Thermoregulatory Behaviour Assessment and Thermal Imaging of Large Felids

by

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ABSTRACT

THERMOREGULATORY BEHAVIOUR ASSESSMENT AND THERMAL IMAGING OF LARGE FELIDS

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Various species of large felid are kept in zoos in climates that differ from those of their wild range. Until very recently thermal comfort and microclimatic zoo exhibit design has not been at the forefront of zoo habitat designs, as it has in livestock production. Few behavioural studies have been reported for captive exotics in the zoo setting. Thermoregulatory behavioural needs and comfort have been investigated in an observational study of several large felid species housed at Toronto Zoo (Toronto, Ontario, Canada), and Busch Gardens in Tampa, Florida. This study included continuous behaviour observations, in association with meteorological measurements (ambient temperature (°C), relative humidity (%), wind speed (m/s), solar radiation (W/m²), and the presence or absence of precipitation and shadows. Infrared thermal imaging of individual animals, were recorded every 15 minutes. In addition, a pilot study including infrared thermal imaging in conjunction with traditional rectal and axillary thermometer readings was carried out with domestic house cats (*Felis catus*) as a model to investigate the use of thermography for core body temperature measurement. Eight tigers (*Panthera tigris*) (n = 5 female, n=3 male), observed during summer, were housed at Busch Gardens, Tampa, Florida. To investigate felid species differences, several species were compared (lions (*P. leo*) (n=3 male and n=2 female), jaguars (*P. onca*) (n=1 female and n=1 male), tigers (*P. tigris altaica*) (n=1 male), cougars (*Puma concolor*) (n=1 female and n=1 male) and snow leopards (*P. uncia*) (n=1 male and n=1 female)) at the Toronto Zoo in Ontario, Canada during summer and winter. Descriptive statistics were used to analyze the data. The tigers in Florida spent most of their time inactive lying (>45%) in the shade (>20%) with water
as an important cooling zoo habitat resource for some individuals. Through species comparisons in behaviour and enclosure feature use, it was found that large felids could be grouped into two subgroups based on habitat of origin (i.e. hot climate cats and cold climate cats), and that zoo habitats could be designed for thermal comfort of these groups. Amur tigers and snow leopards are examples of cold climate cats, where lions and jaguars are examples of hot climate cats. All these felid species spent most of their time lying (40 - 84%) and relatively little time on active behaviours (5 - 10%). Shade was important for all species in summer (23 – 50% average daily time). Finally, eye surface temperature was closest to rectal and axillary temperatures, indicating that this may be the most appropriate thermography target for core body temperature assessment. The combined results the three studies described above, provide evidence that habitat of origin may play a role in the differences in thermal comfort and neutral zones of various felid species studied, and that zoo exhibit microclimatic landscape design can be informed by thermoregulatory behaviour studies to promote thermal comfort and efficiency in captive felid species.
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<table>
<thead>
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<th>Description</th>
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<tbody>
<tr>
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Chapter One: Literature Review

1.1 Introduction

1.1.1 Background

Although hundreds of large felids are kept in zoos around in North America alone, little research has been done on behavioural repertoire and behavioural needs of these animals. In addition, thermoregulatory behaviour has not been described for many large felids in the literature. Behaviour can inform care by revealing important information regarding both the physical and psychological wellbeing of the animals. Thermoregulatory behaviours such as activity level, changes in location, postural changes and orientation to things like solar radiation and wind, are employed by all mammals as a means to regulate homeostasis of core body temperature (Smith and Kok, 2006a). Detailed investigation into behavioural repertoire and thermoregulatory needs could inform zoo exhibit microclimatic landscape design for enclosures that promote thermal comfort in a variety of seasons and climates no matter the species habitat of origin. Due to lack of resources, it is difficult for zoos to carry out this research and often the numbers of individuals available to study, is too low for statistically significant results. However, case studies and studies including low numbers of individuals are not only a commonly excepted accepted limitation of zoo animal research, but also deemed valuable amongst the zoo community (Hutchins et al., 2003). None the less, it is important to have some understanding of the behaviour and welfare of animals in captive settings in order to enable caretakers to better provide for the needs of these animals.

The zoo exhibit is a microclimate within the macroclimate of the zoo and the region in which the zoo is located. The thermal environment of the enclosure may be quite
different than the area where the public observes from, and from that of the rest of the zoo. Depending on the orientation to the wind and sun, the materials used to construct the enclosure and weather conditions; enclosure microclimates may vary drastically in any given zoo. The microclimates of zoo enclosures are created from the landscape elements they are made of interacting with the local macroclimate (Brown and Gillespie, 1995).

1.1.2 Thermoregulation

The thermal environment is intertwined with the life it holds and the fitness and welfare of its organisms (Willmer et al., 2006). As homeothermic mammalian carnivores, large felidae maintain a core body temperature of between 38 and 39°C (Willmer et al., 2006). The thermal neutral zone (from B to B’, Figure 1.1) is the range of ambient temperatures where an organism can maintain core temperature without physiological effort, utilizing low energy behavioural adaptations (Equation 1.1; Smith and Kok, 2006b). Beyond this range, the organism enters the thermal zone of survival (C to C’), the range of relatively extreme temperatures where physiological and higher energy behavioural adaptation efforts are used for core body temperature maintenance (Willmer et al., 2006). Further beyond this range there comes a point where the ambient conditions are either too hot or too cold for the animal to regulate its core body temperature and biological processes will begin to fail. These limits of the thermal zone of survival are known as the lower critical temperature (D) and the upper critical temperature (D’) (Figure 1.1; Cossins and Bowler, 1987; Willmer et al., 2006). Within the thermal neutral zone there is a small range of ambient temperature known as the thermal comfort zone (A to A’) where no energy or behavioural adaptations are needed.

In environments of extreme heat or cold, biothermal defences are initiated at an
energetic cost to the animal (Smith and Kok, 2006b). Cabanac (1972) suggested that ‘if physiology is fine control of thermoregulatory processes in animals, then behaviour is the broadband control’. Thermoregulatory behaviour such as activity level and posture, orientation, and position changes, are employed by many animals in an attempt to regulate homeostasis of core body temperature (Cabanac, 1972; Smith and Kok, 2006a). These behaviours include increasing body surface area for heat loss through postural changes, shade seeking and panting (physiological increase in respiration rate) in hot temperatures and decreasing body surface area for heat loss, sun basking and group huddling in cold temperatures. Behaviour is used to minimize energetic costs of thermoregulatory processes (Smith and Kok, 2006b; Harri and Korhonen, 1988).

Many factors can influence physiological and behavioural thermoregulatory efficiency. Ingestion of food can increase metabolic heat production and since large felids are obligate carnivores their diets contain large amounts of protein and fats which have a higher heat of combustion than carbohydrates (Robbins, 1983). Stress can increase heart and respiration rates and eventually body temperature (Karrow, 2006). Pelage length, density, and body surface dispersion, may all contribute to thermoregulatory efficiency (Hilsberg-Merz, 2008). Lack of shade in an enclosure during hot weather will lead to the animals’ inability to utilize such a crucial feature of an enclosure for maintaining thermal comfort. Lack of water will lead to the inability to use evaporative heat loss effectively reducing thermal comfort drastically (Young et al., 2010).

There is an extensive list of potential factors such as; coat colour, enclosure layout with respect to the sun and shade availability, surfaces used in the enclosure (i.e. real or faux rocks), the provision of a water bath, sociality and group housing, use of shelter etc.,
that could all affect thermoregulatory comfort and efficiency in captive felidae (Young et al., 2010).

1.1.3 Heat Exchange

There are four main methods of heat exchange between an animal and its environment: convection, evaporation, conduction and radiation (Figure 1.2; Willmer, et al., 2006). In all methods heat is transferred across a gradient from higher to lower heat load, except for heat loss through evaporation where heat moves, with water across a vapour pressure gradient. Convection is where heat is lost through the movement of an adjacent fluid (i.e. gas, air or liquid, water). Conduction is where heat moves to or from an animal and an adjacent solid object via direct molecular transfer of energy (Willmer et al., 2006). Radiant heat can be gained through absorption of short wave solar radiation and it can be lost or gained from long wave terrestrial radiation emitted by any object, including the animal, over absolute zero. The Stefan-Boltzman law of conduction, convection and radiation dictates that all objects emit infrared radiation proportionate to their surface temperature (Polat et al., 2010), with a wavelength of between 2.5-40 µm, peaking near 9-10 µm (Willmer et al., 2006). Heat is always transferred from lower to higher temperature or vapour pressure gradient toward equilibrium. See Equation 1.2 for a more detailed thermal energy budget that incorporates heat exchange methods.

Radiation is received as direct (straight beam), diffuse (non-parallel beams coming equally from all directions of the sky or an object), or reflected (direct or diffuse) (Brown and Gillespie, 1995). This form of heat transfer is perhaps the single most important in thermal energy budgets (Brown and Gillespie, 1995). Although they may be easily overlooked, both forms of radiation need to be considered in the energy budget of the
animal. Figure 1.3 shows a more detailed visualisation of heat exchange through the various forms of radiant energy, as depicted in Willmer et al. (2006).

Solar radiation can be altered most effectively through shade use and types. The sun is the highest thermal energy input in a thermal environment and is the most important source of heat gain (Valtorta et al., 1997; Brown and Gillespie, 1995). Valtorta et al. (1997) found that dairy cattle would use any type of shade and Anderson et. al. (2013) found that cattle actively seek shade to reduce radiant heat load. In fact shade is an extremely valuable thermoregulatory resource for cattle (Titto et. al., 2013) and may also be essential for reducing radiant heat loads in large felid species.

Wind (forced convection) is the second most important method of energy transfer in landscape design (Brown and Gillespie, 1995). Wind is very efficient at mixing temperatures and humidity. It carries heat away from the cat and other objects and influences the thermal energy budget greatly. It moves from areas of high pressure to low pressure and there is a net movement from the west due to the rotation of the planet (Brown and Gillespie, 1995). Eddies are parcels of air where heat can be transferred to other eddies (Campbell, 1977). They are smaller nearer to the surface of the earth and larger farther from the earth. The larger eddies can transfer heat over farther distances faster, the smaller ones transfer heat over shorter distances (Campbell, 1977). Mixing of eddies allows for the transfer of heat over very large linear distances without heat transfer through molecular motion (Campbell, 1977).

Convection is the transfer of heat between objects through the movement of an adjacent fluid, i.e. air or water (Figure 1.2; Willmer et al., 2006). Convection can be free or forced. Free being caused by inherent temperature differences and forced caused by
mechanical effects of factors such as wind, moving water or movement of the animal itself (Willmer et al., 2006). Forced convection, when fluid velocity increases by some mechanical means, can increase convective heat loss from an animal greatly (Campbell, 1977).

There is a thin layer of fluid, air or water, around an endothermic animal which can be altered on a very small spatial and temporal scale by adjacent environmental fluids (Willmer et al., 2006). This layer is known as the boundary layer (Figure 1.4; adapted from Curtis 1983). In the absence of wind, convection occurs at the surface of the body in the boundary layer where inertial forces (i.e. temperature gradient) act to cause a turbulent flow of heat to the environment (Campbell, 1977). Wind speeds as little as 0.2 m/s can alter insulation values of an animal's fur coat (Langman et al., 2015). However, still air is a poor conductor of heat making this method of heat loss inefficient.

Within still air such as the boundary layer, free convection occurs along a gradient from high to low temperature very inefficiently. However, the boundary layer is easily disrupted and this can give rise to forced convection that occurs as wind takes heat away from the surface of the body. A visualization of the compartmentalization of heat zones within an animal’s body in relation to the body surface and then to the micro and macroclimate environment is given in Figure 1.4.

Latent heat exchange through evaporation, is another mechanism by which an animal loses heat to the environment (Figure 1.2). As wind moves past the felid, air molecules contact the skin and there is an exchange of heat and moisture (Brown and Gillespie, 1995). This mechanism involves the latent heat of vaporization of water (2500 J/g) from the surface of the animal, taking with it heat (Willmer et al., 2006). If the air is
drier than the animal, the moisture that leaves the animal will take heat with it (Brown and Gillespie, 1995). The rate of heat loss is dependent not only on the difference in surface temperature of the animal and its environment but also the difference in water vapour density of the animal’s boundary layer and that of its environment (Willmer et al., 2006). Both these gradients flow from higher to lower, toward equilibrium and are usually found to be in a negative energy balance with an animal and its environment. Increased water on the skin increases latent heat loss efficiency from the animal dramatically (Brown and Gillespie, 1995). A lack of water will lead to inability to use evaporative heat loss effectively reducing thermal comfort drastically (Young et al., 2010).

The surface of the skin and respiratory tract of an animal are the major sites of heat exchange with the environment (Langman et al., 2015). An animal can alter the amount of water on the skin via sweat, swimming or wallowing, making evaporative heat loss more efficient (Willmer et al., 2006). However, large captive felids utilize evaporative heat loss mainly through panting. In panting the nasal turbinates are utilized as a convoluted large surface area for evaporation of water with expired air (Schmidt-Nielsen et al., 1970). It is also known that in dogs there are additional salivary glands located at the back of the tongue which may be associated with increased ability for evaporative heat loss in panting where the tongue is involved (Pleschka, 1984). It is generally thought that if sweat glands exist, large felids only possess them on the bottom of their foot pads, making panting a more important method for heat loss to the environment for these animals. In addition, some mammals don’t possess the same salivary glands as does the dog, and some pant without tongue involvement (Pleschka, 1984); this makes information leading to knowledge of differences between felid species crucial for understanding respective
thermoregulatory abilities of these animals. Although more difficult to alter, exhibit thermal energy and water balance can be influenced by exhibit microclimatic design.

Finally, conduction is the transfer of heat energy from one object to another through direct physical contact via direct molecular transfer of energy (Figure 1.2; Willmer et al., 2006). Although this represents a smaller portion of the energy budget equation for the feline, it is easily controlled by behavioural posture and location change, and thus, it could be a major thermal comfort tool employed by animals (Brown and Gillespie, 1995).

The rate of heat transfer depends on the surface area in contact, the temperature differences between the two surfaces and the conductive properties of the surfaces involved (Willmer et al., 2006). Surface colour, for example, can significantly impact the thermal properties of surfaces animals may be in contact with (Langman et al., 1996). Animal coat thickness and thus insulative properties can differ greatly over the body and surfaces in contact may also vary greatly in thermal conductance, making this method of heat exchange very complex (Campbell, 1977). Therefore average body surface and object average thermal resistances are used to simplify things (Campbell, 1977).

When all methods of heat energy exchange are considered with water metabolism, a total thermal energy budget can be given, as in Equation 1.3.

**1.1.4 Ontogeny of Feline Thermoregulation**

There are no studies on thermoregulatory development in large felids however there is some literature on thermoregulation in house cats (*Felis catus*). Olmstead et al. (1979) found that it took about 45 days for kittens to develop thermoregulatory capacities of an adult cat. However, on the first day of age kittens are able to move along a temperature gradient toward an ambient temperature (Ta) where they could maintain core body
temperature (Tb). The kittens’ Tb would drop rapidly when placed in a cooler Ta than the nest box until they were 14 days of age. The neonatal Tb was 37.0°C on day 5 and didn’t reach adult levels of 38.2 ± 0.2°C until 7 weeks of age. Once adult Tb was achieved, shivering and piloerection began to occur upon exposure to colder Ta and panting upon exposure to higher Ta.

Larger body sizes can absorb a greater amount of heat but also have impaired heat dissipation (Lovegrove, 2005; Smith and Kok, 2006b). Body size is closely linked to the initiation and duration of thermoregulatory behaviours and small Ta changes are buffered by the mere size of the lion (Smith and Kok, 2006b). Lion cubs are of larger size at birth and grow at a faster rate than kittens and thus may also have accelerated thermoregulatory development.

1.2 Large Felid Thermoregulation

1.2.1 Literature Review

There is very little research done to investigate big cat thermoregulation and thermoregulatory behaviours. Marchie et al. (2009) found that neonatal domestic house cats descended from northern breeds, developed thermoregulatory abilities earlier than their counterparts of oriental origin. Ontogenetic onset of thermoregulatory abilities and perhaps overall thermoregulatory abilities may also differ across several of large captive felid species.

Hilmer et al. (2010) used ingestible Thermachron iButtons to find that feral domestic house cats were more active at night with a corresponding maximal core body temperature and less active in the day with a corresponding minimal core body temperature. This circadian rhythm was reversed in these same animals after one year of captivity.
Depending on management and housing practices, captivity may alter these biological rhythms in large felids as well. Nevill and Friend (2003) also used Thermochron iButtons to monitor core body temperature, but as a measure of stress in circus tigers during transit (2003).

Smith and Kok (2006a) used behavioural methods to investigate the thermal neutral zone of a few wild African Lions (Panthera leo), where shade seeking and loin exposing behaviours were shown to be important for cooling. They proposed a suggested thermal neutral zone for African lions in the Kalahari of 25 to 33°C (Smith and Kok, 2006b). In another publication on the same group of lions, Smith and Kok (2006a) observed more loin exposure during winter, suggesting that this behaviour is also important for gaining heat from solar radiation at that time. Although it has not been investigated properly in the literature, the mane of the male lion is thought to create a thermoregulatory cost for those that possess one, especially in hot environments (Simandle and Tracy, 2003; Hilsberg-Merz, 2008).

Langman et al. (2015) found that Amur tigers (Panthera tigris altaica) and mountain goats (Oreamnos americanus) can increase their coat insulation by 7.2 and 8.4 times in winter respectively. There could be differences in insulative properties of winter coats across species of large felid inherent to adaptations for their habitat of origin. It is reasonable to postulate that tundra derived species such as the Amur tiger and the snow leopard (Uncia uncia) will be more cold adapted than the large ranging puma (Puma concolor) and that equatorial species such as the Sumatran tiger (Panthera tigris sumatrae), and African lion (P. leo) will not be cold adapted.
No other studies could be found investigating thermoregulation in large felids. However, all homeothermic mammals exhibit thermoregulatory behaviours that could be used to assess the thermal welfare of large captive felids kept in climates that differ from that of their origin.

1.2.2 Thermoregulatory Motivation Model

The numerous factors that work together to stimulate thermoregulatory behaviour can be divided into internal and external stimuli. Internal stimuli include physiological factors such as sex, age, status of various biological cycles or rhythms, $T_b$ and $T_b$ sensory status, possession of a mane and its characteristics, over all coat colour, as well as satiety and state of digestion. External stimuli include meteorological parameters like relative humidity, wind speed and direction, rain, availability of shade, $T_a$, as well as terrestrial and solar radiation.

Other external factors could be of social origin. For example age, sex, and dominance status could play a role in comfort level of an individual to expose its vulnerable loin region. Individuals with lower social status may have a heat release disadvantage due to unwillingness to expose their loins. The group housing practices can provide felids with a means for huddling with conspecifics in cold weather. In addition other housing and management practices may influence daily activity patterns and even $T_b$ of large felids in captivity.

A model for three possible control systems for thermoregulation is given by Satinoff (1978) in Figure 1.5. This model is for thermoregulation in general and does not focus on thermoregulatory behaviour, however the various stimuli are represented as altering the set point thermostat and mixing at the comparators (crossed circles). When
positive stimuli outweigh the negative, a certain response or reflex occurs. Thermoregulatory behaviour is controlled in a similar manner with the internal and external stimuli altering the set point (Tb) of the lion and causing a thermoregulatory behaviour response. The behaviour leads to a resetting of the set point Tb and acts as negative feedback for the behaviour to cease (Figure 1.5a).

A more complicated homeostatic model conceptualizing thermoregulatory behaviours such as loin exposure, huddling and physiological panting, based on the description of the lions studied by Smith and Kok (2006a) is given in Figure 1.6. According to Smith and Kok (2006b), if the Ta is less than 25°C in winter, it will act to negate loin exposure in the lions they studied in the Kalahari. However, when Ta is greater than 25°C, as positive stimuli outweigh the negative at the comparator and Tb is altered, loin exposure should occur (Figure 1.6a). Once Tb is reset negative feedback will act to cause the lion to cease exposing. In the summer the process would be the same up until the loin exposing act (Figure 1.6b). Next, this would negatively feedback to stop the behaviour but if Tb was not reset then this would positively feed into physiological mechanisms like panting taking over to reset the internal Tb thermostat.

1.2.3 Species of Interest

The feline species of interest include: African lions (*Panthera leo*), tigers (*P. tigris tigris, P. tigris altaica, P. tigris sumatrae, P. tigris jacksoni*), snow leopards (*P. uncia, or more recently classified as, Uncia uncia*), jaguars (*P. onca*), and puma (*Puma concolor*). It is important to note the diversity of natural habits of origin of these various felid species. Although they are all cats, they may have differences in thermal neutral zones and thermoregulatory behaviour needs.
The African lion is by far the species most studied in the literature and has a broad range of habitat tolerance. They are currently listed as vulnerable on the International Union for Conservation of Nature and Natural Resources’ (IUCN) Red List of Threatened Species (Bauer et al., 2008). Despite common conceptions, lions can withstand the harshness of the interior Sahara while also being found in more hospitable environments such as the tropical rain forests of Africa. Further, water requirements can be obtained from prey and plants in the desert making them a highly adaptable species (Bauer et al., 2008).

Not all males possess a mane (Gnoske et al., 2006) and prepubertal castration may lead to the absence of a mane in adulthood (West and Packer, 2002). Mane development is correlated to the climate the lion is reared in and the Ta which the lion is currently in (Patterson et al., 2006; West and Packer, 2002). For example, mane size and darkness of colour tends to decrease with hotter, and increase with colder rearing environments (West and Packer, 2002). Manes of lions moved to colder environments may get larger and darker where the opposite is true for lions moved to warmer environments (West and Packer, 2002). Areas with higher rain fall seem to be linked to lions producing smaller manes (Gnoske et al., 2006). Due to the mane, it is generally thought that male African lions may be less able to regulate core body temperature at extreme ambient temperatures, although more research would be needed to better investigate this claim.

Tigers are arguably the most diverse species of felid kept in zoos with six extant subspecies confirmed by molecular markers, and three more now extinct which were classified based on morphology (Chundawat et al., 2011). As a whole the species is listed as vulnerable by the IUCN Red List and the population trending toward decline (Chundawat et al., 2011). They once ranged from Turkey to east coastal Russia all through
Asia, however over the last 100 years 93% of their historical range has been lost (Chundawat et al., 2011). Populations have disappeared from most of central and south-western Asia and two Indonesian islands (Chundawat et al., 2011).

Although most tigers currently inhabit the tropical forests of Asia (Chundawat et al., 2011), the tiger is adaptive and may be found in many habitats (Nevill et al., 2004). The Amur tiger (*Panthera tigris altaica*), formerly known as the Siberian tiger, is at home in the cold snowy regions of eastern Russia (Chundawat et al., 2011). This subspecies is listed as endangered by IUCN and 90% of the population occurs in the Sikhote Alin mountain region where little genetic diversity remains (Miquelle et al., 2011). The Northern Indochinese tiger (*P. tigris corbetti*) is found in tropical Myanmar, Thailand, Lao PDR, Viet Nam, Cambodia and southwestern China (Lynam and Nowell, 2011). This subspecies of tiger is estimated to be on the brink of a critically endangered classification by the IUCN (Lynam and Nowell, 2011). The Malayan tiger (*P. tigris jackson*), of Peninsular Malaysia, is listed as endangered and hails from a tropical climate with monsoon seasons (Kawanishi and Lynam, 2008). The Sumatran tiger (*P. tigris sumatrae*), in addition to its genetic markers, is unique in its appearance and is confined to an area of 58,321 km² of humid jungle habitat (Linkie et al., 2008). Due to immediate threat to its small habitat range, this subspecies is listed as critically endangered by IUCN. Most Bengal tigers (*P. tigris tigris*), also listed as endangered, are found in the hot climate of India (Chundawat et al., 2011) where some are found at much colder elevations as high as 1500 m (Nevill et al., 2004). Finally, the South China Tiger (*Panthera tigris amoyanesis*) is listed as critically endangered and may likely be extinct in the wild, although it is possible that a few
individuals persist in the Qizimei Mountains Nature Reserve, Hubei (Nyhus, 2008). The stripes of the tiger’s coat may uniquely impact thermoregulation in this species.

Snow leopards are cats of the high mountainous region of Central Asia and is listed as endangered (Jackson and Nowell, 2011). They typically occur at 3000-4500 m above sea level and are at home in the cool alpine and sub-alpine ecological zones. However they have also been seen in less dense coniferous forests of China and sufficiently covered flat rolling plains of Mongolia and Tibet. They mainly feed on large prey like the blue sheep (Pseudois nayaur) and ibex (Capra sibirica) but also consume small mammals (Jackson and Nowell, 2011). It has been well established that snow leopards are crepuscular in nature being active at dawn and dusk and are rarely seen during the day (Chubykina and Shilo, 1980). Studies indicate that snow leopards are a seasonal breeder given the severity of their natural habitat and based on sexual behaviour observation (Schmidt et al., 1993). Snow leopards have been seen to use their long, furry tail as insulation for their paws and face while sleeping much like the arctic fox. They may also have a very dense winter coat that sheds for the summer months.

Jaguars (P. onca) and puma (Puma concolor) are similar sized, sympatric cats that tend to hunt nocturnally (Harmsen et al., 2011). Although a lot of their home range over laps, the puma is the most widespread terrestrial animal of the western hemisphere and is found in every major habitat of the Americas (Caso et al., 2008a). Jaguars are the larger of the two, and the only extant representative of the Panthera genus in the western world (Caso et al., 2008b). The Jaguar is found in a variety of habitats however they have been driven from their most important habitat, the dry tropical forests of Mexico (Núñez-Pérez, 2011). As such, the Jaguar is listed as near threatened (Caso et al., 2008b) where the puma
is listed as least concern (Caso et al., 2008a) by the IUCN Red List. Both exhibit nocturnal activity patterns and may have prey competition, but some research has shown that they have different prey preferences (Harmsen et al., 2011). Since the puma inhabits a much larger range including high altitudes and cold northern climates of Canada, prey competition is not always an issue. As is common with nocturnal animals the activity patterns of these animals may vary with moon phases due to visibility differences (Harmsen et al., 2011). Both species are highly adaptable however, due to a wider range of habitats, the puma is likely more cold adaptable than jaguars.

1.3 Conclusion

Very few behaviour repertoire studies and thermoregulatory studies have been done on captive large felids. Behaviour can be used as an indication of both physiological and psychological wellbeing of animals. A good understanding of behavioural and thermoregulatory needs of captive species informs better care and husbandry practices and can ensure better welfare and thermal comfort for these animals. More research investigating behavioural time budgets and thermoregulatory behaviour needs of large felids would be highly valued by the zoo community where there is a lack of information in the literature. Any work done in this area could provide a foundation for future studies to follow, and lead to increased awareness of the thermal comfort needs of large felids in the zoo setting.
Figure 1.1. Zone of thermal survival; A and A’ denotes the thermal comfort zone, B and B’ denotes the thermal neutral zone, C and C’ denotes the thermal homeothermy zone, D denotes the lower critical limit and D’ denotes the upper critical limit. From Bianca, W. (1968).
Figure 1.2. Illustration of various heat exchange mechanisms (convection, conduction, evaporation and radiation) between an organism and its environment. Adapted from: Willmer et al., (2004). Tiger image by: author.
Figure 1.3. A more detailed visual representation of heat exchange through various forms of radiant energy (direct, reflected, diffuse or scattered solar radiation or terrestrial radiation), where SW = short-wave (solar) and LW = long-wave (terrestrial) radiation. From Willmer et al., 2006.
Figure 1.4. A simplified diagram of the temperature distribution of an organism and its environment from the internal core body temperature out to the boundary layer of the animal and beyond through the microclimate(s) and further still to the macroclimate. Adapted from Curtis, 1983.
Fig. 1. Schematization of three possible control systems for thermoregulation. The comparators (circles) are mixing points. Whenever the combination of pluses and minuses do not cancel one another, an error signal is generated. When this occurs a response is activated which alters the regulated body temperature (whatever temperature or combination of temperatures that may be). The output of that response is fed back to the comparator and the error signal is adjusted. Feedback temperatures and the separation between controlling and controlled systems have been drawn only in the top model for clarity. (A) One central thermostat whose output activates all relevant behavioral and autonomic responses. (B) Two central thermostats, one activating all behavioral, the other all autonomic responses. (C) Each thermoregulatory response can be elicited independently of any other. This system may be multiply represented at several levels of the nervous system, and the individual integrators at lower levels would then receive input from higher levels (see text).

Figure 1.5. Schematization of three possible control systems for thermoregulation. Adapted from Satinoff (1978).
A

Exogenous stimuli

Endogenous stimuli

Behavioural Motivation

Tb regulated

Tb not regulated

Hibernation or torpor state

Tb regulated

Ta < TNZ°C

B

Exogenous stimuli

Endogenous stimuli

Behavioural Motivation

Tb regulated

Tb not regulated

Panting

Tb regulated

Ta > TNZ°C
Figure 1.6. A detailed schematization of a homeostatic model of loin exposure thermoregulatory behaviour in (A) the winter and (B) the summer. Where comparators are shown as crossed circles, positive stimuli are marked with a plus sign and negative feedback is noted by a negative sign. Note in winter, if the environmental temperature is below 25°C then loin exposure stimuli are negated and in summer if the environmental temperature is over 34°C then loin exposure behaviour may be skipped and physiological panting may be seen instead.
Equation 1.1

Heat transfer energy budget = Heat of metabolism + heat in – heat out = thermal neutrality

Note: It is important to note that the net heat of the energy budget should be zero in order for the tachymetabolic feline to maintain core body temperature at a constant homeostatic rate.

Equation 1.2 (Adapted from; Brown and Gillespie, 1995)


Note: Here heat is added to the budget and taken away from the budget but this relationship must be maintained at a net of zero in order for the tachymetabolic, homeothermic cat to maintain constant core body temperature. If the net energy budget is negative the cat will cool down. If methods are not found to warm it up, the animal will enter hypothermia. As the lower critical limit is approached and as the cat can no longer maintain brain temperature the animal will succumb. On the other hand if the net budget is positive the cat will heat up and if it cannot cool itself it will succumb to heat stress. The upper critical limit is more important physiologically, since animals can typically sustain metabolic rates 3 times that of basal levels in the cold, to maintain core temperature, however this would be to the animal’s detriment in hot conditions (Cossins and Bowler, 1987). Energy expenditure in hot conditions also increases metabolic rate and thus core body temperature which presents a larger threat to the animal than thermoregulatory mechanisms in the cold. It is critical that zoo design take into account the thermal comfort of various species of large felid in order to provide them freedom from physiological or thermal stress (FAWC, 1979).

Equation 1.3 (Adapted from; Brown and Gillespie, 1995).

Thermal energy budget & water balance of the felid = heat of metabolism + net radiation + net conduction + water ingested + water absorbed – convection – evaporation – water exhaled – water evaporated from the surface = Core body temperature maintenance + sufficient body hydration

Note: Here if the cat is gaining more heat than it is losing, its core body temperature will rise. If it is losing more heat than it is gaining, the core will begin to cool down. If the cat is losing more water than it can ingest or find for ingesting, it will become dehydrated. There is rarely a problem of having too much water coming into the felid.
Chapter Two: Study General Rationale, Objectives and Hypotheses

2.1 General Rationale

Behavioural repertoire assessments are difficult to design and infrequently carried out for captive exotic zoo animals. It is important to have some understanding of the behaviour and welfare of animals in captive settings with respect to both their physical and psychological wellbeing, thus enabling caretakers to better provide for the needs of these animals.

With increasing public awareness of animal welfare, the thermal comfort of zoo animals has become a growing concern. This has led to a recent push toward zoo exhibit microclimatic landscape design that takes animal thermal comfort into consideration. There already exists extensive research into livestock thermal comfort and thermal neutral zones due to the immediate perception of the economic impact of animal energy reserves being partitioned toward thermoregulation (Smith and Kok, 2006b). Zoo research in this area however is quite sparse perhaps due to the lack of immediately perceived economic impact. Zoo exhibits should be designed in a way that supports a thermal neutral environment to maximize fitness and welfare through thermal regulatory efficiency of the animal.

There are very few studies in the literature that relate to large felid thermoregulation in any manner. Nevill and Friend (2003) fed Thermochron iButtons to circus tigers to monitor core body temperatures in response to ambient temperatures and stress during transport, a practice that may not be permitted by zoo staff due to potential dangers of broken and unrecovered devices. Smith and Kok (2006b) used behavioural methods to investigate the thermal neutral zone of a few wild African Lions. These three lions showed
a thermal neutral zone of between 25 and 33°C. In another publication on the same lions Smith and Kok (2006a) discuss their evidence for loin exposure behaviour as serving to cool the animal and as a means of sun basking to increase heat in cool weather but only if it is not too cold (2006a). These two studies were done on a particularly small pride consisting of two adult males, one adult female and two cubs. More recently, Langman et al. (2015) published a species insulation adaptation comparison study that included Amur tigers (*Panthera altaica*).

There is a lack of specific research into thermoregulatory behaviour and microclimatic thermoregulatory needs of large felids. In addition there is a lack of behavioural repertoire assessments of large captive felids. An observational study with the magnitude of the one described here in, has never been reported in the literature.

To gain a broader understanding of the behavioural repertoire and thermoregulatory behavioural needs of large captive felids, a continuous observational study was designed to include several species and weather measurements. The various species of the genus *Panthera* and *Puma* should be considered on a species by species basis when it comes to microclimate zoo exhibit design. Depending on species, some large felids are adapted to hot and others to cold climates. Due to climate of origin, physical morphology, and daily activity patterns, it is likely that there are species thermoregulatory adaptation differences which could translate into differing thermal neutral zones.

The feline species of interest include: lions (*Panthera leo*), jaguars (*P. onca*), tigers (*P. tigris*), snow leopards (*P. uncia*) and cougars (*Puma concolor*).
2.2 Study Objectives

Through the case study approach, using continuous observation methods, this study hopes to provide a foundation for future work investigating large felid behaviour and thermoregulatory behaviour and needs assessments.

1. To examine daily maintenance behaviours in captive felids, based on approximate eight hour day time continuous observation periods throughout the year recorded between the hours of 10:00 am – 7:00 pm.

2. To investigate thermoregulatory behaviours in captive felids, associated with eight hour day time continuous observation, thermal images recorded for every animal every 15 minutes, and measurements of ambient air temperature, relative humidity, wind speed and solar radiation also recorded every 15 minutes throughout the observation period.

3. To investigate the use of thermal imaging as a non-invasive method for measuring the core body temperature of captive felids using house cats as a model.

2.3 Study Hypotheses

1. Daily maintenance and thermoregulatory behaviours in captive felids will differ across species and,

2. Information gained could provide information that can be used to enhance zoo exhibit microclimatic landscape design that could better the housing and welfare of these animals.

3. Thermal imaging of body surface temperature, paying particular attention to eye ball surface, the inside of the ear, and urine and fecal material as they are being voided from
the animal body, may provide a non-invasive means of accurately estimating core body temperature.

The research is divided into four chapters, as follows:

• Chapter 1 is a review of the current literature on large captive felid behaviour, with a focus on thermoregulatory behaviour. Information from small domesticated cats (*Felis catus*) has been used when literature was lacking for large captive felids.

• Chapter 3 presents an observational study where nine Bengal tigers (*Pantherta tigris tigris*) were observed using continuous behaviour observation techniques during summer to investigate behavioural repertoires while focussing on thermoregulatory behaviours and enclosure use for core body temperature maintenance.

• Chapter 4 presents an observational study where several species of large felid (*Panthera tigris altaica, Panthera leo* (both tawny and white in colour), *Panthera onca, Uncia uncia, Puma concolor*) were observed during summer and winter, for behavioural repertoire while focussing on thermoregulatory behaviour and enclosure use for core body temperature maintenance. Species differences in thermoregulatory behaviours were investigated at seasonal extremes in hopes of investigating thermal neutral zone and/or thermal comfort zone differences amongst the species observed.
• Chapter 5 presents preliminary data from a pilot study investigating the validity of using thermography for core body temperature measurement using house cats (*Felis catus*) as a model.
Chapter Three: Behavioural repertoire assessment via continuous observation and thermal imaging of large felids (*Panthera tigris*) with focus on thermoregulatory behaviour

3.1 Abstract:

The behavioural repertoire and environmental feature needs for thermoregulatory behaviour performance and comfort have not been reported in the literature for large captive exotics in the zoo setting. An observational study was done to investigate the behavioural repertoire of tigers via continuous observation, while focusing on thermoregulatory behaviour, in order to examine behavioural and thermoregulatory needs of these animals, and inform microclimatic landscape design for thermal comfort. Nine Bengal tigers (n=6 females, n=3 males, housed at Busch Gardens, Tampa, FL) were observed in June 2012 and behaviour data recorded every minute, while thermal images of each individual, wind speed, ambient temperature and relative humidity were recorded every 15 minutes. Descriptive statistics were used to analyze the data using Microsoft Excel. All tigers spent on average over 45% of the time lying down, less than 19% of the time in direct sunlight and over 20% of their time in the shade. Males (25.6%) panted more than females (15.1%). There was more individual variation in water and cave usage which could be related to social pressures or basic individual preferences. Adding more shade structures to this habitat to increase thermal comfort could increase activity in these cats (around 10% on average active behaviours) by adding to the space available in the shaded areas.
3.2 Introduction

Behavioural repertoire assessments are difficult to design and infrequently carried out for captive exotics in zoos. It is important to have some understanding of the behaviour and welfare of animals in captive settings with respect to both their physical and psychological wellbeing thus, enabling caretakers to better provide for the needs of these animals.

Carnivores maintain a body temperature between 38-39°C (Willmer et al., 2006). Cabanac (1972) suggested that ‘if physiology is fine control of thermoregulatory processes in animals, then behaviour is the broadband control’. Thermoregulatory behaviour such as activity level and posture, orientation, and position changes, are employed by many animals in an attempt to regulate homeostasis of core body temperature (Smith and Kok, 2006a).

The thermal neutral zone (TNZ) is the range of ambient temperature (Ta) where the animal can maintain core body temperature (Tb) without physiological effort (see Figure 1.1), which is complimented by low energy, behavioural adaptations (Smith and Kok, 2006b). The zone at which an animal feels most comfortable is known as the thermal comfort zone (TCZ). This is a zone of Ta within the TNZ perhaps the environmental temperature range where no physiological or behavioural methods are required for thermoregulation (Cossins and Bowler, 1987).

There are four main methods of heat exchange between an animal and its environment (Willmer, et al., 2006). In all methods heat is transferred across a gradient from higher to lower heat load, except for heat loss through evaporation where heat moves...
across a humidity gradient where heat moves with water vapour. Convection is where heat is lost through the movement of adjacent air. Conduction is where heat moves to or from an animal and an adjacent solid object. Radiant heat can be gained through absorption of short wave solar radiation and it can be lost or gained from long wave terrestrial radiation emitted by any object, including the animal, over absolute zero. According to the Stefan-Boltzman law of conduction, convection and radiation, all objects with a temperature over that of absolute zero (-273°C) emit infrared radiation proportionate to that of their surface temperature (Polat et al., 2010). Heat is always transferred from lower to higher temperature gradient toward equilibrium.

Thermoregulatory behaviour has not been described for many large felids. Smith and Kok (2006a) investigated the thermoregulatory behaviours of a small group of free living African lions (Panthera leo), where shade seeking and loin exposing behaviours were important for cooling. They also proposed a suggested thermal neutral zone for African lions in the Kalahari (Smith and Kok, 2006b). No other studies could be found investigating thermoregulation in Panthera genus cats. However, all homeothermic mammals exhibit thermoregulatory behaviours that could be used to assess the ‘thermal welfare’ and related enclosure needs of large captive felids.

Various features of a habitat provided to a captive animal can aid in thermoregulation or hinder thermoregulatory efforts of captive animals. Shade can be a very valuable thermoregulatory resource. It is well documented that shade from a tree can decrease solar radiation by up to 25% (Brown and Gillespie, 1995) and that dairy cattle find it an extremely valuable resource for staying cool in sunny summer months (Anderson et
Tigers are known to use water when provided, and may therefore find it a valuable thermoregulatory aid in the heat of summer through forced convection, and evaporative cooling upon exit. A cave for shelter from the sun may also be a valuable thermal resource for keeping cool.

Types and properties of the materials used in the construction of the enclosure can also impact the efficiency of heat transfer between an animal and its environment. Gunite is known to have different thermal properties compared to natural rock, however its surface temperature can be lowered by painting the gunite a colour with lower absorptive properties (Langman, et al., 1996). Langman et al. (1996) used a combination of shade and darkening the surface of gunnite to effectively reduce the heat load of the surface used by sea lions at the Audubon Zoo. Grass surfaces are cooler than sandy substrate. Even natural and artificial shade can be quite different with respect to heat sensibility, which also needs to be taken into account (Valtorta et al., 1997).

The objectives of this study were to investigate the behavioural repertoire of captive tigers at Busch Gardens in Tampa, Florida while paying close attention to thermoregulatory behaviours and enclosure use. The information gained by this continuous behaviour study will be valuable to the zoo community where little information has been reported on the fundamentals of captive big cat behaviour. Behavioural time budgets and enclosure use budgets could also yield valuable information about the thermal environment experienced by these animals and inform microclimatic landscape design for more thermal neutral habitat space providing for better thermal comfort.
3.3 Methods

Behaviour data was recorded continuously every minute for approximately 8 hours. Infrared thermal images were taken of each cat every 15 minutes and meteorological parameters such as wind speed, solar radiation, air temperature and relative humidity were also recorded every 15 minutes.

3.3.1 Animals

Nine Bengal tigers were housed in 3 groups (Group 1 was n = 1 orange female and n = 1 orange male, Group 2 was n = 3 females (1 orange and 2 white) and Group 3 was n = 2 females and n = 2 males. In total there were n= 6 females and n= 3 males. The tigers were housed at Busch Gardens in Tampa, Florida in three stable social groups, which were on display to the public on separate days. Group 1 was a brother sister pair about 4 years of age, Group 2 was composed of three older female cats (around 11 years of age), and Group 3 had 2 brother and sister pairs (1 orange male and 1 ‘cinnamon’ female sibling pair and 2 white siblings). The cinnamon tiger lacked black pigmented stripes and instead had cinnamon, or rusty red coloured stripes.

3.3.2 Enclosure

The groups were rotated daily on display in the River Habitat shown in Figure 3.1, where there was access to a large flowing water area, known as the river, a cave like tunnel, 2 levels of elevation and access to shaded areas. There was a waterfall on the upper level that fell into a small pool were tigers could lay, which then flowed down through another
waterfall to the river area on the lower level. There were gunite surfaces as well as grassy areas and tree logs to climb and walk on.

3.3.3 Weather

Weather parameters were recorded every 15 minutes during the observation periods for comparison to behavioural data. Relative humidity and ambient air temperature were measured using a Kestrel 4000 pocket weather meter (Nielson-Kellerman, Boothwyn, PA). Wind speed was measured using a Sims DIC-3 Anemometer (Simerl Instruments, Annapolis, MD). Precipitation and overcast conditions were recorded as ‘all or none’ events.

3.3.4 Behaviour

Continuous observation was used to assess the behavioural repertoire of captive tigers at Busch Gardens in Tampa, Florida, where volunteers recorded what the animals did for the majority of each minute, every minute. Observation periods began between 9 am and 11 am and concluded between 3:30 pm and 5 pm in June of 2012. Observations were conducted outside the ‘river habitat’ from areas freely accessible to zoo visitors.

Behaviour data was recorded every minute manually, by trained volunteer observers on data sheets (Appendix I). Behaviours and contexts were created through preliminary observations and trial and error until a full behavioural ethogram was established (Table 3.1). Behaviours and contexts were given a number between 1 and 23 and are described in Table 3.1. Behaviours were the activities the cats were seen to be doing while contexts were ways or places behaviours could be performed. Each observer recorded behaviours for
an individual felid, to avoid confusion between individual tigers. Observers would randomly observe different cats each day or switch part way through the day in an effort to avoid observer bias. At times, more than one observer would independently watch the same cat so that observer reliability could be tested and calculated.

3.3.5 Thermal Imaging

Thermal imaging was done every 15 minutes with a ThermaCAM SC 2000 thermal imaging camera (FLIR Systems, Danderyd, Sweden (with 45° add on lens) or FLIR E60 (FLIR Systems, Burlington, Ontario, (with a built in 15° and add on 45° lens)), with an emissivity setting of 0.95. Other special events were photographed with the thermal camera which include, loin exposure, urination, defecation and spraying. The camera had a built-in 24 mm lens; however all images were taken using the add-on 45 mm lens. The camera detects naturally emitted long wave radiation (7.5 – 13 µm) from an object or animal surface, dependant on surface temperature, and converts this to electrical signals which are outputted as visual-light-translated thermal patterns. Images were then analyzed using FLIR proprietary software: ThermaCam Researcher Pro. 2001. An example image with several targets of interest is shown in Figure 3.2.

3.3.6 Data Analysis

Behaviour time budgets (Figure 3.3a-c) and enclosure use budgets (Figure 3.4a-c) were created using Microsoft Office 2010 Excel, based on numbers assigned to behaviours and contexts. Most behaviours were recorded as mutually exclusive events however, some were not. For example a tiger could be panting and laying down at the same time and every
time a special event like urination, defecation or spraying occurred, it was recorded even though these would rarely take an entire minute. For these reasons the percent of time spent on a behaviour or in a context was depicted as a ratio of total number of observation points in order to standardize from one tiger to another and one day to another. All time budgets account for 100% of the observation periods. This was done due to the tigers being able to perform more than one thing at a time and therefore having a total of more than 100%. Behaviour budgets include the behaviour portion of data where contexts were used to generate the enclosure use figures (3.4). Average time budgets were generated by averaging, average daily values per individual (Females n=5. Males n=2).

Daily behavioural ethograms were also created with the continuous behaviour recordings using the Microsoft Excel scatter plot function. These figures show all continuous behaviour recordings which are shown in real time.

Descriptive statistics were used to generate behavioural ethograms, time budgets and enclosure use budgets. These figures are based on one day of data per cat. Time budgets for females and males were averaged using descriptive statistics and also presented.

*All research was approved by the University of Guelph’s Animal Care Committee and the Research Review Committee at Busch Gardens.*
3.4 Results

3.4.1 Animals

Group 1 consisted of a male and female sibling pair that were both orange and approximately 3 years of age. Group 2 consisted of three older females, one orange (approximately 11 years of age), a white female (approximately 10 years of age) and another white female (approximately 11 years of age). Group 3 consisted of white sibling pair (about 7 years of age) and an orange sibling pair (about 6 years of age). One white female from Group 2 (G2F3) was not on display for part of the observation periods, so this data was left out. One white male from Group 3 (G3M2) was also not on display for most of the observation periods and this data was also removed from analysis. In both situations this was the individual with the lowest level of dominance in that respective group. The remaining data that was analysed consists of n=2 males and n=5 females. Information on dominance hierarchy of the groups was obtained by communications with the tiger keepers (Hackman, J., Personal Communication., May 2012).

In group 1 neither cat was dominant, this was evidenced by little confrontation and little to no displacement of individuals by their conspecific (observed during this study). In Group 2 G2F1 was dominant and G2F2 second, which was evidenced by these individuals displacing their lower ranking conspecifics on several occasions during this study. In Group 3 G3F1 was the dominant cat and her male sibling G3M1 was second in the dominance hierarchy. The dominance behaviours were most strongly noted with individual G3F1 as she would constantly spray scent over any conspecific’s previous scent spray markings and
displace any other individual in the group, including her brother (observed during this study).

3.4.2 Enclosure

The flowing river area (Figure 3.1) was large enough (approximately 15 tiger lengths of visible area long and approximately 7 tiger lengths wide) that all tigers could wade at the same time with enough room that negative confrontations could be avoided. At no point in time did more than 2 individuals use the water at the same time and no negative interactions were observed between tigers using the water at the same time.

3.4.3 Water Use

For all days of observation weather conditions were fairly consistently hot and humid with no precipitation and few cloudy periods except day 2 (D2) and day 3 (D3) of observation with Group 3. Group 3 day 2 (G3D2) was overcast for most of the day with some precipitation and G3D3 had a lengthy cloudy period as well. For this reason this G3D2 is kept out of average calculations used to create Figure 3.5.

Average daily ambient temperature ranged from 30.4 °C to 33.8°C (Figure 3.5). Average daily relative humidity ranged from 41.7% to 58.4% where average daily vapor pressure ranged 6549.4 kPa to 7938.0 kPa. Most days were sunny with few cloudy periods but for one day, of overcast conditions. Wind never reached more than 3 m/s, and this was rare and for short periods of time. Typically there was no wind or very little (1-2 m/s) for all weather observation days. Overcast conditions were only a factor for G2 on D2 and for G3 on D3 and only lasted for a short period of time during the observation day.
3.4.4 Behaviour

For all observation days all cats spent most of their day laying down and inactive with averages for time spent lying head up ranging from 16.2% to 37.7% for all individuals (Figure 3.3a), the same for females (n=5) (Figure 3.3b) and 23.5% to 27.7% for males (n=2) (Figure 3.3c). Average time spent lying with head down ranged from 18.9% to 57.0% for all individuals (Figure 3.3a), 18.9% to 36.8% for males (Figure 3.3c) and 27.5% to 57.0% for females (Figure 3.3b). When combined individuals spent an average of between 46.6% and 75.6% of their time lying down, females spent between 47.8% and 75.6% of time lying down and males between 46.5% and 60.3% of their time lying down.

3.4.5 Thermoregulatory Behaviours and Enclosure Use

Panting is a physiological indication of heat stress and it should be noted that it is not behavioural although it may appear to be. The reflexive and central nervous system control mechanisms of panting have been well characterized in dogs and are reviewed by Richards (1970). Most tigers spent a fair amount of time panting. On average males spent 25.6% of their time compared to females, which spent 15.1% of their time panting. G2F2 panted the most, spending on average 31.2% time daily panting. G3M1 was a close runner up who spent 29.5% of his time panting. However, the felines G2F1 and G2F2 spent an average of less than 7.1 and 5.6% of their time panting (Appendix 2).

Loin exposure was rarely performed. G2F1 spent on average 13.1% of the observation period exposing her loin. All others spent less than 4% of the time performing loin exposure.
All cats spent less than 19% of their time on average in the direct sunlight. Average time spent in the sun ranged from 6.2% to 18.7%. The time they did spend in the sun was typically short in duration and would only last a few seconds to minutes. Overall average time spent in the sun was 11.3% with females averaging 10.8% and males averaging 12.4% (Figure 3.4).

There was enough shade from the sun provided for all cats to use the shade for most parts of the day. All tigers used shade for at least 20% of all observation periods. Average time spent in the shade was 60.5% and ranged from 22.9% to 80.8%. Males spent an average of 48.5% of their time shade seeking. The average time females spent in the shade was 64.4% and ranged from 49.6% to 80.8% (Figure 3.4b).

Some individuals spent more time in the water than others. Average time spent in the water for all tigers was 6.8% however there was a lot of individual variation across cats. Some individuals spent on average less than 6% of their time in the water (G1F1 1.0%, G2F2 5.9%, G3F2 2.9%) where others spent over 10% of the observation period (G2F1 11.1%, G3M1 13.6%).

The cave was also used in varying proportions by different individuals. For example G2F1 only used the cave for an average of 0.3% of the time where G3M1 used the cave for 53.2% of the time. Four out of six cats used the cave for more than 20% of the observation period on average. Overall tiger average cave use was 18.8% with males ranging from 5.2% to 53.2% average daily cave use and females ranging from 0.3% to 26.4% (Figure 3.4c).
Most of the observations days included in the results had very little overcast moments and were mostly sunny. The average daily time spent outside in overcast conditions was less than 4% on average and was less than 8% for all individuals and was zero for individuals G1F1 and G1M1.

3.5 Discussion

3.5.1 Behaviour

Males seemed more active than females. When lying head up is combined with lying down, all cats spent over 46% of their time lying down. Males averaged 53.4% on average of their time lying down and females 63.0%, which about a 10% difference. Males walked 10.4% of the time and females walked, about three quarters of that, at 7.7% of the time. Perhaps this stems from territory patrolling type behavioural gender differences.

Males spent about 10% more of their time panting compared to females which could be related to the males having been more active; but also be related to differences in body size and heat dissipation efficiency. However, one female spent the most time panting compared to all other individuals which shows how there was high individual variation in panting.

3.5.2 Thermoregulatory Behaviours and Enclosure Use

Given speculation discussed by Smith and Kok (2006a), it was originally thought that dominance could play a role in an individual’s willingness to perform loin exposing behaviour and in amount of panting. It was also thought that coat colour may play a role in
amount of panting and loin exposure. It would be suspected that more dominant individuals would be more comfortable and less fearful to perform loin exposure than their subordinate conspecifics. This is due to the vulnerable position of exposing the loins to the potential attack by the more dominant individual (Smith and Kok, 2006a). In the current study both G3F1 and G3M1 the dominant individuals of G3 were never recorded to perform loin exposure. G2F1 however, spent the most time doing loin exposure (13.1%). One way to address this could be by providing more space or increasing the complexity of the current space to provide more escape options. By providing more things to climb and more physical barriers within the current habitat individuals would have more access to escape areas or privacy areas were they may feel more comfortable being in the vulnerable loin exposing position.

When it came to panting, G3F2, a subordinate white female, did the most panting at a 31.2% daily average. The orange subordinate female from group 2, G2F2 did the least amount of panting daily on average at 5.6% (Appendix 3). This also suggests that coat colour is not affecting panting level. These results are very counter intuitive and without further study with a similarly large group of tigers it will be unclear whether coat colour or dominance play a role in loin exposing behaviour or physiological heat dissipation through panting in tigers.

There was enough shade provided for all cats to use the shade for most parts of the day. However, during the times when the sun was highest in the sky this area was reduced. Since the tigers used shade for such a long period of time during the day to remain cool
they may require more shade so that subordinate individuals are not left out in the sun to overheat.

Later in the day after 3:30 pm the sun came more from the west and reduced the shade available to the tigers to that of 2 -3 palm trees on the upper level. It was very typical to see all cats, regardless of the group, in this area of shade by around 3 pm in the sunny afternoon. They would remain there for the rest of the observation period. After leaving the observation area the researchers would sometimes returned an hour or 2 later to observe what the tigers were doing and often they were still in the same place laying with their heads down. Since they all spent so much time in the shade and so little in the sun, it would seem that shade is a very valuable resource.

During the hot days of this study the cats tended to use shade more than water to cool down. It should be at least considered that shade is more important to the tigers for cooling than the water. Since the enclosure has little shade for over half the day, new shade structures could be beneficial to the cats in addition to the existing trees.

When you look at individual tigers there seems to be a link to dominance and water use. G2F1 and G3M1 used the water the most and were dominant cats. However the water area was quite large and no more than 2 cats were ever seen in the water at once. No negative interactions were observed between cats in the water. In addition, individual G3F1 was only in the water on average 6.7% of the time and demonstrated some of the most dominant behaviours (spraying and urinating over conspecific’s markings, see behaviour ethograms of Appendix 1).
Some variation in cave use is likely due to individual preference. For example, G3M1 used the cave but seemed to prefer to use the water to cool himself. Some individuals were often ‘refused’ entry to the cave. G3F2 was often refused entry to the cave by conspecifics at the entrance. Several altercations occurred in the cave and area between individuals. It is unfortunate that dominance interactions were not a focus of this study or perhaps this could be discussed further.

The tiger keepers speculate that there is some greenhouse effect going on in the tunnel since there are so many windows, which would allow it to heat up from sun exposure. None the less tigers would frequently spend large amounts of time in the tunnel. In a study by Titto et al. (2013) shade was found to be so important to cattle that they would seek the shade inside the barn during the hottest part of the day, even when the ambient temperature in the barn was hotter than that which was outside in the sun. It could be that shelter from the sun, or shade, is so important to tigers that they will brave the hotter ambient temperature of the tunnel to avoid sunlight. There are other sources of shade in the habitat which would suggest this is not the case, however. It is possible there are other motivating factors such as the desire to hide from public view. Without further observation and putting a thermometer into the tunnel to measure the ambient temperature it is hard to speculate what sort of thermal environment it provides and what is motivating the tigers to spend so much time in there.

Average daily time spent outside in overcast conditions was less than 4%. This is skewed because most of the time that it was overcast, animals were either still under the shade of a tree or object and had not moved until it became sunny again or because they
were in the cave until the sun remerged from behind temporary clouds. So the average time spent in overcast conditions would probably be ignored by most, but it was noticed also that some individuals seem to become more active in these conditions and start walking around more (Appendix 3).

On the rainy day the tigers of Group 3 were quite active. They each spent more than 65% of their time outside in the overcast and rainy conditions. They all seemed to pant much less with G3F2 and G3M1 panting less than 5% of the time. G3F1 was still panting 23.4% that day but this could be due to her dominance and the possible stress involved.

3.5.3 Thermography

In addition to these results there are other observations worth mentioning. For example, the use of the thermal camera provided functional evidence for various thermoregulatory behaviours with respect to their cooling efficacy. The current study found that loin exposure in these tigers actually functioned to increase average loin temperature over time rather than to decrease it (Data not shown). However, this still may function to have a net cooling effect. The increase in surface temperature of the loin could be the heat escaping from that area allowing for overall cooling of the core body area. More focus on loin exposure and its effects on loin surface temperature would likely yield functional evidence of this behaviour in support of Smith and Kok’s (2006a) lion exposure study. It is possible that loin exposure is used more often by lions since the cats in their study performed it more often than those of the current study. Lions of another study by the authors also seem to perform loin exposure in hot weather more often than the current...
felids. More research is needed into the significance of loin exposure to tigers and other large felid species in captivity as it could indicate some sort of threshold where heat is becoming more unbearable. Extra shade, a larger pool or cave space if available could provide a more thermal neutral environment.

Water was also noted several times to decrease surface temperatures as shown in Figure 3.6a-d. Figure 3.6a-d shows the average surface temperature of a G3M1 dry (39.9°C) and the wet (34.6°C). In figure 3.6d, a comparison is made on the flank of the same cat where the average of the dry surface is 38.6°C and the wet surface is 34.1°C. The area of wading water provided to the tigers of this study seemed more than adequate, as more than two or more tigers could wade with more than 4 tiger lengths of space between them and a conspecific, at one time. It can be learned from this study that increased space allows for no negative confrontations in the water amongst cats.

Another interesting observation noted through the use of thermal imaging was the fact that after about half an hour in the shade, the thermal stripes of the tiger disappear and the surface of the animal becomes a more solid temperature as shown in Figure 3.6e. However, upon remerging from the shade back into the sun, it would take seconds for them to return (Figure 3.6f). The latency of the return of the stripes under sunlight is probably dependant on the solar radiation in the direct sunlight at that moment. Unfortunately not enough data could be collected to confirm this observation.

During observations volunteers noticed every morning that reflected solar radiation may cause heating up of the exhibit. There is a large windowed observatory for the public
to see the Bengal tigers (Figure 3.1). The orientation of the window is facing south and it receives early morning sun which is visibly reflected into the exhibit, and probably heating it up. This could be one reason why the keepers view this as the hotter exhibit compared to the gorge habitat (Hackman, J., Personal Communication., May 2012).

There is more than one way to deal with the heating of the glass window and reduce reflected solar radiation and transmitted terrestrial radiation from it. One way to reduce heating and reflection at once would be to shade the glass with a wooden structure on the adjacent side of the enclosure blocking the morning to midday sun (Figure 3.1a). This will not allow the solar radiation to heat the glass or be reflected into the enclosure. Another way would be to place a shade structure above the glass window such as an awning (Figure 3.1b). Alterations can be made to existing zoo habitats to increase thermal comfort of animals kept within them.

There is a large pool in this exhibit that is used by the cats in very hot weather with some males spending hours in the pool. This pool is worth mentioning since it is a cycling, moving water system that is chilled. This seemed to be a valuable enclosure feature for cooling purposes. The movement of the chilled water provided forced convective heat loss from the animals that used it.

3.6 Conclusion

The eight tigers included in this study spent most of their time inactive lying in the shade. Shade was used considerably more than water as an enclosure feature for cooling the body and increasing thermal comfort. Neither dominance, nor coat colour were observed to
play a role in loin exposure, water use or duration of panting by any individual tiger. However, a larger study with more individuals of the orange and white colour variations could show this.

This study brought about recommendations for low cost shade structure that could reduce the reflected solar radiation from a window and that could increase the amount of shade available to the tigers throughout the day. It is possible that similar studies on large felids kept in other zoo habitats could lead to low cost microclimatic landscape design recommendations for increasing thermal comfort of its resident animals.

To date no other study with this number of tigers (n=8), based on continuous observation behaviour methods has been reported. In this context the results from the current study will inform better zoo habitat microclimatic landscape design which will support increased thermal comfort for the resident animals.
Table 3.1. Definitions and descriptions of behaviours and contexts recorded during the study. This ethogram was developed by holding preliminary trial observation days and was developed over time according to observations.

<table>
<thead>
<tr>
<th>Behavior:</th>
<th>Definition:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing</td>
<td>standing with not locomotion</td>
</tr>
<tr>
<td>Walking</td>
<td>Slow locomotion from one place to another</td>
</tr>
<tr>
<td>Running</td>
<td>Quick locomotion from one place to another</td>
</tr>
<tr>
<td>Pacing</td>
<td>Repetitively walking back and forth usually near a fence, at least three times</td>
</tr>
<tr>
<td>Sitting</td>
<td>On rump with front legs straight</td>
</tr>
<tr>
<td>Panting</td>
<td>Rapid open mouth breathing, may involve tongue or not</td>
</tr>
<tr>
<td>Lying head up</td>
<td>Lying with the head off the ground</td>
</tr>
<tr>
<td>Lying head down</td>
<td>Lying with the head on the ground</td>
</tr>
<tr>
<td>Lying loin exposed</td>
<td>Lying on back with loin exposed</td>
</tr>
<tr>
<td>Rolling/rubbing/Marking</td>
<td>Rubbing cheeks on ground, rolling over, scratching, scratching with back feet</td>
</tr>
<tr>
<td></td>
<td>and urinating repeated small amounts in to the whole created.</td>
</tr>
<tr>
<td>Eating</td>
<td>Consuming food</td>
</tr>
<tr>
<td>Drinking</td>
<td>Consuming water</td>
</tr>
<tr>
<td>Urinating</td>
<td>Excreting urine</td>
</tr>
<tr>
<td>Spraying</td>
<td>Marking territory with scent glands</td>
</tr>
<tr>
<td>Defecating</td>
<td>Expelling feces from the rectum</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contexts:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>In cave</td>
<td>Making use of enclosure shelter</td>
</tr>
<tr>
<td>In shade</td>
<td>Some part of the animal is shielded by shadow</td>
</tr>
<tr>
<td>Body only</td>
<td>The body and not the head are involved.</td>
</tr>
<tr>
<td>Head only</td>
<td>The head and not the body are involved (check both if whole animal)</td>
</tr>
<tr>
<td>In water</td>
<td>Some part of the animal is in water</td>
</tr>
<tr>
<td>Grooming</td>
<td>Grooming by licking</td>
</tr>
<tr>
<td>Panting</td>
<td>Shallow increased respiration rates, with or without tongue involvement</td>
</tr>
<tr>
<td>Chin exposure</td>
<td>Chin exposure with upside down and flat to the ground, exposing the jugular</td>
</tr>
</tbody>
</table>
Figure 3.1. Image of the river habitat at Busch Gardens, Tampa, Fl looking towards the east (A) with the observation window on the left and the staff food dropping area to the right. A shade structure for blocking the morning sun from heating the observation window which leads to reflected solar and transmitted terrestrial radiation that could be a reason behind this exhibit being hot for the cats (Hackman, J., Personal Communication., May 2012) is suggested in B and an awning structure for shading the window for most of the midday period is suggested in C.

Figure 3.2. An example of a thermal image with several promising targets including; the eye ball (AR01 Max 31.1°C), ear canal (AR02 Max 33.5°C), mouth (AR03 Max 32.6°C), tongue (AR04 Max 33.2°C), spray (AR05 Max 34.5°C) immediately after ejection from the cat and the inner thigh (AR06). Note: Maximum surface temperatures (Max) of targets are given.
Figure 3.3. Average behaviour time budgets; for all tigers (A), females (B), and males (C) over all observation days.
Figure 3.4. Average enclosure use budgets; for all tigers (A), females (B), and males (C) over all observation days.

Figure 3.5. Average Ambient Temperature (°C) and average ambient vapor pressure (kPa), for all groups (G1, G2, G3) and days (D1, D2, D3) of observation.
Figure 3.6. Functional example of thermoregulatory behaviour; (A) dry face (average surface temperature 39.9°C), (B) submerged face, (C) wet face (Average surface temperature 34.6°C), (D) comparison between dry (38.6°C) and wet (34.1°C) average flank surface temperatures, (E) a wet tiger in shade showing very little stripe pattern that returns very quickly under sunlight (F).
Chapter Four: Species comparison of continuous behaviour assessment and thermal imaging of large felids of the *Panthera* genus with focus on thermoregulatory behaviour, thermal comfort and zoo exhibit microclimatic design

4.1 Abstract:

Several species of large felid are kept in locations with climates that differ from their habitat of origin and there has been little research published investigating their behavioural and thermoregulatory needs in captivity. This observational study was done using the case study approach, to investigate the behavioural repertoire of large captive felids through continuous observation, with focus on thermoregulatory behaviour, in order to investigate potential species differences and inform microclimatic design for thermal comfort. The study took place at the Toronto Zoo from summer 2012 to winter 2015, where behaviour data were recorded every minute for a day, while thermal images of each individual, wind speed, ambient temperature and relative humidity were recorded every 15 minutes. Although it was done more in summer on average, all cats spent between 40 and 84% of their time lying down. Cats spent between 5 and 10% of their time on active behaviours. Panting was more important in summer and cave use seemed more prevalent in winter. Shade was more important in summer for all species, with daily use ranging between 23 and 50%. The white lions were the least active despite being the youngest cats in the study and also did not seem to pant in summer. Water was also important for the male Amur tiger. It is possible to group various species of large felid, based on habitat of origin, into two groups; hot climate cats and cold climate cats. This classification can lead to potentially low cost microclimatic zoo habitat design recommendations that could increase thermal comfort and welfare of the resident wild animals.
4.2 Introduction

Many zoos are located in climates with varying extreme seasonal temperatures over the course of the year. This may place thermoregulation of captive carnivores as an issue high on the list of zoo keepers in these climates. In order to provide for animals in captive environments that may differ drastically from their natural habitat, there is a need for scientific research to ensure that the behavioural and welfare needs of the animals are met.

Behaviour repertoire investigations are difficult to conduct and design and are rarely carried out on exotics in the zoo setting. Behaviour can inform care by giving important information regarding both the physical and psychological wellbeing of the animals. In addition, thermoregulatory behaviour has not been described for many large felids in the literature. Thermoregulatory behaviours such as activity level, changes in location, postural changes and orientation to things like solar radiation and wind, are employed by all mammals as a means to regulate homeostasis of core body temperature (Smith and Kok, 2006a). Detailed investigation into behavioural repertoire and thermoregulatory needs could inform zoo exhibit microclimatic landscape design for enclosure promoting thermal comfort in a variety of seasons and climates no matter the species’ habitat of origin.

Species of interest included; African lions (*Panthera leo*), jaguars (*P. onca*), Amur tigers (*P. tigris altaica*), snow leopards (*P. uncia*) and cougars (*Puma concolor*). These various species originate from very diverse natural climates and habitat, and have variable fur colours and lengths and a range of average body sizes. The lion is the only group living and maned species, is typically tan in colour although there is also a rare white phenotype. The African lion is comfortable in habitats ranging from the harsh Sahara interior to the tropical forests of Africa (Bauer et al., 2011).
The jaguar is the only extant member of the *Panthera* genus in the western world (Caso et al., 2008a) and can inhabit a variety of habitats in the Americas, however it have been driven from its most important one, the dry tropical forests of Mexico (Núñez-Pérez, 2011). The puma or cougar is a similarly sized sympatric species that shares much of its home range with the jaguar (Harmsen et al., 2011). Although both inhabit a variety of habitats, the puma is adapted to every major habitat type in all of the Americas (Caso et al., 2008a), including the high altitudes and cold northern climates of Canada, making it likely that the puma is more cold adaptable than the jaguar.

Amur tigers, once known as Siberian tigers, are now concentrated in the cold, Sikote Alin mountain region, near the Amur River in eastern Russia (Chundawat et al., 2011; Miquelle et al., 2011). Like the Amur tiger, the snow leopard is also at home in cool alpine and sub-alpine ecological zones in Central Asia and typically occur at 3000-4500 m above sea level (Jackson and Nowell, 2011). However, they may also be found in less dense coniferous forests of China and slightly covered, rolling plains of Mongolia and Tibet (Jackson and Nowell, 2011).

The objectives of this study were to investigate the behavioural repertoire of several *Panthera* genus cats and the *Puma concolor* housed at the Toronto Zoo (Ontario, Canada) while focusing on thermoregulatory behaviour in order to gain knowledge on species differences in thermal requirements from their environments. It could be beneficial to consider the various species of the genus *Panthera* and *Puma* on a species by species basis when it comes to microclimate zoo exhibit design. Depending on species, some large felids are adapted to hot and others to cold climates. Due to climate of origin, physical morphology, and daily activity patterns, it is likely that there are species thermoregulatory adaptation differences which could translate into differing thermal neutral zones.
4.3 Methods

4.3.1 Animals and Behaviour

All animals were housed at the Toronto Zoo in Toronto, Ontario, Canada. Species of interest included African lions (*Panthera leo*, 2 adult males and 3 juveniles), jaguars (*P. onca*, 1 male and 1 female), tigers (*P. tigris summatae*, 1 male and 2 females, and *P. tigris altica*, 1 male 1 female), snow leopards (*P. uncia*, 1 male and 1 female) and cougars (*Puma concolor*, 1 male and 1 female). All cats had access to a cave, hanging toys, balls and logs to climb on. Tigers and jaguars had access to water, while jaguars, snow leopards and cougars had access to platforms.

All behaviour observations were conducted from areas freely accessed by the zoo’s visiting public by trained volunteers (Appendix 4). Behaviour data was recorded continuously every minute for the entire observation period which ranged from 3 (winter) to 7 (summer) hours. Behaviours and contexts were created and given a number between 1 and 23 which are described in Table 3.1. Behaviours were those activities cats were seen to be doing while contexts were ways or places behaviours could be performed. Each observer recorded behaviours for an individual felid, to avoid confusion between individual felids. Observers would randomly observe different cats each day or switch part way through the day in an effort to avoid observer bias. At times, more than one observer would independently watch the same cat so that observer reliability could be tested and calculated. A different species was watched per day and attempts were made to have 3 summer and 3 winter days of data with the longest duration possible.

Infrared thermal images were taken every 15 minutes, with a ThermaCAM SC 2000 thermal imaging camera (FLIR Systems, Danderyd, Sweden (with 45° add on lens) or FLIR E60 (FLIR Systems, Burlington, Ontario, (with a built in 15° and add on 45° lens)), with an
emissivity setting of 0.95, of each individual with focus on targets such as eyes, ears, mouth, tongue, loin, anus, urine, or feces. The camera detects naturally emitted long wave radiation (7.5 – 13 µm) from an object or animal surface, dependant on surface temperature, and converts this to electrical signals which are outputted as visual-light-translated thermal patterns. Images were then analyzed using FLIR proprietary software: ThermaCam Researcher Pro. 2001. An example image with several targets of interest is shown in Figure 3.2.

Meteorological parameters were recorded every 15 minutes. Relative humidity and ambient air temperature were measured using a Kestrel 4000 pocket weather meter (Nielson-Kellerman, Boothwyn, PA). Wind speed was measured using a Sims DIC-3 Anemometer (Simerl Instruments, Annapolis, MD). Precipitation and overcast conditions were recorded as ‘all or none’ events.

4.3.2 Data Analysis

Behaviour time budgets (Figure 4.1) and enclosure use budgets (Figures 4.2) were created using Microsoft Office 2010 Excel, based on numbers assigned to behaviours and contexts. Most behaviours were recorded as mutually exclusive events however, some were not. For example a tiger could be panting and laying down at the same time and every time a special event like urination, defecation or spraying occurred, it was recorded even though these would rarely take an entire minute. For these reasons the percent of time spent on a behaviour or in a context was depicted as a ratio of total number of observation points in order to standardize from one tiger to another and one day to another. All time budgets account for 100% of the observation periods. This was done due to the cat being able to perform more than one thing at a time and therefore having total of more than 100%. Behaviour budgets include the behaviour
portion of data where contexts were used to generate the enclosure use figures (4.2). Average
time budgets were generated by averaging, average daily values per individual (Females n=5.
Males n=2).

Daily behavioural ethograms (Appendix 4) were also created with the continuous
behaviour recordings using the Microsoft Excel scatter plot function. These figures show all
continuous behaviour recordings which are shown in real time.

Descriptive statistics were used to generate behavioural ethograms, time budgets and
enclosure use budgets. These figures are based on one day of data per cat. Time budgets for
females and males were averaged using descriptive statistics and also presented.

All research was approved by the University of Guelph’s Animal Care Committee and the
Research Review Committee at Toronto Zoo.

4.4 Results:

Summer weather days ranged in temperature from approximately 20 to 33°C (Figure
4.3a) and winter days ranged from approximately -5 to 7°C (Figure 4.3b). Most summer days
recorded had little to no cloudy periods where winter days were mostly overcast. On all days the
wind was typically 0-1 m/s and never reached more than 3 m/s even on very windy days. Vapor
pressure ranged from approximately 3800 to 7800 kPa in summer (Figure 4.3a) and
approximately 500 to 1900 kPa in winter (Figure 4.3b) on average.

Attempts were made to observe each species for 3 days in the summer and 3 days in the
winter, although this was not possible in each case. The male Amur tiger and the male and
female puma were all observed for 3 summer days and 3 winter days. The white, African lions
were observed for 2 summer and 2 winter days each and the jaguars were observed for 3 summer and 2 winter days. The snow leopards were observed for 2 summer and 2 winter days however, the male leopard was not available for the second winter day. The tawny African lions were observed for 1 summer day and 3 winter days. No differences between observers could be calculated (Data not shown).

4.4.1 Behaviour

For all observation days all cats spent more time lying down than doing anything else. Average total time spent lying down for each species were as follows; jaguars 75.6% in summer (S) and 44.2% in winter (W), puma 64.8% in S and 55.4% in W, white African lions 84.7% in S and 82.1% in W, tawny African lions 91.1% in S and 63.2% in W, amur tiger 39.1% in S and 41.5% in W, and for the snow leopards 46.2% in S and 37.1% in W (Figure 4.1a-f).

Cats spent less time on active behaviours like standing, walking and pacing and this seemed to vary more across species, seasons and individuals (Appendix 5). The average results were as follows for standing; jaguars 1.8% in S, 1.1% in W, puma 1.7% in S, 2.3% in W, white African lions 0.2% in S, 0.5% in W, Tawny African lions 0.9 in S, 9.9% in W, for the Amur tiger 0.6% in S and 2.1% in W, and for the snow leopards 2.4% in S and 5.8% in W (Figure 4.1a-f). Average time spent walking was 2.4% in S and 5.3% in W for jaguars, 12.3% in S and 16.8% in W for puma, 3.6% in S and 7.4% in W for white African lions and 1.6% in S and 1.9% in W for tawny African lions, 4.4% in S and 12.8% in W for the amur tiger and 4.8% in S and 10.0% in W for the snow leopards (figure 4.1a-f).

Some species would spend time pacing and others did not seem to pace at all. The species that paced the most was the amur tiger (20.4% in S, 15.0% in W), next was the snow leopard
(14.8% in S, 14.1% in W, with the male performing most of this behaviour), and lastly the jaguars (5.4% in S, 35% in W) (Figure 4.1a-f). Both the female jaguar (3.6% in S, 30.4% in W) and snow leopard (16.5% in S, 21.2% in W) paced more than their male (jaguar 7.1% in S, 39.6% in W, with 63.8% occurring on the second observation day and snow leopard 13.1% in S, 0% in W) counter parts. All other species spent less than 6% of their time pacing on average for any season, and both types of African lion did no pacing at all during the observation periods.

Time spent on maintenance behaviours such as grooming, eating, drinking, urinating and defecating were typically small compared to the aforementioned behaviours (Figure 4.1).

4.4.2 Thermoregulatory Behaviour and Enclosure Use

Panting was seen more in summer and males seemed to pant more than females. The male amur tiger, male puma, and female snow leopard were the only cats observed to pant in the winter. In fact the amur tiger panted nearly as much in winter as in summer (24.2% in S, 21.1% in winter). Puma were seen to pant 14.2% in S and 3.3% in W (always figure 4.1b). Snow leopards panted 18.0% in S and 0.1% in W (Figure 4.1f). The jaguars and tawny lions panted very little in both seasons and white African lions were not observed to pant during summer or winter observations.

Cats seemed to spend more time in their caves in winter than summer. Jaguars didn’t have access to a cave as the other cats did, but would sometimes have access to their indoor areas during observation days and they were recorded as being in the cave if they went inside. The male jaguar spent 11.1% of a summer observation day inside (Figure 4.1a). The snow leopards spent more time in their cave in the summer (10.8%) than in the winter (0%) (Figure 4.1f). The rest of the cats had the following average time spent in the cave; puma 50.5% in W and 23.3% in
S, white African lions 42.9% in W (heated floor) and 3.0% in S, tawny African lions 42.7% in W (heated floor) and 0% in S, and the male amur tiger 21.3% in W and 13.1% in S.

Water was available to the amur tiger in a pool in summer and to the jaguar in a pool filled year round. Jaguars did not use water in the winter other than to retrieve a toy from the banks without entering (Figure 4.2a). The Amur tiger was observed in the water for an average of 2.3% of the time ranging from 1.1 to 4% over three days (Figure 4.2e). The male jaguar spent on average 3.2% of his time in the water, ranging from 0 to 8.0% over three days. The female jaguar was never seen to enter the water, but did retrieve toys from the banks on occasion.

All species of cat had access to shade year round. The puma were only observed to use shade in the summer (39.4%) (Figure 4.2a-f). All others used the shade more in summer but also at times in the winter. Average daily shade use was as follows: Jaguars 50.1% in S, 10.0% in W, 39.8% in S and 8.3% in W for white African lions and 37.1% in S and 4.7% in W for tawny lions, amur tiger 48.3% in S, 12.3% in W and finally 23.6% in S and 4.1% in W for snow leopards (Figure 4.2a-f).

In addition to shade, all species had access to sun exposure year round. Average times spent in sun exposure for all cats were; jaguars 22.0% in S, 39.8% in W, puma 40.4% in S and 8.4% in W, white lions 41.6% in S, 13.0% in W, tawny lions 37.1% in S, 4.7% in W, amur tiger 31.7% in S, 37.7% in W and for the snow leopards 29.1% in S and 35.1% in W (Figure 4.2a-f).

Overcast conditions occurred for periods on several but not all summer observation days and occurred for most of the duration of winter observation days on occasion, however there were some winter days with very few overcast conditions. On almost every observation day with overcast conditions, every individual would spend time exposed to the overcast sky. These
average results are as follows; Jaguars 50.5% in S and 50.2% in winter, puma 4.0% in S and 41.1% in W, white lions 11.1% in S 35.8% in W, tawny lions 47.8% in S and 14.4% in W, amur tiger 4.6% in S and 28.7% in W and snow leopards 36.4% in S and 60.0% W (Figure 4.2a-f).

4.5 Discussion:

4.5.1 Behaviour

All species spent more time lying down in summer and most of this lying down was done either in the cave or shade. The white African lions spent nearly the same amount of time lying down in both seasons. In fact they spent more than 80% of their time lying down which is less active than any other species during either season. This could be due to their age. These were juveniles (over 135 kg at around 1 year to 1.5 years of age) and when they were active they were typically more active with playing, running around and wrestling with each other occurring. The other species typically moved slower and more consistently when they became active and were all much older. They were included in the study since their body mass was within the range of the other cats selected.

Due to high variation in overcast conditions the average time spent in overcast conditions, were more variable due to the weather conditions being variable but it may also have impacted activity levels. Cats seemed more active on overcast days but due to a lack of overcast condition extreme caution should be used when making any conclusions. More research is needed to compare overcast days with sunny days to be sure of this impact on activity.

The jaguars seemed to pace the most on the second winter observation day. This is perhaps due to being uncomfortable with the weather conditions and wanting to go back inside. They would tend to pace by the entrance to the indoor housing areas. This day had an ambient
temperature range from 2.1 to 4.8 °C (approx. 3.5 hours) where the first day had a range of 2.5 to 7.6°C (approx. 5 hours). It should be noted that the Toronto Zoo does not usually put the jaguars outside under 5°C for longer than 2-3 hour periods due to their perceived intolerance of the cold (Jaguar Keepers, Toronto Zoo, Personal Communication, Mar. 2015) and that special provisions were made with zoo staff to observe jaguars on warmer cold days. One observation day was cancelled on site due to the weather being too cold for the cats to tolerate (approx. -2°C).

Pacing seemed to be an indication of anticipation of going inside at the end of the day. Some individuals, the male amur tiger, male snow leopard and both jaguars paced more than other individuals. Although they too would do this more at the end of the day seemingly in anticipation of keepers coming to bring them in and feed them, some would pace at times that had no apparent connection to this anticipation.

This type of anticipatory pacing has been reported in large felids before. Bergerner and Gusset (2008) found that snow leopards displayed food related anticipatory pacing which was not an effective coping mechanism as evidenced by fecal hormone analysis.

The male amur tiger paced the most of all individuals which could be due to enclosure design. Bashaw et al., (2007) found that both lions and Sumatran tigers (Panthera tigris sumatrae) paced more when housed in their exhibits that contained more chain link fencing. The tiger exhibit in this study also had a lot of chain link fence and this was where the tiger would pace. This particular individual seemed the most stressed out of all the cats.

4.5.2 Thermoregulatory Behaviour and Enclosure Use

Panting was likely seen more in summer due to its physiological impact on evaporative cooling efficiency in the heat. What’s more interesting behaviourally is that males tended to pant
more than females and the female snow leopard was the only female seen to pant in winter. These bouts of panting could have been more due to stress in the individual. Although it was not behaviourally focused on or physiologically tested for, the male snow leopard, male amur tiger and female snow leopard all seemed more stressed on certain days than other individuals which appeared more consistently relaxed. The amur tiger, male snow leopard and male puma, in that descending order seemed by most observers to be more alert and more restless in their behaviours. They would often pace, walk more and seemed much more vigilant of the public.

It should be noted that some panting may have been overlooked in the tawny lion and snow leopard records. These observations were made early on in the study and there was some difficulty at first explaining the definition of panting to observers, and what it visually looks like in the big cats effectively to volunteers. For example, the male snow leopard was noticed panting often, even in winter (as recorded on infrared image data sheets) but this was not recorded in the behaviour data. If the data were recorded properly at that time these males may have been seen to pant more. It could be though that lions are able to tolerate hotter ambient temperatures than most other species in the study. The jaguars however, panted very little in both seasons. This is more likely actual evidence of an ability to tolerate a higher range of ambient temperatures than the other species due to their habitat of origin.

The Amur tiger spent the most time in the sun in summer at nearly 50%. This is result was not expected given the original home range of this species. As mentioned above, this animal did seem more stressed than the other individuals which may be evidenced by the amount of time he also spent pacing. He also spent the most time pacing out of all individuals and seemed the most restless in summer temperatures. It is possible that he was so uncomfortable in the heat that he could not relax.
The white lions and the puma spent over 40% of their time in the sun during the S. In fact the puma spent on average 4.8 and the white lions 3.2 times more time in sun exposure during the summer. This is likely due to the higher amount of time spent in the cave during winter when compared to the other species. It is interesting to note here that the tawny lions only spent time in the cave during winter.

The construction of these two caves was quite different. The lion cave (Figure 4.4a) is an east facing structure unique in its gunnite material and lack of side walls. The puma cave is more standard and is similar to those available to the other cat species (Figure 4.4b). The cave design in the puma exhibit likely provides a more suitable microclimate for staying warm in winter than that of the lion exhibit however, the lion cave makes up for this with its heat floor which can hold a surface temperature of around 31°C. Both species likely spent more time in the cave in winter not to avoid sun exposure but because it was likely warmer than in the sun. This is supported in the fact that other species used their caves more in winter than summer, other than the snow leopards.

Cave placement may have also been an issue. For example, the snow leopards may have used their cave more in winter if it was not placed in direct view of the public. Snow leopards are particularly reclusive in the wild and may be more stressed in a situation where they feel readily seen by the passing public (Malik, 1995). The other caves were placed differently on a much lower level than the public viewing area or even behind a barrier like glass that was partially mirrored on the side adjacent to the cats to reduce their view of the public. In the case of the puma cave, it was placed at the back of the exhibit with objects like trees and stumps in front of it, placed in a way that had a minimal impact on public viewing but may have made the cats feel more secure regardless.
Coat colour may have also played a role in the puma and white lions spending more time in the sun. Hutchinson and Brown (1969) found that the absorbance of solar radiation by white cattle hair is approximately 50% and that the reflectance of long-wave radiation was also low. The lions were not as white as white cattle are but they were visibly obviously lighter in colour than any other cat in the study. Along with their natural habitat adaptations, it could be that their lighter coat colour allowed them to tolerate much more direct sun exposure than the other cats. This is further evidenced by the complete lack of panting in these cats even in S. Many factors could be at play here that warrant further investigation and no studies have been done on the radiation absorbance and reflectance properties of the various coats of large felids.

Due to the differences in the area of shade provided in S and W in each exhibit it is hard to draw any conclusions about shade use by cats. For example, the puma, snow leopard and jaguar habitats were all furnished with three levels of platforms, topped with a roof of safety mesh covered in leafy vines in S that would lose their leaves in fall allowing for sunlight to enter to aid in warmth for the animals. The use of shade in S was expected to be higher for all cats in S however, the snow leopard, jaguar and puma exhibits were mostly shaded with only small areas where sun could get through the overhanging vines and trees. This has likely skewed the data on shade use for these species. The puma and jaguar used the shade a similar amount of time and more than the snow leopards did in S. Further, some of these species used shade more in W than S, making shade use results even more difficult to interpret.

It is interesting to note here that the melanistic female jaguar used the shade more (67.1%) than her yellow brother when the two sunnier summer days are averaged. The third day had several overcast periods. Hutchison and Brown (1969) found that the absorbance of solar radiation of black cattle hair is approximately 90% and that the long-wave reflectance is
similarly high. Given this information, it is likely that the melanism lowered the upper limit of the female’s thermal comfort zone.

Water was typically only used by the amur tiger and this was likely for thermoregulatory purposes. Figure 4.5 shows the average flank temperature increasing before bouts in the water on an observation day. After exiting the water this individual would pant and pace and warm up again before re-entering the water. It is evident that this had a thermoregulatory purpose as he seemed to do this near the end of the day perhaps as the heat started becoming unbearable.

4.5.3 Microclimatic Zoo Exhibit Landscape Design

It may be possible to arrange the cats into 2 or 3 categories based on thermoregulatory needs, habitat of origin and seasonal changes in insulation. This brings the level of complexity in designing for each individual species down greatly, although specific species needs will still have to be taken into account. Hot climate (HC) cats could be species like the jaguars and lions as they seem more comfortable in hotter temperatures than other species. Lions seem to have a wider thermal neutral zone than jaguars however, since they seemed more comfortable at lower temperatures. The jaguars were not let out on cold days where the lions were and special arrangements had to be made to view them on warmer winter days. Puma are highly adaptable to ambient conditions and may have the widest range of thermal comfort zone due to being the most wide spread animal of the western hemisphere which can be found in any habitat of the Americas (Caso et al., 2008a). This type of species would be the intermediate group as they are able to be more comfortable in colder temperature than the African lions. Finally, there could be a cold climate (CC) group. The amur tiger and snow leopards fit in the group due to hailing from snowy mountainous regions of Asia.
Cats from CC may do better in elevated, north facing enclosures which would decrease sun exposure and allow more wind flow for increased convective cooling. Woody plants and solid structures influence solar radiation most at a site since they can provide shade from 90% of solar radiation (Brown and Gillespie, 1995). Full shade can be provided to CC cats in summer and not in winter to allow for differing seasonal solar radiation absorbance. This can be accomplished as done at the Toronto Zoo where vines that lose their foliage in winter are used to cover the mesh roofed snow leopard exhibit. The amount of incoming solar radiation including reflected solar radiation that is kept at the enclosure by design is the important part (Brown and Gillespie, 1995). Natural features such as plants and trees are very good at creating a thermal neutral environment (Brown and Gillespie, 1995).

Habitats for CC cats could be built with a wind tunnel designed into the construction to increase convective cooling of cats in summer (Figure 4.6a) that could be shielded in the winter (Figure 4.6b). The west facing entrance to this type of wind tunnel exhibit is illustrated in Figure 4.6. The wind tunnel could be an area for displaying educational information to enhance visitor’s experiences.

The use of deciduous trees and vines as seen at the Toronto Zoo would allow for more shade in S and more solar radiation in W. Deciduous trees, if placed in the center and at the west of the enclosure would lessen the impact on the view of the animals by zoo visitors while maximizing shade provided later during the hottest parts of the day when animals may have accumulated excess heat load throughout the day.

Lighter coloured rough surfaces could be used instead of dark coloured smooth surfaces. Light colours will absorb less and reflect more solar radiation making them cooler to the touch.
and available as surfaces for conductive heat loss from the animal in summer. Shade could increase this effect. The rough surface will increase air mixing through turbulence which could increase convective heat loss (Campbell, 1977; Oke, 1987). Darker surfaces that have reduced solar radiation reflectance could be used under the shade of deciduous trees as a conductive cooling surface for these CC cats.

In S, adding water sprayers and/or misters to increase evaporative heat loss could be a very effective way to reduce heat load in CC cats. This method is used at the Toronto Zoo however, there is caution used not to allow the cats to be wet for too long. This can have negative effects on the natural oils in the fur (Barney, D., Director of Wildlife, Toronto Zoo) which could alter the effectiveness of the insulative properties of the fur and thus negatively impact thermoregulatory efforts.

Cats from HC could do well in a southern facing enclosure with an appropriate amount of seasonal shade provided (Figure 4.6). Once again deciduous trees could be used to shade HC cats in summer (Figure 4.6c) but allow solar radiation into the enclosure in the winter (Figure 4.6d). Coniferous shrubs could be used as a wind break area for winter and could be placed in a trajectory which reduces wind entering the geothermal microclimate cave described above. Trees should be avoided however since height will decrease the amount of solar radiation in the later part of the day when cats may be beginning to lose heat load, due to long shadows. The cave should face a south direction as well to reduce convection and increase solar radiation in winter.

Although these animals are adapted to HC care must be taken to ensure they don’t overheat. In summer wind can be provided by open areas with unobstructed wind allowance. This is easily provided via elevated platforms or suspended logs for climbing in order to gain
access to increase surface area for convective heat loss. Cool surfaces for conduction can be provided in similar ways mentioned above for CC cats. On extremely hot days sprinklers can be used for these cats as well. Shade structures could be built for HC and CC cats that could double as a precipitation shelter in winter.

Enclosures for HC cats could make use of several materials and surfaces to aid in creating a more thermal neutral microclimate. Other substrates like peat and provision of grass could be used with shade to provide cooler surfaces for conduction. Again methods such as using a dark coloured gunnite with deciduous tree shade, allowing solar radiation to heat the same surface in winter, can be used for HC cats (Figure 4.6c-d). Dark rock would be more able to absorb solar radiation in winter as a heat source and a heated gunnite pad could be used as a source of conductive heat gain in winter. As mentioned this pad could be maintained at a constant temperature in summer as well, providing a conductive cooling surface using electric or geothermal heating mechanisms.

For cats from hot humid climates some effort may be made to maintain a humidity level in the enclosure. In some zoos this will not be needed since humidity can be quite high in temperate zoo locations. Relative humidity is hard to control however, it may be possible to increase humidity by using absorbent substrates such as peat, mulch, and taller grasses. Keeping these substrates shaded and moist may cause increased humidity in the exhibit. Enclosing the exhibit with vines can help trap the water vapor inside the enclosure. These vines will give way in winter to allow for solar radiation to enter as a heat source for these animals.
4.6 Conclusion

The various species included in this study has allowed for species differences in thermoregulatory needs to be reported. It is theoretically possible to build zoo housing exhibits that would enhance thermoregulatory comfort for various species of large felid despite the temporal location of the zoo in which they reside. This can be done based on natural habitat of origin, by classifying felids as either cold or hot adapted. Although it may be more complex than this (i.e. there could be intermediate cats), building for two types of cats could keep exhibit construction costs down while still addressing thermal comfort of the animals. Further, low cost adaptations to existing exhibits could be made to increase thermoregulatory efficiency of existing exhibits for their residents.
Figure 4.1. Average summer (S) and winter (W) behaviour time budgets for all species; (A) jaguars, (B) Puma, (C) white African lions, (D) tawny African lions, (E) male Amur tiger, and (F) snow leopards over all observation days.
Figure 4.2. Average summer (S) and winter (W) enclosure use budgets for all species; (A) jaguars, (B) Puma, (C) white African lions, (D) tawny African lions, (E) male Amur tiger, and (F) snow leopards over all observation days.
Figure 4.3. Average daily summer (A) and winter (W) ambient temperatures for (J) jaguars, (P) puma, (wL) white African lions, (A) tawny African lions, (T) male amur tiger and (L) snow leopards (L).

Figure 4.4. Image of the cave in the African lion exhibit at Toronto Zoo showing the open sides and floor which is heated during cold winter months to maintain a surface temperature around 30°C.
Figure 4.5. The comparison of flank maximum (Fk max), average (Flank) and minimum (Fk min) of the male Amur tiger to shade and sun exposure and ambient temperature.
Figure 4.6. A design example of how an exhibit could be constructing for large cats from cold climates (A and B) or hot climates (C and D). (A) The west entrance of a wind tunnel observation area for cold climate cats open for summer (A) and closed for winter (B). Placed on a raised area and with the incorporation of surrounding buildings and tree placement wind can be funnelled toward this exhibit during summer to provide thermal comfort through convective heat loss for the animals and the public. Education can be provided on the green cooling energy of the wind and the natural habitat of the animals on exhibit here. The north facing view of a hot climate cat enclosure in summer (C) and winter (D). Note the use of deciduous trees for shade in summer while allowing solar radiation in during winter. In addition the coniferous trees block the westerly winds from entering the geothermal cave altering its insulative properties. Note the placement of a natural rock beneath a tree for shade in summer as a cooling conductive surface and exposed for a warming surface in winter. This type of captive habitat can provide a variety of thermoregulatory options for the feline which inhabits it.
Chapter Five: Validation of infrared thermal imaging as a means for core body temperature assessment: A pilot study

5.1 Abstract:

Due to their dangerous nature, routine health examinations of large captive carnivores lack the crucial information of a core body temperature measurement. With infrared technology, there is the potential for the use of thermal imaging for measuring core body temperature, which would provide a new tool for zoo veterinarians. A pilot study was conducted on 2 house cats (n=1 female, n=1 male) undergoing routine health examination at the Smith Lane Animal Hospital, University of Guelph, Ontario, Canada. Infrared thermal images were taken of each cat, focusing on targets such as; eyes, ear canal and pinna, nose and anus, while technicians took a rectal temperature and axillary temperature measurement immediately after via thermometer insertion. Eye surface temperatures were between 36.6°C (Female Cat) and 38.1°C (Male Cat), rectal temperatures were 38.6°C (FC) and 39.7°C (MC), and axillary temperatures were 37.5°C (FC) and 36.4°C (MC). Given that the differences between eye surface temperature and rectal temperatures were 2.0°C (FC) and 2.7°C (MC) and the differences in eye surface temperature and axillary temperatures were 0.9°C (FC) and 0.6°C (MC), the eyes seem like promising targets for core body temperature measurement via infrared thermography.
5.2 Introduction

Life and its fitness are intertwined with the thermal environment (Willmer et al., 2006). Many large felid species and other dangerous carnivores are kept in various zoos around the world, some of which in climate that differ greatly from that of their habitat of origin. There is a lack of scientific research into both normal core body temperatures (Tb) and thermoregulatory behaviours of large captive felids. Typically, Tb is not included in routine examinations of dangerous carnivores by zoo veterinarians. This is due to the necessity of anesthetization for such readings to be taken safely which in turn lowers Tb.

The use of thermal imaging in an experimental setting has been in practice for quite some time (Hilsberg-Merz, 2008), although it is not yet common practice. The potential for the use of infrared cameras in veterinary diagnostics has been proposed before (Hilsberg-Merz, 2008) and the potential for Tb assessment is very real.

Due to the dangerous nature of large captive felids, a thermography validation study was planned to be conducted on smaller house cats (*felis catus*) in the clinical setting. During preliminary facilitation efforts of the study it was discovered through conversation that this tool would be of valuable use for veterinarians in the companion animal setting as well. Some family dogs and cats in particular become too stressed in the clinic for routine rectal thermometer insertion and thermography could be a solution for dealing with fractious animals.

In addition this approach may be beneficial to companion animal veterinarians with difficult patients. In clinical situations, fractious cats may undergo axillary thermometer insertion or infrared pinna measures, to replace transrectal measurements of core temperature in order to reduce stress on the animal. These methods still require touching and even restraining the animal.
Large carnivores at the zoo typically have the core temperature omitted entirely from the exam due to their dangerous nature. These alternate methods have largely been investigated in humans only and have been compared to rectal temperature readings and not core body temperatures (Muir et al., 2001; Fortuna et al., 2010; Stine et al., 2012).

It is important to have empirical information regarding basic body functions since slight fluctuations in core body temperature may indicate infection or disease in the animal (Colditz, 2002). Core body temperature is an indication of the physiological wellbeing and health status of an individual animal. Without such basic information, it is difficult to routinely assess health of animals under care.

Non-invasive methods of body temperature measurement are of particular interest for large captive carnivores and fractious house cats in clinic since it is difficult to get close enough, without causing the animal stress, and while the examiner remains safe. There has been little work done to investigate potential non-invasive methods. With new technology, has come the possibility of the use of a thermal imaging camera for core body temperature assessment.

The objective of this observational study were to investigate the potential of thermography for core body temperature estimation and eventual measurement to augment the zoo veterinarian’s examination efficacy for large captive carnivores. It is hypothesized that surfaces such as that of the eyes, ears, ear canal, mouth, nose and anus may be of particular interest when estimate core body temperature.

5.3 Methods

Two house cats (n=1 male and n=1 female) were observed during routine examination at the Smith Lane Animal Hospital at the University of Guelph. After being asked for participation
by the receptionist at the clinic, owners were approached and asked to sign a consent form for the participation of their pet in the study. It was explained that thermal images would be taken of their pet in addition to the regular examination.

Thermal images were taken of each cat during the examination paying particular attention to eyes, ear pinna, ear canal, nose and anus. Veterinary technicians took rectal and axillary temperature readings as per routine procedure at the clinic.

5.4 Results

One female and one male cat were included in the study. Maximum eye temperature for the female cat was 36.6°C for the right and 36.5°C for the left and 37.0°C for the right and 38.1°C for the left eye of the male cat (Table 5.1). The maximum surface temperature of the ear pinna of the FC was 34.9°C and was not recordable for the male (Table 5.1). Ear pinna surface temperature was 32.0°C for the FC and 37.5°C for the male where average nose surface temperature was 33.9°C for the FC and 33.7°C for the male (Table 5.1). Rectal temperature was 38.6°C for the FC and 39.7 for the MC, and finally axillary temperature was 37.5°C for the female and 36.4°C for the male (Table 5.1).

The difference between rectal and eye surface temperatures were 2.0°C (FC) and 2.7°C (MC) and the differences in eye surface and axillary temperatures were 0.9 (FC) and 0.6 (MC).

5.5 Discussion

Although this study is quite small (n=2), there is a promising indication in these results suggesting that eye surface in relation to rectal and axillary temperatures, may be of benefit when estimating Tb remotely. The small number of individuals included is due to a lack of available
study subjects at this location and a lack of time available for completing the study. However, there are plans to complete this study with more individuals at a later date. Given the low number of individuals, results should be interpreted with caution as a number of things from age and size, sex, individual variation, estrus cycle, reason for veterinary visit, and even difference in stress levels could have had an impact on target surface temperatures.

Due to the infrequent cat appointments at the clinic and limited time allotted for the study, only 2 cats were included in this pilot study (n=1 female and n=1 male). The clinic sees mainly canine patients and it may be more beneficial to conduct a study at another location that sees more feline patients.

The differences between rectal and eye surface temperatures were 2.0ºC for the FC and 2.7ºC for the MC and the differences in eye and axillary temperatures were 0.9ºC for the FC and 0.6ºC for the MC, demonstrating a high potential for these thermography targets for Tb estimation.

Rectal temperature readings are typically seen as the gold standard (Fortuna et al., 2010) in the companion animal practice, however little scientific research has been done to investigate the validity of this technique. Other techniques have evolved such as axillary thermometer insertions and infrared pinna surface temperature measurement as mentioned. Common methods such as rectal temperature reading, may not reflect the true temperature of the animal given the spatial distribution of heat throughout the body and the proximity of the rectum to the core organs where most heat is produced (Willmer, et al., 2006).
5.6 Conclusion

Further research is needed to investigate this method of core body temperature assessment. As mentioned, due to the low number of cats (n=2) included, age and size, sex, individual variation, estrus cycle, reason for veterinary visit, and even difference in stress levels could have had an impact on target surface temperatures.

The eye surfaces give the closest values to the traditional ‘gold standard’, rectal thermometer reading, and are also very close to that measured for axillary thermometer insertion. Ear canal, pinna, nose and anus all give lower values than the axillary or rectal temperatures measured by conventional means. Although reproducibility of temperature measurement from eye surface temperature, nor does it allow an accurate assessment on how much this is expected to vary from rectal or axillary temperature. However, with more extensive data it should be possible to develop a method for estimating rectal and axillary temperature from eye surface temp by thermal imaging.

Core body temperature is a key factor in physiology representing the balance between heat production and loss (Benedict and Lee, 1936). Thermography could increase the efficiency and efficacy of routine health examinations for large captive carnivores by providing a non-invasive remote method of Tb assessment resulting in decreased stress on the animal.
Table 5.1. Results for the maximum surface temperatures (°C) of the right eye (R eye), left eye (L eye), ear canal, external portion of the ear (Ear pinna), anus, the average surface temperature (°C) of the nose, and thermometer readings (°C) for the rectal and axillary locations of the cats (*Felis catus*).

<table>
<thead>
<tr>
<th>ID</th>
<th>R eye</th>
<th>L eye</th>
<th>Ear canal</th>
<th>Ear pinna</th>
<th>Nose Ave</th>
<th>Anus</th>
<th>Rectal</th>
<th>Axillary</th>
</tr>
</thead>
<tbody>
<tr>
<td>F Cat</td>
<td>36.6</td>
<td>36.5</td>
<td>34.9</td>
<td>32.0</td>
<td>22.9</td>
<td>35.3</td>
<td>38.6</td>
<td>37.5</td>
</tr>
<tr>
<td>M Cat</td>
<td>37.0</td>
<td>38.1</td>
<td>37.5</td>
<td>33.7</td>
<td></td>
<td></td>
<td>39.7</td>
<td>36.4</td>
</tr>
</tbody>
</table>
Chapter Six: Conclusion

Over time, through study and education, public opinions have changed with regard to wild animals in captivity. This has led to an increase in the responsibility placed on zoos to provide, through scientific investigation, conditions that support optimal welfare for their animals with respect to enclosure design and management practices. The results described in this thesis provide a foundational basis for future studies on thermal comfort and thermoregulatory behaviour of large captive felids. Due to the inclusion of several species of large captive felids and the uniqueness of the continuous observation methods used, these results are valuable to the zoo community. Due to the lack of published data on thermal comfort and welfare of large felids in zoos where climates differ from those of the species’ natural habitats, there is a substantial need for further action by zoo animal behaviour and welfare researchers in this area.

The behavioural repertoire of eight tigers at Busch Gardens in Tampa, Florida was investigated and reported on, with a focus on thermoregulatory behaviours (Chapter 3). The data set presented in the current study is the largest of its kind to be published to date.

In the heat of the Florida summer, these tigers spent most of their time inactive lying down, and around 10% of their time in active behaviours such as walking, standing and running. Detailed ethograms for each individual are available in Appendix 1.

Through enclosure use budgets (Appendix 3) detailed information is presented on habitat feature use by individual tigers. This information allows for the formulation of recommendations for potentially low cost shade structures that could be used to increase thermal comfort for the tigers in this habitat by decreasing reflected and direct solar radiation. Future studies of this nature will provide similar information for zoo habitat design and construction for carnivores in
zoos elsewhere. These results will immediately impact the comfort of the individuals involved and will also provide valuable information to other zoos.

The differences in the behavioural repertoire of several species of large felid (species) at the Toronto Zoo in Toronto, Ontario, Canada were investigated and compared, with a focus on their thermoregulatory behaviours (Chapter 4). Detailed ethograms, behaviour time budgets and enclosure use budgets are given in Appendices 4, 5 and 6 respectively.

Although some species may be considered as intermediates, large felids can be grouped into two groups, based on habitat of origin, to simplify the construction of thermally comfortable environments. Zoo habitats built for cats from hot climates (species) could be built with a south facing orientation and design features to increase sun exposure in winter. Similarly, zoo habitats built for cats from cold climates (species) could be built in an area with high wind exposure and extensive shade during summer.

The species comparison reported here, is also the largest to be published and as such it will be of considerable valuable to the zoo community. Additional low cost options are given for adapting existing zoo habitats which should allow zoos to relatively easily increase thermal comfort for resident animals.

The potential for using thermal imaging as a means of measuring core body temperature was investigated in a pilot study using house cats (Felis catus) as a model (Chapter 5). Although the pilot study is limited in the information it can provide, it was noted that the eye surface temperatures gave the closest values to the rectal and axillary temperatures measured using traditional thermometers. With a more extensive investigation, the individual variation in eye
surface, rectal and axillary temperatures may be detected. In addition, the difference between eye
temperature and the two traditional methods should also be elucidated. With this
information it should be possible to develop a method for using thermal imaging to estimate
rectal and axillary temperatures noninvasively. A noninvasive method of core body temperature
measurement would add to the zoo veterinarian’s tools when dealing with large carnivores and
also provide a means for reducing stress in both wild and domesticated cat species.
Chapter Seven: References


Karrow, NA 2006. Activation of the hyperthalamic-pituitary-adrenal axis and autonomic nervous system during inflammation and altered propramming of the neuroendocrine-immune axis during
fetal and neonatal development: Lessons learned from the model inflammagen, lipopolysaccharide. Brain, Behavior, and Immunity 20, 144-158.


Young T. 2010. Lions and tigers in zoos, oh my! An exploration of thermal comfort and its implications for zoo exhibit design: MSc Thesis Presented to the Faculty of Graduate Studies of The University of Guelph.
Appendix 1: Individual Daily Ethograms for Chapter 3

Raw continuous behaviour observation data was used to generate these ethograms.
G2F1D1

- Standing
- Walking
- Running
- Pacing
- Sitting
- Lying head up
- Lying head down
- Lying loin exposed
- Rolling/rubbing
- Eating
- Drinking
- Urinating
- Spraying
- Defecating

G2F2D1

- Standing
- Walking
- Running
- Pacing
- Sitting
- Lying head up
- Lying head down
- Lying loin exposed
- Rolling/rubbing
- Eating
- Drinking
- Urinating
- Spraying
- Defecating
- Grooming
Appendix 2: Individual Daily Behaviour Time Budgets for Chapter 3

Raw data behaviour time budgets for Chapter 3 are shown for each individual for each day observed. These data were used and averaged for Figure 3.3.
Appendix 3: Individual Daily Enclosure Use Budgets for Chapter 3

Raw data enclosure use budgets for Chapter 3 are shown for each individual for each day observed. These data were used and averaged for Figure 3.4.
In water
In sun
In shade
In cave
Overcast

G2F1D1

G2F2D1

G2F1D2

G2F2D2

G2F1D3

G2F2D3
Appendix 4: Individual Daily Ethograms for Chapter 4

Raw continuous behaviour observation data was used to generate these ethograms.
Female Jaguar Wd1

- Standing
- Walking
- Running
- Pacing
- Sitting
- Lying head up
- Lying head down
- Lying loin exposed
- Rolling/rubbing
- Eating
- Drinking
- Urinating
- Spraying
- Defecating
- Grooming
- Panting

Male Jaguar Wd1

- Standing
- Walking
- Running
- Pacing
- Sitting
- Lying head up
- Lying head down
- Lying loin exposed
- Rolling/rubbing/marking
- Eating
- Drinking
- Urinating
- Spraying
- Defecating
- Grooming
- Panting
Female Jaguar Wd2

Male Jaguar Wd2
Female Puma Sd2

- Standing
- Walking
- Running
- Pacing
- Sitting
- Lying head up
- Lying head down
- Lying loin exposed
- Rolling/rubbing/marking
- Eating
- Drinking
- Urinating
- Spraying
- Defecating
- Grooming
- Panting

Male Puma Sd2

- Standing
- Walking
- Running
- Pacing
- Sitting
- Lying head up
- Lying head down
- Lying loin exposed
- Rolling/rubbing
- Eating
- Drinking
- Urinating
- Spraying
- Defecating
- Grooming
Female Puma Wd2

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<td>-2</td>
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<td>1</td>
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<td>15:07</td>
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Male Puma Wd2

<table>
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<td>14:38</td>
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<td>15:07</td>
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</tr>
</tbody>
</table>

- Standing
- Walking
- Running
- Pacing
- Sitting
- Lying head up
- Lying head down
- Lying loin exposed
- Rolling/rubbing/marking
- Eating
- Drinking
- Urinating
- Spraying
- Defecating
- Grooming
- Panting
F2 White Lion Sd1

Male White Lion Sd2
F1 White Lion Sd2

- Standing
- Walking
- Running
- Pacing
- Sitting
- Lying head up
- Lying head down
- Lying loin exposed
- Rolling/rubbing
- Eating
- Drinking
- Urinating
- Spraying
- Defecating
- Grooming

F2 White Lion Sd2

- Standing
- Walking
- Running
- Pacing
- Sitting
- Lying head up
- Lying head down
- Lying loin exposed
- Rolling/rubbing
- Eating
- Drinking
- Urinating
- Spraying
- Defecating
- Grooming
Ambient Temperature (°C)

Time (min.)

Maned Lion Sd1

- Standing
- Walking
- Running
- Pacing
- Sitting
- Lying head up
- Lying head down
- Lying loin exposed
- Rolling/Rubing/Marking
- Eating
- Drinking
- Urinating
- Spraying
- Defecating
- Grooming

Manless Male Sd1

- Standing
- Walking
- Running
- Pacing
- Sitting
- Lying head up
- Lying head down
- Lying loin exposed
- Rolling/Rubing/Marking
- Eating
- Drinking
- Urinating
- Spraying
- Defecating
- Grooming
- Panting
Appendix 5: Individual Daily Behaviour Time Budgets for Chapter 4

Raw data behaviour time budgets for Chapter 4 are shown for each individual for each day observed. These data were used and averaged for Figure 4.1.
Appendix 6: Individual Daily Enclosure Use Budgets for Chapter 4

Raw data enclosure use budgets for Chapter 4 are shown for each individual for each day observed. These data were used and averaged for Figure 4.2.
Female Jaguar Sd3
- In water: 0.0%
- In sun: 11.4%
- In shade: 66.5%
- In cave: 0.0%
- Overcast: 0.0%

Male Jaguar Sd3
- In water: 0.0%
- In sun: 31.0%
- In shade: 65.1%
- In cave: 0.0%
- Overcast: 0.0%

Female Jaguar Wd1
- In water: 0.0%
- In sun: 78.7%
- In shade: 21.3%
- In cave: 0.0%
- Overcast: 0.0%

Male Jaguar Wd1
- In water: 0.0%
- In sun: 80.7%
- In shade: 19.3%
- In cave: 0.0%
- Overcast: 0.0%

Female Jaguar Wd2
- In water: 60.1%
- In sun: 39.9%
- In shade: 0.0%
- In cave: 0.0%
- Overcast: 0.0%

Male Jaguar Wd2
- In water: 100.0%
Female Puma Wd1

- In water: 42.9%
- In sun: 0.05%
- In shade: 0.0%
- In cave: 51.9%
- Overcast: 0.0%

Male Puma Wd1

- In water: 69.9%
- In sun: 0.0%
- In shade: 25.3%
- In cave: 0.0%
- Overcast: 0.0%

Female Puma Wd2

- In water: 0.0%
- In sun: 22.3%
- In shade: 34.7%
- In cave: 43.1%
- Overcast: 0.0%

Male Puma Wd2

- In water: 0.0%
- In sun: 7.7%
- In shade: 0.0%
- In cave: 86.7%
- Overcast: 0.0%

Female Puma Wd3

- In water: 0.0%
- In sun: 26.4%
- In shade: 73.6%
- In cave: 0.0%
- Overcast: 0.0%

Male Puma Wd3

- In water: 77.7%
- In sun: 0.0%
- In shade: 22.3%
- In cave: 0.0%
- Overcast: 0.0%
Female Snowleopard Sd2

- In water: 8.1%
- In sun: 41.6%
- In shade: 50.3%

Male Snowleopard Sd2

- In water: 20.8%
- In sun: 33.2%
- In shade: 44.2%

Female Snowleopard Wd1

- In water: 12.2%
- In sun: 55.4%
- In shade: 32.4%

Male Snowleopard Wd1

- In water: 25.8%
- In shade: 74.2%

Female Snowleopard Wd2

- In water: 24.1%
- In shade: 73.6%