Fire associated exertion myopathy as a mechanism contributing to mortality in *Chamaesaura macrolepis* (Cope 1862)

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ABSTRACT

Following a fire event, an abnormally high number of *Chamaesaura macrolepis* (Cope 1862) road mortalities were observed on two sections of tar road south of Maputo Special Reserve, Maputo Province, Mozambique. Although most specimens were driven over by vehicles, three intact individuals were collected on the shoulder of the tarred road surface, without exhibiting any external signs of vehicular trauma or thermal damage. Histopathological examination of dissected tissues revealed acute skeletal and cardiac myopathy in all three specimens, suggesting a novel facet of faunal responses to fire and the physical strain exerted to avoid these conditions. No reports of fire associated exertion myopathy could be located for any other animals in the available literature.

KEYWORDS: direct fire effect, histopathology, road mortality

The direct effects of fire, injury or mortality, on animal populations and communities are largely considered insignificant when compared with the longer-lasting modification of the environment brought on by burning and the corresponding faunal responses (Masterson et al. 2008; Engstrom 2010). Consequently, the mechanisms responsible for fire-induced faunal mortality have been under studied and under reported (e.g. Dickenson et al. 2010; Jordaan et al. 2020). Incidence of high fire-associated mortality is however known for members of the Cordylidae, genus *Chamaesaura* Schneider 1801 (De Villiers and De Villiers 2004; Coombs 2015). Although these observations include instances where individuals presumably burnt to death (e.g. De Villiers and De Villiers 2004), large numbers of *Chamaesaura* have also been observed fleeing from fire onto roads (Boycott 1990; Du Toit 2001; Boycott 2015) where many are exposed to, and driven over by vehicular traffic (Coombs 2015). Such a mortality event occurred in southern Mozambique, on the recently constructed tar road linking the city of Maputo to the Farazela/Kosi Bay border post with South Africa, in the Maputo Province, south of the Maputo Special Reserve (Jordaan 2020). Although the vast majority of *Chamaesaura macrolepis* (Cope 1862) mortalities were damaged by vehicles (92%, $n = 34$), three undamaged mortalities were collected from the western shoulder of the road. Because neither thermal damage nor vehicular trauma was evident following external inspection, these three specimens were collected to investigate possible causes of mortality using histopathological analyses as documented in Jordaan et al. 2019 and Jordaan et al. 2020.

Chamaesaura is a genus of elongated Cordylid lizards, with a tail four to five times the length of the body, rudimentary or absent limbs, and a severely reduced body girth, making them remarkably well adapted to rapidly move through grass using a serpentine swimming motion (Branch 1998; Boycott 2015). Even periods of torpor are generally spent in the centre

of grass tussocks with structured refugia, such as crevices and rock cover, seldom utilised (Du Toit 2001; Boycott 2015). The obligated reliance of these lizards on the herbaceous layer is the likely reason for reported population collapses and the failure of these species to recolonise areas following large-scale fires or increased fire frequencies (Jacobsen 1989; Du Toit 2001; Bates 2014; Boycott 2015). *Chamaesaura macrolepis* is considered one of the most abundant reptiles regionally (Bruton and Haacke 1980) despite the first official records of the species for southern Mozambique only confirmed recently (Jordaan 2020).

The fire that induced the mortality discussed in this paper occurred on 24 July 2019, burning less than 1 000 ha of vegetation, including secondary grassland, thicket vegetation, and moribund *Eucalyptus* plantations to the west of the tar road. The fire was first noticed at 07:00 in the morning and burned throughout that night. *Chamaesaura macrolepis* specimens were only observed on two sections of the tar road, approximately 2 km in length each (4 km in total), the following morning (25 July 2019) where the fire burned directly up to the western road edge (Jordaan 2020). These stretches of road were surveyed from a vehicle driven at a maximum speed of 30 km h^{-1}, recording all observed mortalities and their position across the width of the road surface relative to the burn. The position of each observed specimen across the width of the road was assigned to one of five sectors: 1, the western road shoulder, less than 1 m in width, directly next to the burn ($n = 5$); 2, the western road lane, 2 m in width, ($n = 20$); 3, the middle of the road, approximately 2 m in width ($n = 10$); the eastern road lane, approximately 2 m in width ($n = 1$); and the eastern road shoulder on the opposite side of the fire, approximately 1 m in width ($n = 1$). As stated above, three seemingly undamaged *C. macrolepis* specimens were collected from the western road shoulder (sector 1). These specimens were dissected into body width cross sections and fixed in 10% buffered formalin before being processed and stained using haematoxylin and eosin for light microscopic examination (Bancroft and Gamble 2002). The entire body, including the head, of each specimen was consumed during this process.

In total, 37 specimens were recorded, translating into a mean density of 9.25 *C. macrolepis* mortalities per km of road. Avian scavenging might, however, have removed some specimens before they could be counted, potentially impacted these observed mortality numbers (Degregorio et al. 2011). No live individuals were observed. These densities are comparatively sparse, compared with previously documented quantified observations for *Chamaesaura anguina anguina* (Linnaeus 1758) of 68 individuals per km (De Villiers and De Villiers 2004) and 21.3 individuals per km of road (Coombs 2015).

During histopathologic examination, all three undamaged specimens were confirmed to be males, exhibiting inactive testes. No signs of internal trauma, like bone fractures or organ rupture with haemorrhage, were evident during histopathological assessments, ruling out vehicular trauma as a possible cause of death. Some similarities to documented abnormalities in externally undamaged fire associated reptile mortality histopathological analyses were observed, such as minor peripheral pulmonary atelectasis, minor pulmonary oedema, the partial deciliation of the trachea and congested blood vessels in the brain (Jordaan et al. 2019; Jordaan et al. 2020). Unlike these earlier accounts, the blood vessels of the heart, liver and kidneys were also congested. In addition, the kidneys showed peracute tubular necrosis affecting the proximal convoluted tubules terminally (Figure 4). Monophasic skeletal muscle degeneration and necrosis, characterised by multifocal myofibrillar hypereosinophilic swelling (hyalinisation), fragmentation and loss of cross striations, was observed in all three specimens (Figure 1). Importantly, these injured muscle fibres selectively affected deep muscle bundles of the neck, thorax, and tail (especially paravertebral muscle groups) (Figure

2). Myocardial oedema associated with monophasic myofibrillar fragmentation was also observed (Figure 3). This finding suggests terminal heart failure and it is supported by significant pulmonary and cerebral congestion. The renal findings in this case could also be attributed to prolonged terminal ischaemia resulting from a failing heart. The external dermal structures (epidermis and scutes) and outer muscle layers showed no evidence of thermal-, or other mechanisms of injury. This combination of histopathological features affecting the musculature suggests exertion myopathy as the most probable mechanism of death for the three examined individuals. Other regional studies on fire-associated mortality in reptiles (e.g. Jordaan et al. 2019; Jordaan et al. 2020) reported no histopathological evidence of exertion myopathy in analysed specimens. This could best be attributed to the responses and strategies of different species to avoid fire. Although most of the analysed reptile mortalities described in Jordaan et al. 2019 and Jordaan et al. 2020 were largely attributed to the fatal effects of toxic or heated gas inhalation by animals that presumably sought shelter underground to weather the direct effects of fires, *Chamaesaura* actively avoids the progressing fire front by moving rapidly away from it, without seeking refuge (Du Toit 2001; De Villiers and De Villiers 2004). Such sustained intensive activity over relatively extensive distances, may cause fatal muscle injury in the form of exertion myopathy, which results when the strain brought on by the increased activity extends beyond the limit of sustained intrinsic physical ability of the species or individuals. This is further compounded or even solely precipitated by abnormal strenuous physical activity and stress (hyperadrenalism) in an attempt to cross hazardous terrain. In the case of *Chamaesaura*, locomotion in these lizards is hampered outside of grassy material, requiring additional strain and effort to move over hard flat surfaces (Branch 1998; Du Toit 2001), such as the tarred road. In addition, the emotional stress experienced by these creatures results in prolonged and abnormally high cardiac output, terminating in acute heart failure (Harthoorn 1976; Bartsch et al. 1977). This was supported by the histological finding of widespread congestion in parenchymal organs.

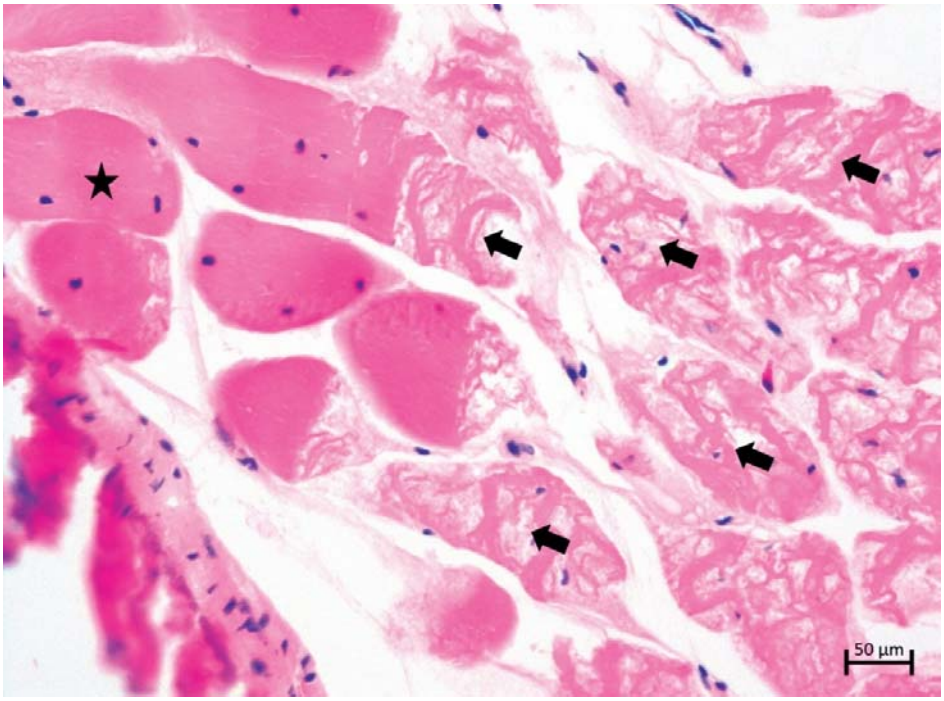

Figure 1. Paravertebral muscle fibres exhibiting degenerative fragmentation (arrows); Normal cross-sectioned muscle fibre (stars). Photomicrograph of a cross section from the tail of *Chamaesaura macrolepis* (Cope 1862) specimen. Haematoxylin and eosin staining, 200× magnification.

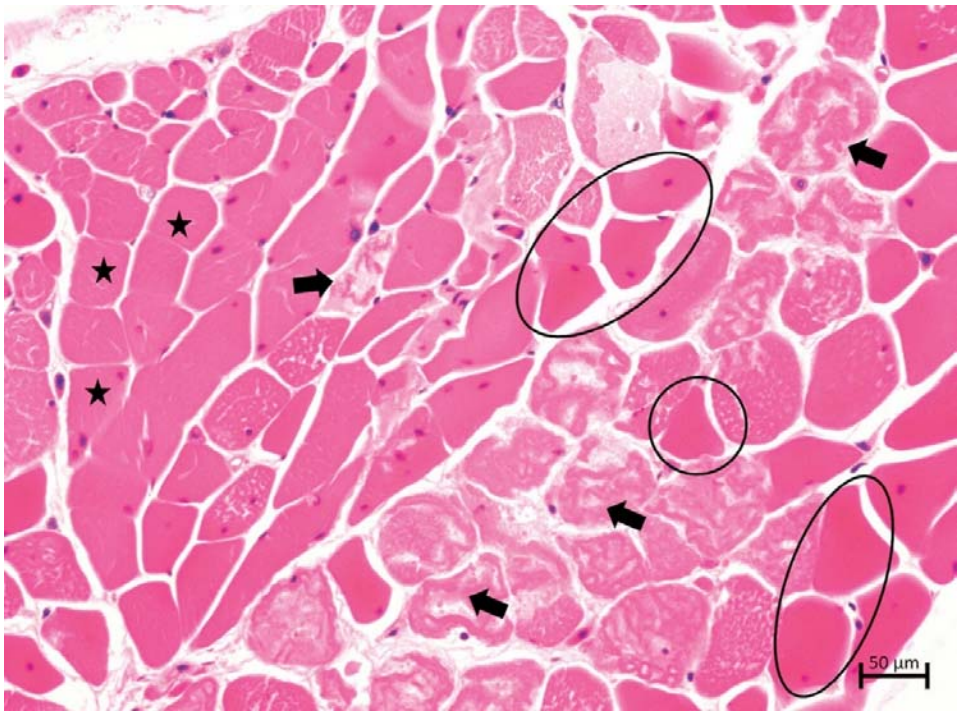

Figure 2. Deep thoracic muscles. Severe monophasic muscle characterised by variable degenerative fragmentation (arrows), hyalinisation and swelling (circles); Normal cross-sectioned muscle fibre (star). Photomicrograph of a cross section through the chest of *Chamaesaura macrolepis* (Cope 1862) specimen. Haematoxylin and eosin staining 200× magnification.

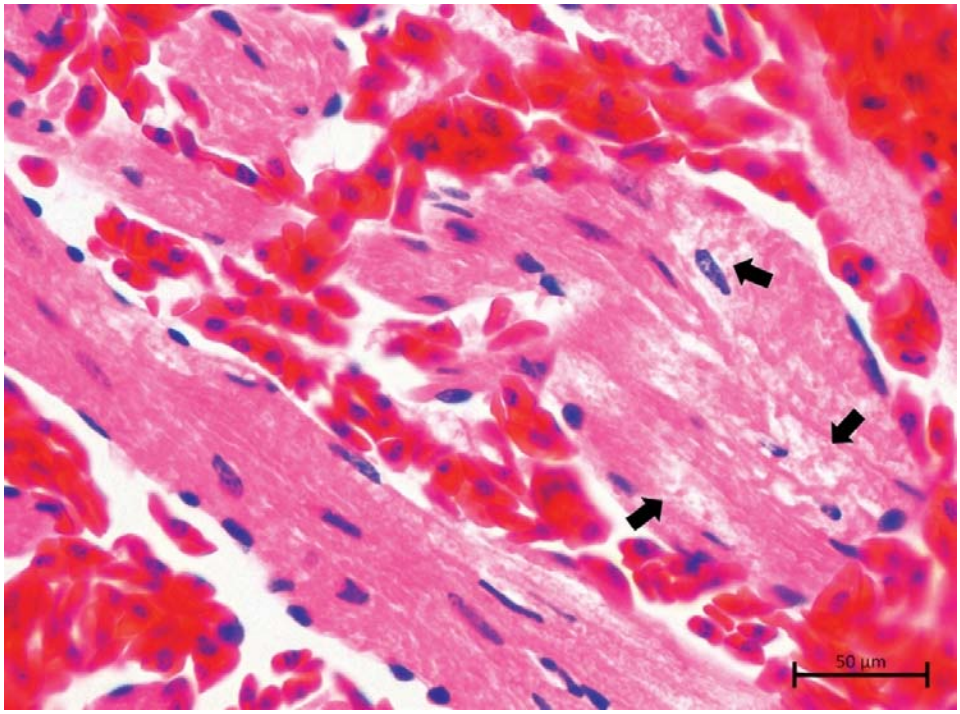

Figure 3. Myocardium. Severe monophasic myofibrillar fragmentation and oedema (arrows). Photomicrograph of a cross section through the heart muscle of a *Chamaesaura macrolepis* (Cope 1862) specimen. Haematoxylin and eosin staining, 200× magnification.

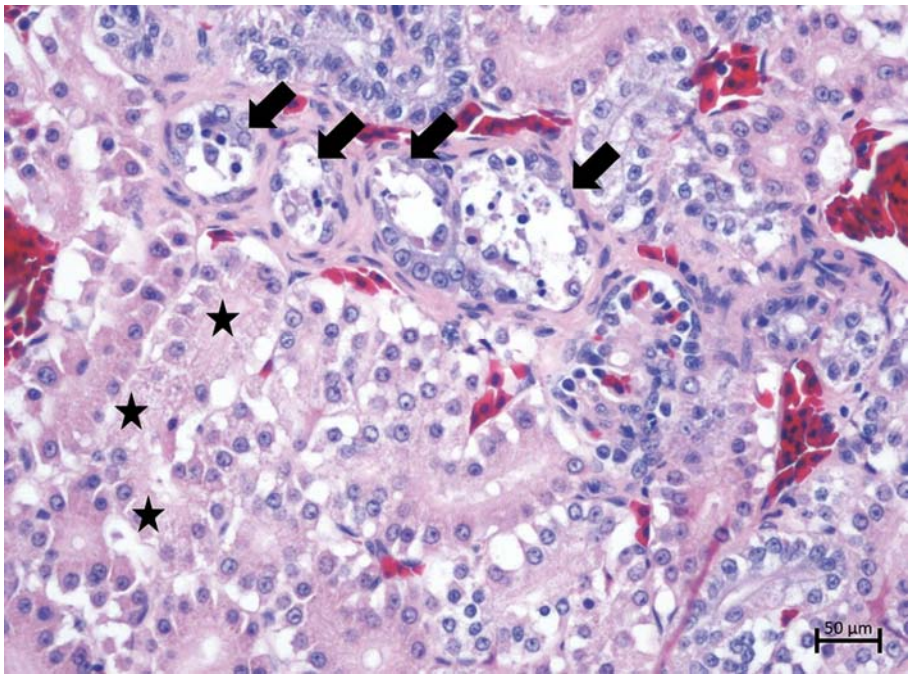

Figure 4. Kidney. Moderate, acute, multifocal widespread (proximal convoluted tubules) tubular hydropic swelling and necrosis (arrows). Hydropic swelling of renal tubular epithelium (stars). Photomicrograph of a cross section through the kidney a *Chamaesaura macrolepis* (Cope 1862) specimen. Haematoxylin and eosin staining, 400× magnification.

Exertion myopathy (also synonymously known as capture myopathy, exertion rhabdomyolysis, stress myopathy, transit myopathy, muscular dystrophy and white muscle disease (Jarrett et al. 1964; Spraker 1993)) can be defined as a pathologic syndrome where extensive muscle (cardiac and skeletal) injury and associated pathophysiological events are pivotal to the condition (Harthoorn 1976; Bartsch et al. 1977). This syndrome is a well-known condition in a variety of animal species, especially mammals, observed with sustained maximum muscular (cardiac and skeletal) activity, most often associated with capture evets of wildlife (Breed et al. 2019). It has also been recorded in some reptiles, such as marine turtles (e.g. *Chelonia mydas* (Linnaeus 1758) in Phillips et al. 2015) and crocodiles (e.g. *Crocodylus porosus* Schneider 1801 in Seymour et al. 1987), when individuals have undergone prolonged strenuous activity struggling against restraint. It should be noted, however, that exertion myopathy has not been adequately described or studied in reptiles (Phillips et al. 2015) and no reports of fire-associated exertion myopathy could be found for any other animal taxa in the available literature. Clinically in other animal groups, exertion myopathy has been observed to result in lethargy, muscle stiffness, weakness, and partial paralysis (Breed et al. 2019), impeding mobility. In addition to its anatomical locomotory disadvantages in non-vegetated substrates, members of *Chamaesaura* would therefore be further hampered to avoid vehicular traffic, while suffering from this syndrome.

When comparing the distribution of mortalities across the width of the surveyed road, most of the observed specimens ($n = 25$) were observed between one and three metres from the burned western side of the road (sectors 1 and 2), followed by the centre of the road ($n = 10$) (sector 3), with only two individuals making it to the eastern side of the road, before being driven over (sectors 4 and 5). This may indicate the synergetic constraints imposed on individuals when exertion myopathy and unhospitable terrain combine to hamper mobility,

leading to an increased chance of being hit by vehicles. Individuals might also have succumbed to the lethal effects of myopathy itself, as illustrated by the non-damaged specimens, collected from the western road shoulder.

Histopathological analysis identified pathologic changes in skeletal and myocardial musculature consistent with acute exertion myopathy in the three examined *C. macrolepis* specimens, likely brought on by prolonged high-energy locomotive activity to avoid fire. The influence of fire on *Chamaesaura* populations has been shown to be significant, because of their reliance on the grass layer (Du Toit 2001; Boycott 2015). This observation documents a likely fire-driven mechanism potentially contributing to elevated mortality rates for *Chamaesaura* in areas bordering road infrastructure. The development and expansion of road networks across the rage of these lizards, and the predicted influence of climate change on the general fire regime of the region (e.g. Hoffman et al. 2009), are likely to increasingly influence the survival of *Chamaesaura macrolepis* populations (Bates 2014), as well as other members of the genus. The conservation of these species would likely benefit from additional studies aimed at doing short-term and long-term research describing the recovery of populations following fire events and associated ecological implications for this genus, building on the work of Boycott (2015), as well as observing the direct responses and pathology of *Chamaesaura* sp. and other similar reptile species, such as *Tetradactylus* Merrem 1820, to fires.

Acknowledgements

Specimen collection was done during the first author's tenure as Lubombo Transfrontier Conservation Area Scientific Technician for Maputo Special Reserve and Tembe Elephant Park 2018–2020. The position was funded by the Deutsche Gesellschaft für Internationale Zusammenarbeit via the Peace Parks Foundation. The collection and transport of specimens was organised and sanctioned via the Administracao Nacional das Areas de Conservacao. The histopathological analyses were done at the department of Paraclinical Sciences at the Faculty of Veterinary Sciences, University of Pretoria.

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