI: 10.1002/zoo.20276

Pre-publication copy

Measuring zoo animal welfare: Theory and practice

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Short title: A practical look at measuring welfare

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ABSTRACT

The assessment of animal welfare relates to investigations of how animals try to cope with their environment, and how easy or how difficult it is for them to do so. The use of rigorous scientific methods to assess this has grown over the past few decades, and so our understanding of the needs of animals has improved during this time. Much of the work in the field of animal welfare has been conducted on farm animals, but it is important to consider how the methods and approaches used in assessing farm animal welfare have been, and can be, adapted and applied to the measurement of welfare in animals in other domains, such as in zoos. This is beneficial to our understanding of both the theoretical knowledge, and the practicability of methods. In this paper, some of the commonly-used methods for measuring animal welfare will be discussed, as well as some practical considerations in assessing the welfare of zoo animals.

Key words: behavior; captive settings; coping; legislation; physical health; psychological health

INTRODUCTION

Animal welfare can be measured scientifically, and its assessment relates to investigations of how animals try to cope with their environment, and how easy or how difficult it is for them to do so (Broom 2001). It is important to define the term "animal welfare" clearly, because "welfare" as a word is often used in common language in a variety of ways that are not scientifically rigorous (Broom and Johnson 2000), and can mean different things in different parts of the world (Appleby and Hughes 1997). Several definitions of welfare have been put forward in relation to the scientific assessment of animals, but many of these fail to recognize that it can be measured on a sliding scale that ranges from very poor to very good. The definition used here is that animal welfare is the state of an animal as regards its attempts to cope with its environment (Broom 1986).

Thus, animal welfare is a broad term (Dawkins 2001), but this definition acknowledges welfare as a state of being that can be measured, recognizes that it ranges from very poor to very good, introduces the concept of coping, allows measurement separate from moral considerations, and refers to feelings as well as physical and psychological health (Broom 2001). The definition of welfare that we use also emphasizes that it relates to an individual, and thus welfare can differ between different members of the same species, even when they are exposed to the same conditions (Hosey et al 2009). In the case of zoo animals, which have often come from very heterogeneous backgrounds, individuals may vary greatly in their previous life experiences, and this can influence their ability to cope with certain challenges; by using each animal as its own control, an individual's welfare can be tracked in responses to changes in its environment and, thus, an

individual's welfare can be measured. There are also some species-specific characteristics that have evolved to enable animals to cope with different environments, and thus we should also consider welfare at the species level; such species-level adaptations could relate to dietary needs, hearing sensitivity, thermoregulatory needs, and so on.

In the context of the definition of welfare that we use, coping refers to having control of mental and bodily stability (Broom and Fraser 2007), and to the ability of an organism to tolerate and respond to a range of stimulation, including noxious stimuli. These adjustments are adaptations to the environment, and the ability to make these adaptations depends on genetic and environmental influences. Thus, individual animals may cope in different ways. When an organism's homeostatic balance is challenged beyond its tolerable limits by some change in its environment, the organism's attempts to adapt to the change are inadequate or inappropriate and there is failure to cope, stress and perhaps death. Thus, the meaning we ascribe to 'stress,' in this scientific context, does not make it largely synonymous with 'stimulation': by 'stress,' we refer to the effects of some challenge to the individual that disrupts homeostasis, and not simply to some stimulation that involves some response and neural development that has long-term benefits to the animal (Broom 2001). Using this definition, we recognize that some degree of stimulation or challenge can have eventual benefits to an individual, whereas 'stress' is never good, as it overtaxes an animal's control systems and eventually results in reduced fitness (e.g. see Broom 1983; Broom and Johnson 2000; Broom 2001).

Individuals of any given species have been equipped, through evolutionary processes, to cope with the demands of their particular ecological niche with specific physiological, behavioral and motivational responses (Sachser 2001). Animals use these responses to try to cope with challenge, but they can also anticipate future challenges to their welfare, and their behavioral and physiological responses will differ accordingly (Dawkins 2001). Scientific methods for assessing animal welfare are complex and multi-disciplinary across the biological sciences (Dawkins 2006), and have been refined over the past thirty or so years. Nevertheless, there are still gaps in our knowledge of the biological needs of animals to have access to particular resources and to have opportunities to do certain behaviors. This is particularly the case for exotic species, such as those housed in zoos, sanctuaries and aquaria (hereafter simplified to 'zoo(s)').

Much of the research on animal welfare has involved farm animals (e.g. Hagen et al 2004; Peeters et al 2006; Napolitano et al 2008). This is, no doubt, related to the financial interest in commercial farming, as well as the sheer number of animals involved in food production (world estimates range from 19 billion (FAO 2007) to 24 billion individuals (Pickett, unpublished data) at any one time), from a relatively small number of species.

In contrast with farms, a much larger number of animal species are held in zoos worldwide, albeit with smaller numbers of individuals. In the 1990s, the International Union of the Directors of Zoological Gardens (now the World Association of Zoos and Aquariums (WAZA)) estimated the total number of zoo vertebrates to be 1 million, in about 1,000 organized zoos (IUDZG 1993), and the International Species Information

System (ISIS) database, to which a subscription is required, contains information on 1.8 million animals of 10,000 taxa (WAZA 2005). The different life experiences and temperaments of zoo animals, which can include poorly-understood species, are sometimes well-documented in zoo records, and in other cases much less so (Fidgett et al 2008). For many species housed in zoos around the world there are relatively small sample sizes, and there has also been a 'taxa-bias' in zoo research, with the focus thus far being on mammals, especially primates (Melfi 2005), which should be redressed in future studies.

The effects on welfare of many husbandry practices, such as relocations to new enclosures, or improvements in animal nutrition, zoo-visitor effects, social conditions, or physical environment, are often not assessed in a rigorous scientific way. Changes in these are commonly made on the unsubstantiated assumption that the animals' welfare will improve, which it may or may not do. For example, do changes in practice encourage appropriate behavioral repertoires, such as being more similar to those of conspecifics living in good conditions in their natural habitats (which could indicate good welfare), or do they cause a measurable disturbance to the animals (indicating poorer welfare), or is there a neutral effect (and, thus, no change in an animal's welfare)? Whilst general evaluations of animals' responses can still have their benefits, a scientific approach to these issues is important, as is effective collaboration and communication between zoos, and with other institutions, such as universities (WAZA 2005), or field sites.

Animal welfare should be an important consideration in modern enclosure design. Some new zoo enclosures may cost millions of dollars and, whilst some studies have been published to document animals' uses of enclosures (e.g. Ross and Lukas 2006), or the attitudes of zoo visitors towards particular species in enclosures (e.g. Lukas and Ross 2005; Ross and Lukas 2005), relatively few pre-and post-occupancy studies are conducted specifically on the effects of the new environment - and of the translocations to them - on zoo animal welfare (e.g. mandrills: Chang et al 1999; red river hogs: Dayrell and Pullen 2003; gorillas: Hill 2004). In some cases, measures have to be put into place after animals have exhibited problems post-occupancy, because the new environments have not met the animals' needs fully (e.g. mandrills: Pansini 2006). As with enrichment efforts (Young 2003), the ideal should be to work towards good welfare in a proactive way, and not wait until problems emerge.

In captivity, restrictions imposed by various factors, like enclosure design or keepers' routines, can limit the opportunities for animals to do certain behaviors, such as appropriate levels of foraging. Keepers' routines might reflect the needs of the keepers, or zoo visitor expectations ('consumer pressure,' e.g. Hosey et al 2009), or at least might be heavily influenced by these. Whilst zoos should not ignore these needs, a primary aim should be good welfare in the animals. One way of achieving this is through appropriate exhibit design and animal management; for example, Bloomsmith and Lambeth (1995) investigated the effects of predictable versus unpredictable feeding schedules on chimpanzee behavior, and their results suggested that these apes could benefit from being fed on a more unpredictable schedule.

Often, the focus of animal welfare studies is primarily on identifying, solving and preventing conditions that result in poor welfare (Appleby 1995), whereas we should also be investigating aspects of good welfare, such as what causes pleasure and how to measure this (Broom 2001). Some measures may give information about good and poor welfare (Dawkins 2001). Scientific studies of individual welfare, and of welfare at the species level (such as a species' needs for thermoregulation), should be an essential component of modern wild animal keeping.

Fundamental questions in zoo animal welfare research could include the following:

1. What are the needs, for both behavior and resources, of particular species of zoo animal, and what appropriate conditions help meet these needs?

2. How do animals respond to our efforts to improve welfare, and what opportunities are important to animals living in different settings, or to animals of different sexes, ages, and so on?

3. How do individual animals differ from one another in strategies to meet their needs, and hence in their responses to environmental stimuli, including their responses to efforts to improve their welfare?

4. Do the opportunities given to zoo animals promote the conservation-education of the public, through a better representation of wild animal species and their habitats?

Through the rigorous investigation of questions such as these, we can further improve the situation for captive animals, and also have a greater scientific understanding of issues important to modern zoos and conservation biologists. By giving animals choices in their environment ('asking' the animals what they want), we can increase our understanding of their needs for access to resources, and for opportunities to express particular behaviors that are important to them. For example, a study of regurgitation and reingestion (R/R) in gorillas, which is a potentially injurious behavior (Hill 2009), documents how this behavior was significantly reduced in a 'group' of two gorillas, by making their feeding environment more complex, thus giving them more choices and control over their environment (Hill 2004). Studies of what is required to achieve good welfare, as well as studying cases where welfare could be improved, are important areas of research in this field.

An additional outcome of research into animal welfare is to understand the potential consequences for some other types of research: if the welfare of an individual or particular group of subjects is sub-optimal, then researchers must ensure that this variable is taken into account when conducting their studies, as failure to do so may confound the results. For example, in laboratory animals, inadequate conditions and treatments, such as confinement, handling, pain and anxiety, may cause detectable physiological and behavioral responses and lead to aberrant experimental results (Monamy 2000), whereas provision of enrichment, or other opportunities for good welfare, may improve the quality of scientific research (Garner 2005), and this issue should be taken into account in zoo research as well. The more advanced methods and approaches used in assessing farm and laboratory animal welfare have been, and can be,

adapted and applied to the measurement of welfare in other captive settings, such as in zoos, and so a multi-disciplinary approach to this research is beneficial and should be encouraged.

ASSESSING ANIMAL WELFARE

Text books and other literature cover the precise methods that can be used to assess animal welfare (e.g. Broom and Johnson 2000; Broom and Fraser 2007), and it is beyond the scope of this paper to discuss these methods in their entirety. Instead, some of the 'pros and cons' of some of the more commonly-used techniques for assessing zoo animal welfare will be considered. The Zoos Forum, the UK Government's advisory body on zoo matters, has produced a useful online handbook, including a chapter on zoo animal welfare and its assessment (Zoos Forum 2007), which explores these issues further.

Behavioral measures

Animal behavior can be relatively inexpensive to measure, and it is often the most obvious indicator that an individual is having difficulty coping with a particular situation, both for short- and long-term responses. Thus, behavior can be a very useful tool in assessing an animal's welfare. That said, it must be noted that some animals, such as the domestic cat, have evolved methods of avoiding the display of overt signs of pain or other welfare problems (Rochlitz 1997). This should confer an evolutionary advantage, as it would be disadvantageous for an animal to 'advertise' to potential predators or competitors that it is experiencing a problem. No doubt many zoo species use this strategy also, and any zoo veterinarian or keeper will almost certainly know of

236 animals that appeared to be fit and healthy one day, and were dead the next, due to a
237 progressive, but well-hidden, condition. Not only can animals 'hide' signs of poor
238 welfare in their behavior, but they vary in their behavioral responses to stimuli
239 (Dawkins 2001) and so behavioral indicators of welfare need to be validated and
240 interpreted carefully (Knierim et al 2001). For behavior to be a useful indicator of
241 welfare, we also need far more information on the full range of the behavioral repertoire
242 for a particular species, to enable us to identify meaningful welfare indices.
243
244 Within zoos, behavior is often referred to as being either 'normal' or 'abnormal' (or
245 'maladaptive'), and behavioral data must be interpreted realistically and with caution.
246 Animals have a range of behaviors in their repertoire, and so they have a variety of
247 ways of responding to conditions that affect their welfare. Hence, it can be argued that
248 animals do not have universal indicators of welfare, because they do not have universal
249 responses to threats to their welfare (Dawkins 2001). Thus, it is important to conduct
250 studies that document behavioral changes in response to changes in the captive
251 environment and, where possible, to document normal behavior patterns for individuals
252 living in good conditions (wild and zoo), as a guide for comparison.
253
254 Normal behavior should occur in healthy animals whose behavioral repertoires have
255 developed under conditions that offer uninhibited opportunities, and are appropriate to
256 the animals' needs for behavior and resources. However, the recognition of a normal
257 range of activity, or deviations from this range, pre-supposes a good knowledge of the
258 species being examined and of the typical range of individual differences (Knierim et al
259 2001). Such knowledge is currently lacking for many species and, in particular, for

many of those housed in zoos, as the needs of conspecifics living in their natural habitats is not always fully understood. The behavioral responses of certain taxonomic groups, such as fish or reptiles, may also be harder for us to recognize 'intuitively' than mammalian responses, and so further error can occur if we are not experienced enough in the behavior of the species we are observing.

If, for example, a zoo animal spends 'X%' of its time in a normal behavior, such as resting, at what threshold above or below 'X%' does this behavior deviate from whatever may be considered to be normal? Of course, an activity budget *per se* is not the be-all-and-end-all of using animal behavior as an indicator of welfare: for example, an animal might locomote for a behaviorally-'healthy' amount of time, but might be limping, thus indicating a problem affecting its movement. Thus, a variety of indices should be examined together, including behavioral patterns, frequencies and contexts, as well as physiological measures, where possible. Some farm animal and horse welfare scientists are using a combination of qualitative and quantitative measures in their assessments of coping strategies (e.g. pigs: Wemelsfelder et al 2000; dairy cows: Rouser and Wemelsfelder 2006; horses and ponies: Napolitano et al 2008). The adoption of recognized methods being used in other areas of animal welfare assessment can be used to help drive zoo research in this area forward.

It is widely accepted that a maladaptive (abnormal) behavior is one that differs in pattern, frequency or context from that which is shown by most members of the species under conditions that would allow a full behavioral range, and can make the situation worse for the animal(s) involved, i.e. is a behavioral pathology (Broom and Johnson

2000). Animals on farms, in laboratories or zoos and other captive settings often face environmental challenges that their species will not have encountered during most of their evolution, or only lately in domestication (Knierim et al 2001). Thus, captive animals may be poorly equipped to adapt to certain aspects of captivity that fail to meet their needs. This failure to fulfill needs may lead to the development of abnormal behavioral repertoires, which may include stereotypic or injurious behavior, and these indicate poorer welfare, even if the behavior was expressed more frequently or intensely in the past and has become a habit (Broom and Johnson 2000).

Further research should include investigations of particular environmental situations or husbandry practices that may be stressors, to complement research exploring what animals need in order that welfare will be good. Behavioral monitoring, which is a means of collecting scientific data on animal behavior, to document normal behavior patterns and any changes to these, can also be a useful tool (Watters et al 2009). Behavioral monitoring programs can be beneficial in establishing baseline information at the multi-zoo level (subject to the usual methodological considerations being met, such as inter-observer reliability), and such programs can be useful when carrying out pre-and post-occupancy studies (e.g. the 'EthoTrak' behavioral data monitoring system, initiated by the Chicago Zoological Society, Brookfield Zoo, USA (see http://www.brookfieldzoo.org/pagegen/media/Ethotrak_Manual.pdf for further information).

Even if the knowledge of normal behavioral repertoires for wild animals is available in the scientific literature, do animal keepers generally have access to this information?

Can most keepers access up-to-date peer-reviewed papers, for example, or are they more restricted to information they can obtain from professional literature, books and the internet, which may or may not report the latest (or most accurate) findings on animal behavior? If access to appropriate literature is limited for keepers, other zoo colleagues and university collaborators can assist by forwarding pertinent information. If such information is simply not available for a given species, predictions about their needs can be based to a certain extent upon knowledge of those of similar species, or of species occupying similar ecological niches, about which more may be known. A similar approach is also adopted in terms of zoo animal nutrition: it is unlikely that the ingredients of any animal's diet can be duplicated exactly in captivity, whereas the nutrients contained within that diet can be provided as the best alternative (Dierenfeld 1996).

One example, demonstrating the need for an improved understanding by some keepers of a species' natural behavior, is from a southern European zoo, where S.P.H. was studying the effects of a targeted environmental enrichment program, on the behavior of gorillas (Hill 2004). As the gorillas originally lived on a bare floor, with no nesting material, one of the experimental changes made was to provide a deep litter of wood-wool, for the apes to forage in and use for nests, as they would in the wild, and to assess the effects of this on behavior. The wild-born silverback, who had been housed without access to any meaningful nesting materials for some 30 or more years, immediately built himself a large nest and adopted a relaxed pose, typical of gorillas resting (lying on his back, legs in the air and ankles crossed, arm bent underneath his head), and he spent longer periods of time lying down - interspersed with the occasional movement to

readjust his nest - than he would usually do with no opportunities to nest (Hill 2004). His keepers expressed concern that the wood-wool was making him 'ill,' as he did not usually lie down for long periods in the day, but they were unaware that resting in day-nests is a normal behavior for gorillas. Once it had been explained that this individual was actually now able to express a normal behavior, they agreed to continue providing wood-wool for the duration of the study (but, unfortunately, its provision was stopped afterwards).

Behavioral flexibility and measuring zoo animal welfare

Behavioral flexibility and the ability to adapt to changes in the environment are important coping strategies for animals and help to maintain homeostatic stability; hence it is useful to investigate behavioral traditions, or cultures, of zoo animals. A tradition can be defined as a behavioral practice, shown repeatedly over a period, that is shared among a minimum of two members of a group and depends partly on socially-aided learning (Fragaszy and Perry 2003; van Schaik 2003). It is likely that behavioral geography will apply across most species, in the wild and in captivity; recent research on wild orang-utans (*Pongo* spp.) and other primates has found evidence for the existence of traditions that differ between populations, and cannot be linked directly to demographic or habitat differences. Wild orang-utans, for example, exhibit cultural differences in behaviors between geographically-separated study sites, such as with food-sharing (van Schaik 2003) and foraging (Fox et al 1999), as do chimpanzees (*Pan troglodytes*) with grooming techniques and tool-use (McGrew 1992), and Japanese macaques (*Macaca fuscata*) with sweet-potato washing (Nishida 1987). Examples of

355 traditions in non-primates are also known, including bird species (e.g. Lefebvre and
356 Bouchard 2003) and dolphins (*Tursiops* spp.) (Mann and Sargeant 2003).
357
358 Animals not only face different environmental challenges in their diverse habitats, but
359 individuals can show innovation and can learn by observation and imitation of adult
360 behavior. Thus, it is hardly surprising that behavioral traditions exist across different
361 populations (Goodall 1996), and repertoires of behavior that are considered 'normal'
362 can vary between groups. Individual animals can be expected to have diverse behavioral
363 repertoires and different ways of responding to a stimulus (Dawkins 2001), and such
364 issues should be considered in any behavioral study, especially of welfare.
365
366 Just as the behavioral repertoires of animals can vary between different communities or
367 populations in the wild, so too can captive animals exhibit novel behavior patterns that
368 are not usually seen among their wild conspecifics, but this does necessarily mean that
369 the behavior is 'abnormal'. Thus, the species-typical behavior of animals living in good
370 conditions in the wild (i.e. animals that we would consider to have good welfare), may
371 not be identical to the behavioral repertoires of zoo animals with good welfare. For
372 example, play behavior in adult animals may occur at higher rates in captivity compared
373 with the wild, as it is a 'luxurious' behavior made possible because the importance of
374 certain other behaviors, such as anti-predatory tactics, may be reduced in a zoo
375 environment. In this case, a rise in play behavior would not in itself indicate a welfare
376 problem, just because the behavioral repertoire is different to the wild situation.
377

Captivity presents animals with different niches and opportunities, or lack of the same, from those in nature. For example, zoo-housed chimpanzees cannot be expected to use tools if they are not provided with objects to manipulate in this way. The absence of a type of behavior does not mean that the animals are incapable of doing it under different conditions. Novel behavior patterns that develop in zoos are adaptations to the captive environment and might be beneficial to the animals. The behavior patterns might also be similar in motivation to the corresponding behavior in the wild, although the two environments are very different. For example, captive animals might play with cage "toys," such as rubber balls, whereas in the wild they might play with rocks, or they might "fish" for ketchup in a converted drainpipe instead of "fishing" for termites in an earth mound. In both of these examples, the motivation for the behavior is the same, even though the materials available may differ between captivity and the wild. The captive environment may not look naturalistic when compared with the wild (for example, because of cage bars), but the functionality of the wild environment and the opportunities for a normal range of behavior can be mimicked to a degree in captivity, a key quality for good welfare.

Behavioral traditions can be lost if animals' repertoires become restricted, as social learning is involved in their transmission, and this is particularly important if zoos (and especially sanctuaries) hope to reintroduce animals to the wild in the future, or to convey accurate conservation messages to their visitors. Thus, zoos should aim to make captivity stimulating for their animals, and in species-appropriate ways. The physical and social environments of animals living in their natural habitats are dynamic and may change randomly and unpredictably, and so captive animals need to be challenged in

order to lead a good life (Sachser 2001). It is important, however, that these challenges do not overtax the individual's capacity to cope.

Animals that have experienced environmental deprivation are known to be susceptible to social and physical developmental problems (Harlow 1971). Problems in social development can result in the inability of an individual to cope with certain challenges that enrichment efforts can present, such as the exploratory behaviors involved in food-seeking activities. Thus, some individuals may not respond to our efforts to encourage good welfare in ways that we might automatically assume, because of the incorrect tendency for some people to equate the action of 'enrichment efforts' with the outcome of 'successful enrichment.' For some animals, it may be the case that a particular type of enrichment effort, which seems sensible and appropriate for us to try, causes more of a disturbance to them than if that particular effort had not been made, because the challenge is too great for those individuals and overtaxes their ability to cope. Thus, we should assess the efficacy of our enrichment efforts, as well as other aspects of husbandry, and behavior can be a useful measure.

Physiological measures

In addition to behavioral measures, animal welfare assessments should ideally also incorporate physiological indicators, such as changes in heart and respiratory rates, adrenal response, neurotransmitters and carcass characteristics, and these can be interdependent. It is useful to use a range of measures, because the excessive reliance upon any one indicator alone can produce misleading results, often as a consequence of the complexity of individuals' responses to stimuli. For example, the study of behavior

426 in two groups of animals may lead to different results, but that does not necessarily
427 indicate that one group's welfare is poorer than the other's, nor does the absence of
428 abnormal behaviors in an animal's repertoire necessarily imply that welfare is good
429 (Manser 1992).
430
431 For some of the physiological indices, knowledge of the emotional state of the animal
432 provides other important information (Dawkins 2001), as some changes can occur due
433 to beneficial behaviors: for example, you would expect to see an increase in heart rate
434 during energetic bouts of play, but the same response in a stationary animal could
435 indicate a problem. Animal welfare can also be measured using clinical/pathological
436 indicators, such as evidence of disease or injury, which are recognized universally as
437 signs of poor welfare (Dawkins 2001), but it is beyond the scope of this paper to discuss
438 veterinary issues in any detail (for more information on this topic, and advice on further
439 sources, see Hosey et al 2009).
440
441 A commonly-used physiological measure of welfare in zoo animals, and one that can be
442 obtained non-invasively, is of adrenal hormones: measuring activity in the sympathetic-
443 adrenal medullary system and in the hypothalamic-pituitary-adrenocorticol (HPA)
444 system (Broom and Johnson 2000). Measurement of fecal glucocorticoids, or their
445 metabolites, can be useful to studies of welfare in the zoo environment, especially in
446 assessing short-term responses to stressors, for a variety of species, although it must be
447 remembered that, whilst the HPA axis is one of the main mediators of the endocrine
448 response to stress, it also responds to other types of stimulation that are beneficial and
449 may require activity (Manser, 1992), including behaviors like mating rituals, copulation

and long play sessions, hence the need to measure a range of welfare indicators and not only endocrine response. There is also the potential for adrenal hormones to be assessed in animals living in their natural habitat, using methods developed within zoos (e.g. Wielebnowski and Watters 2007). This can contribute non-invasively to the work of conservation biologists, for example in measuring the effects of disturbance on wild populations, as well as to provide zoo biologists with knowledge of what might be a 'normal' range in good conditions in the wild.

Whilst it may be ideal to use a range of measures in assessing zoo animal welfare, how practical is it to do so? Some of the physiological measures used regularly in assessments of animal welfare in other settings, such as laboratories or farms, are not always practicable for use with zoo animals, due to handling and sampling difficulties, especially in untrained animals. Zoo species include large, powerful and unpredictable wild animals that have evolved strong 'fight or flight' responses in order to cope with perceived threats. Health and safety regulations are in place to protect zoo staff and researchers and, depending on the zoo and the species, these can mean that some researchers are never allowed beyond the public areas of the zoo. Much of what is allowed to happen, in practice, relies upon the goodwill of the keepers and the amount of time they can devote to helping researchers. This can vary by zoo and by keeper, and it can also depend on the attitude of the researcher and how well they conduct themselves on site at the zoo.

Training of zoo animals for sample collection is used in some parts of the world and can increase the chances of obtaining physiological data for husbandry and research

474 purposes. Even without formal training of the subjects, Davis et al (2005) were able to
475 collect urine samples from Colombian spider monkeys (*Ateles geoffroyii rufiventris*) at
476 Chester Zoo, UK, for assessment of urinary cortisol in relation to effects of zoo visitors.
477 They compared data collected during the UK-wide outbreak of foot and mouth disease
478 in 2001, when the zoo was closed to all but essential staff for six weeks, and at other
479 times throughout the year, when visitor numbers fluctuated widely. In this study, sample
480 collection was facilitated by exhibit design, as the monkeys would typically rest in a
481 mesh tunnel, while being vacated from their main enclosure for a short time as part of
482 the husbandry routine, and urine could be collected opportunistically in trays held below
483 the animals. In another study, Hill (2004) was able to collect fecal samples, and samples
484 of regurgitated food (Hill 2009), opportunistically, from untrained western lowland
485 gorillas (*Gorilla gorilla gorilla*), in several zoos in the UK and Europe, but it was
486 difficult to collect a large number of samples, due to the challenges of working with
487 such large, potentially-dangerous and coprophagous animals, and it required excellent
488 relations with zoo staff to be able to obtain any samples at all.
489
490 Other researchers have also been able to measure reproductive and adrenal hormones
491 using non-invasive sampling methods, in a variety of zoo species, some of which
492 include black (*Diceros bicornis*) and white (*Ceratotherium simum)* rhinoceros (Brown
493 et al 2001; Carlstead and Brown 2005), tigrina (*Leopardus tigrinus*), margay
494 (*Leopardus wiedii*) (Moreira et al 2007), Asian elephants (*Elephas maximus*) and Indian
495 rhinoceros (*Rhinoceros unicornis*) (Menargues et al 2008). Some zoos, such as Chester
496 Zoo (UK), St Louis, Cincinnati and National Zoos (USA), and Toronto Zoo (Canada),
497 have in-house reproductive biologists or endocrinologists to take this work forward, and

may include some services for diagnostics or research, whereby they process samples from other institutions at a charge, or as part of an agreed collaboration.

Some physiological measures are difficult to obtain safely in non-trained zoo animals without the use of anesthesia, which is a highly disturbing procedure in itself. It may be possible for zoo researchers to request samples, such as blood, to be collected opportunistically, when an animal is under anesthetic for a required veterinary procedure. Measures of heart rate, which would require the attaching of a heart rate monitor to each animal's body, has proved suitable for some animals (e.g. sheep: Baldock et al 1988; Elliker 2005; cattle: Hagen 2001;), but would not be feasible for many zoo species, for which, even if it were possible to attach heart rate monitors to them safely and calmly, would most likely be damaged beyond repair in a matter of minutes. Other physiological measures that are often not practical or accurate to obtain in studies of the welfare of zoo animals, but have been successfully used for species in other settings, include body temperature and respiratory rates. That is not to say that useful techniques will not be developed in the future, for application in zoo animal welfare research, and the need for effective collaboration and communication between disciplines is clearly needed to assist with this.

SOME OTHER CONSIDERATIONS FOR MEASURING ZOO ANIMAL WELFARE

The World Association of Zoo and Aquariums (WAZA 2005) refers to the importance of animal welfare to modern collections, in terms of managing healthy, viable populations for conservation reasons, and conveying reliable conservation-education

messages to the visiting public. Regarding the latter, some zoos, such as Chester (UK), are very active in the field of visitor studies (e.g. Francis et al 2007; Moss et al 2008), which contributes towards this. Further studies could combine assessments of efforts to improve animal welfare with assessments of the impact of these efforts on zoo visitors' perceptions, as both are important angles to consider.

WAZA (2005) also encourages zoos and aquaria to surpass the minimum legal requirements for animal welfare in their respective counties. Zoo legislation can vary by country, or even by region of a country (Hosey et al 2009), but there are common themes running throughout (Cooper 2003), relating to conservation and animal welfare. There are also specific laws in place regarding the collection, use and disposal of biological samples, which may be being used to aide the assessment of zoo animal welfare. The ideal of measuring animal welfare using a range of indicators, including behavioral and physiological ones, has already been discussed here. Even when zoo animals have been trained to give biological samples for research purposes, some of the legislation will affect some types of zoo-based research. It is beyond the scope of this paper to describe these in detail (see Hosey et al 2009 for a greater discussion), but zoo researchers need to be aware of the local and international legislation in place to regulate research on animals, and guidance from the appropriate authorities should always be sought in advance of a particular project, if clarification is needed. The Research Group of the British and Irish Association of Zoos and Aquariums (BIAZA) has also published a series of guidelines for zoo research, including guidelines on sample collection (BIAZA 2000), and these offer some useful advice to researchers whether in the BIAZA region or beyond.

Welfare assessments are complex, especially when incorporating best practice of using a range of measures, or conducting multi-zoo studies. Nevertheless, it is important to conduct such research, in order to document animals' responses to certain situations or stimuli, where such information may currently be lacking (Dawkins 2001). This will enable us to refine our knowledge of animals' needs for good welfare and ultimately provide captive animals with more appropriate conditions in the future, and to maintain good welfare in the long-term.

CONCLUSIONS

1. Animal welfare can be measured on a sliding scale from very poor to very good, and should be measured scientifically. Zoo researchers should make more use of knowledge gained in other captive settings, such as on farms or in laboratories, adapting the methods as appropriate. Greater collaboration is needed among zoos, as well as between zoos and other institutions (animal facilities, universities, etc.).

2. Behavior can be one of the most obvious and inexpensive indicators of animal welfare, but it is more useful if a range of behavioral and physiological measures can be taken.

3. It is important to document zoo animals' responses to stimuli in their environments. This will help us to provide conditions that fulfill the animals' needs to show certain behaviors and to have access to particular resources, and can affect physical and psychological health.

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571 4. In providing conditions for good welfare and in the process of researching this, it is
572 important to ensure that minimum legal requirements are being met and exceeded.

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575 **ACKNOWLEDGMENTS**

576 The authors are very grateful to the Women's Board of the Chicago Zoological Society
577 (CZS), for their generous financial support for S.P.H.'s participation in the 'Measuring
578 Zoo Animal Welfare: Combining Approached and Overcoming Challenges'
579 symposium. We are also grateful to the CZS's Tim Sullivan, Jason Watters and Nadja
580 Wielebnowski, for practical support, and for the invitation to take part in this
581 Symposium. Thanks also go to Heather Pickett and Phil Brooke, from Compassion in
582 World Farming, for providing unpublished data, and to Liz Genever and Roger
583 Wilkinson, Jason Watters, and two anonymous reviewers, for useful comments.

584

585

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