

# ENVIRONMENTAL STRESS ON THE REPRODUCTION OF NON-HUMAN PRIMATES

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Received 9 January 2020/Accepted 29 May 2020

## ABSTRACT

This paper aims to review some highlights on the effects of environmental stresses on the non-human primate population, particularly, climate change and food limitation that may have resulted in their poor reproductive performance. The International Union for Conservation of Nature (IUCN) lists more than a third of the world's primates as critically endangered or vulnerable. Non-human primates, which are the closest biological relatives of humans, are threatened with extinction from human activities and environmental stress. Deforestation is the main problem that intercalates with climate change. Either, indirectly or directly, those extinction factors could interrupt the physiological basis of reproduction among non-human primates. Researches on other species showed that high ambient temperature causing heat stress had harmed the reproductive performance by interfering with the hypothalamic-pituitary-gonadal axis. Therefore, the survival, conservation and sustainability of nonhuman primates growing in captivity and in the wild, require more works and researches to be done.

**Keywords:** climate change, conservation, heat stress, primate, reproductive

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## INTRODUCTION

The non-human primate populations are increasingly endangered as they experienced warnings and threats from abrupt climate changes that slowly result in their population extinction. The Intergovernmental Panel on Climate Change (IPCC) has warned about the impacts of the escalating global temperatures. Moreover, global warming will continue even though it is not regionally uniform and the nations' potential for adapting to this situation is limited in terms of protecting the natural systems. This situation is more complex than just rising temperature because climate change is an environmental stress causing changes in the body physiological metabolism in a short-term to long-term fight-or-flight response (Schulte 2014). The intense increases in humidity and

ambient temperature had resulted in animals and plants being exposed to adverse circumstances that threaten their survival, and ultimately, their biodiversity. Climate change would directly or indirectly cause reduction and shifting of wildlife populations and habitats, including the non-human primates, thereby eventually inhibiting the survivability and sustainability of the species.

Most primates are widely distributed throughout the tropical and subtropical regions of Africa, America and Asia. The majority of primates live in tropical areas that are rainfed and rain forested (Reed & Fleagle 1995), but they also exist in tropical dry forests, mangrove vegetation above high-tide levels, savannas, grasslands, inland wetlands and rocky areas (Mittermeier *et al.* 2013). Habitat for this group of animals is widespread but some of the areas are no longer able to accommodate these primates' populations, as the areas have been mostly disturbed by human activities. About 80% of the Malaysian rainforests are degraded

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by logging and largely covered with oil palm plantations (Sophie 2013). Logging had threatened the biodiversity of those areas, including the nonhuman primate populations. Deforestation is also a result of human overpopulation happening in some places in the African and Asian countries. The populations of nonhuman primates are disturbed by human population growth, economic expansion and other human activities, such as those in the agricultural industry. The significant thermal impact that obviously elevated the effects of climate change has led to phenological changes in the wildlife habitats. Extreme irregularities in phenological events have also resulted in shifting food sources that has changed many natural cycles of pollinators and plants, predators and prey, and of primate and their food sources (Visser 2008; Both *et al.* 2009; Butt *et al.* 2015). All these disturbance factors threatening the nonhuman primate species have forced them to move out of their habitat range to get clean water, food, and to raise their offspring. These external factors, such as climate change, demanded an adaptive response from the animals to a new environment (Altmann *et al.* 2002; Beehner *et al.* 2006a; Estrada *et al.* 2017; Fairbanks *et al.* 2011). The critical challenge facing the global population of nonhuman primates is therefore, survival or extinction, because as animals lose the ability to control their environment (for examples, habitats lost and climate change), their physiological structure ultimately change. Moreover, it could cause adverse effects on their reproduction and development.

This paper briefly reviews and discusses the impact of physical disturbances such as feed restriction and climate change on the reproductive physiology as these factors slowly create stress affecting reproduction and eventually, the survival of the nonhuman primates.

## REVIEW

### Does Climate Change Affect the Reproductive Performance of Nonhuman Primates?

In the last few decades, the effects of environmental stress to animals, mainly climate change, has become a major concern. However,

still sparse works are done on the sustainability of wildlife, particularly the nonhuman primates, in this complex stress phenomenon. Many researches showed that continuous increase of the ambient temperature resulting in heat stress had significantly affected the reproductive physiology of animals, including nonhuman primates (Beehner *et al.* 2006ab; Sharpe, 2010; Rylander *et al.* 2013; Wang *et al.* 2014). An acute increase of ambient temperature generally affect the breeding patterns of animals through physiological changes in the brain, the center of the nervous system. Studies among livestock animals showed that extremely high temperatures strongly affected the hypothalamic-pituitary-gonadal axis (Shelton & Huston 1968; Wolfenson *et al.* 2000; Santolaria *et al.* 2014). These deleterious effects of heat stress could lead to disruptions in the reproductive performance of nonhuman primates.

About 419 primate species, such as lemurs, lorises, tarsiers, monkeys and apes, would experience 10% more warming than the global average (Taylor 2016). Meanwhile, some primates would experience increases of more than 1.5 °C in annual average temperature for every degree in global warming. Therefore, primates that show high sensitivity to little changes on ambient temperature could experience more intense effects in their reproduction as compared to other primates. The consequence of climate change on the reproductive performance of nonhuman primates not only occurs in females but also in males. A 43 °C heat stress of about 30 minutes could induce apoptosis of germ cells in the testis of *Macaca fascicularis*, a non-human primate, (Zhang *et al.* 2005). This situation was described in studies where suppression of testicular function under heat stress had led to a decrease in fertility in ruminants (Hamilton *et al.* 2016), and humans (Garolla *et al.* 2013; Rao *et al.* 2015). Those testis exposed to high ambient temperature could constantly effect the DNA fragmentation of sperms; thus, reduces the quality of sperms. An elevated surrounding temperature causing a rise in testicular temperature result in a reduction in sperm output, low sperm motility and an increase of morphologically abnormal spermatozoa (Hansen 2009). Germ cell depletion and increase in DNA damage are induced by heat stress (Lue *et al.*

1999; Paul *et al.* 2008). Oxidative stress clearly disturbs the functionality of sperm and leads to sperm damage, deformity, and eventually, male infertility (Halliwell & Gutteridge 2007; Mahfouz *et al.* 2010). Animals vulnerable to environmental changes, particularly heat stress, also exhibited changes in their mating behavior (Deutsch *et al.* 2008; McFarland *et al.* 2014). In female, heat stress had significant adverse effects on the reproductive performance particularly, delayed estrus cycle, lower embryo survivability, slow fetus development and early pregnancy abortion (Beehner *et al.* 2006b; Hansen 2009; Wiederholt *et al.* 2011). Documented information on the effects of these environmental stressors towards reproduction patterns of the female and male nonhuman primates is still sparse. Hence more studies are needed on understanding the impact of heat stress or climate change particularly on reproductive-physiology and reproductive behavior. Identifying anthropogenic stressors on nonhuman primates is also essential for conservation planning and management of these primates (Graham *et al.* 2016).

### **Importance of Nutrition and Reproduction**

The overall functions of the reproductive system are largely controlled by the hormonal interactions of the hypothalamic-pituitary-ovarian axis, but the final output also depends on extrinsic factors such as nutrition. The diet that is easily digested and rich in fibre, carbohydrates and lipid from fruits, leaves, buds and insects, constitute an immense food source for most nonhuman primates (Strier 2007; Lambert 2010; Moges *et al.* 2014; Kassim *et al.* 2017). However, habitat fragmentation and climate change could harm food availability. Captive orangutans fed with high-quality feeds have shorter inter-birth intervals as compared to wild orangutans (Kuze *et al.* 2012). Therefore, with a good quality food sources, the orangutan population will result in an increased reproductive performance and eventually increased population density. Food availability and nutritional composition are also important to the population density of nonhuman primates (Hanya & Chapman 2013).

Two factors that contribute to pregnancy failure in females are the inadequate food intake

and increased energy expenditure. It is important for pregnant females to meet the basic metabolic requirements mainly during early pregnancy to avoid negative energy balance. Studies done on the nutritional status and reproduction of laboratory and livestock animals recorded that underfed animals experienced delayed puberty period, decreased embryo survival rate, suppressed spermatogenesis and reduced number of sperm motility. Moreover, females that were deprived of food or underfed were less fertile and this reduces the chances of fertilisation; thus, affecting the population birth rate and eventually causing a decrease in population. This probably occurs severely among subordinate females of a nonhuman primate. Dominant females of marmoset monkey produced more offsprings as compared to subordinate females in a healthy environment (Abbot 1987). In the physiological level, dominant females can defeat the reproductive performance of subordinate females. The impact of a threatening activity, such as forest abuse, can damage the individual survival of nonhuman primate species, decrease fertility, and will shrink the population through time.

Climate disaster also leads to the extinction of plants and animals. A study on wild baboons documented that pregnancy failure was high if the females conceived after the drought (Beehner *et al.* 2006b). During the 1990s, the decline in the orangutan population by at least 30% of its total population was caused by fires and drought in the Bornean forests (Gould *et al.* 1999). In addition, wildfires in Mexico also affected the nonhuman primates, whereby the habitats of New World monkeys were destroyed by drought and El Nino. Reduction of food availability as a result of El Nino event caused the population size reduction of atelines one year after the event (Wiederholt & Post 2010). Extreme temperatures can decrease the food production and drinking water availability of the existing nonhuman primates. High ambient temperature could decrease the concentration of fibre and protein contents of leaves due to high atmospheric carbon dioxide. In addition, a rising level of heat and carbon dioxide could make the leaf or green resources less nutritious (Gray & Brady 2016) and could also affect the plant physiology resulting in changes in the number and size of leaves (Taylor *et al.* 2003; Dermody *et*

*al.* 2006). Higher temperatures also increased the plant matter toxicity resulting in reduced leaf sizes (Moore *et al.* 2015). Decreasing food source could also increase the competition within the population. In the long run, this indirect effect might impact the evolutionary and ecological processes of a certain population.

Obviously, several factors contribute to food limitation in nonhuman primate habitats, such as forest exploitation, forest clearing for agriculture and climate change. As mentioned earlier, nutritional restriction can interrupt the breeding pattern, fertility, puberty development, embryo growth and development, and can increase susceptibility to disease and predation, intensify mortality of infants and mothers, and can delay reproductive maturity to a much later age (Korstjens & Hillyer 2016; Chaves *et al.* 2019; Laver *et al.* 2020). The synchronization of reproductive events of primate to fit the availability of the resources was also affected (Van Schaik *et al.* 1993; Post 2013). Climate change occurring in the African regions has caused significant changes in fruit production, as it was lower between 1988 and 1993 than between 1994 and 2003 (Erhart and Overdorff 2008). This event negatively affected the red-fronted lemurs (*Eulemur fulvus rufus*), specifically their reproductive patterns, sex ratio, group sizes and population density. Early embryo wastage, one of the key factors towards species extinction, is a particularly critical issue for nonhuman primates. The nonhuman primates in captive management may need to refine the feed intake that would satisfy the dietary needs and take into account to have an optimal reproductive functions.

### **Reproductive and Stress Hormones on Reproduction**

It is well-known that progesterone is the main reproductive hormone that is essential to maintain pregnancy in animals, including in nonhuman primates and humans. Meanwhile, testosterone is important in mating behaviour and confounded with dominance rank in male primates (Dixson 1998; Wallen & Zehr 2004). Expressions of reproductive hormones depend on maternal responsiveness with the environments and differ between young and experienced female primates (Rangel-Negrín *et*

*al.* 2009; Saltzman & Maestripieri 2011). The understanding of neuroendocrine and primate maternal behaviour has increased, but of the physiology mechanism underlying the effects is still limited.

During early pregnancy in nonhuman primates, progesterone secretion is solely from corpus luteum and it is replaced by the placenta during mid-pregnancy (Beehner *et al.* 2006a). An *in vitro* study on Macaque recorded the direct actions of progesterone and oestradiol on primate pre-antral follicle development (Ting *et al.* 2015). Androgens appeared to be a survival factor but hindered antral follicle differentiation; oestradiol appeared to be a survival and growth factor at the pre-antral and early antral stages, whereas progesterone may not be essential during early folliculogenesis in primates. Macaque and baboon are nonhuman primate models used for studies related to human reproductive health, such as contraception, reproductive aging, infertility, ovarian function, and reproductive tract disorder (Wandji *et al.* 1997; D'Hooghe *et al.* 2004; Ting *et al.* 2015).

Maternal stress during pregnancy that is controlled by the hypothalamus–pituitary–adrenal (HPA) axes could produce disruptive effects on embryo and fetal growth and development (Del Giudice 2012; Laver *et al.* 2020). Among wild baboons, food limitation due to drought contributed to fetal loss in the Amboseli population (Beehner *et al.* 2006b). A study on orangutans in Southeast Asian tropical forests showed that solitary lifestyle is relative to late weaning which is a consequence of their ecological environment (Vogel *et al.* 2015). Faecal glucocorticoid (fGC) is a survival probability indicator of many nonhuman primates, such as ring-tailed lemurs and red-bellied lemurs. It shows high mortality rate due to habitat degradation that would cause reduction in fruit availability (Pride 2005; Tecot 2013; Balestri *et al.* 2014).

The non-invasive technique was used to measure reproductive hormones and cortisol through urine and faeces during a normal reproductive cycle (Rangel-Negrín *et al.* 2009). Chaves *et al.* (2019) used non-invasive biomarkers, fecal glucocorticoid metabolites to assess the physiological stress of adult wild brown howlers and the food availability in Brazilian Atlantic Forest fragments, and found

that nursing females are highly nutrition demanding for their pregnancy and lactation. It shows that hormones obsess and affect the appetite throughout pregnancy, explaining the consistent association between undernutrition and reproductive failure. Studies on brain activity via hypothalamic-pituitary-ovarian axis and stress hormones on embryo and fetal losses are still scarce. We suggest that researches need to focus on this because as observed, maternal hormonal patterns and external factors are important in sustaining embryo survivability.

### CONCLUSION AND FUTURE PERSPECTIVES

This article has focused on how environmental stress, mainly climate change and poor dietary intake, can lead to reproductive stress and failure among nonhuman primates. These factors, known to be either directly or indirectly link to the hypothalamic-ovarian axis, harm the reproductive sites. Furthermore, the anthropogenic stressors on primate populations also contribute towards species extinctions, particularly in animals with slow reproductive rates. All these factors are closely related to the extinction of this vulnerable species. Primates are a flagship species for entire ecosystems, so its conservation also present important consequences for many other species.

The success of its conservation and preservation programs are dependent on the ability of the species to reproduce successfully and to minimize offspring loss. Thus, important information on the fitness and success of its reproduction provides an understanding of the physiological-environment interactions of the nonhuman primates reproduction. Moreover, the successful reproduction is fundamental to the survival and evolution of all species. Hence, further studies are needed to understand the impact of environmental stress on their physiological changes mainly the reproductive performance and endocrine reproduction of nonhuman primates. It would probably help researchers or governments to properly manage this species by investing on resources to safeguard the animals from the threats of habitat destruction, and, to monitor their reproductive

performance through hormonal control for sustainable primate populations.

### ACKNOWLEDGEMENTS

The authors would like to thank the Reprophysio Team from the Department of Biology, Faculty of Science, Universiti Putra Malaysia and Putra Grant GP/2018/9619600 for generously supporting this publication.

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