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Decomposition of *Equus caballus* roadkilled in the brazilian semi-arid region: temperature and vultures accelerate the decomposition process

Decomposição de Equus caballus *atropelado na região semiárida brasileira: temperatura e urubus aceleram o processo de decomposição*

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ABSTRACT: Roads play a vital role in the socioeconomic development of modern society, facilitating the transportation of goods and passengers between different locations. However, they are also a major driver of biodiversity loss, primarily due to the direct impact of animal roadkill. The carcasses resulting from these accidents are a rich source of nutrients for a variety of decomposer organisms, including arthropods, vertebrates, fungi, and bacteria. The decomposition process of a carcass follows a series of distinct stages, influenced by both abiotic and biotic factors such as temperature, humidity, the presence of scavengers, and characteristics of the surrounding vegetation. Scavengers, such as vultures, are essential for nutrient recycling and maintaining environmental health by preventing the proliferation of pathogenic organisms. This case study investigated the decomposition of a horse carcass in a Caatinga environment, observing the presence of invertebrate and vertebrate scavengers. The results indicated that vultures significantly accelerated the decomposition process, leading the carcass to the skeletal decomposition stage in just a few days. Additionally, local environmental factors such as temperature and precipitation played an important role in the decomposition rate. These findings suggest that, in addition to causing biodiversity loss, roadkill can be a valuable resource for scavengers, influencing the dynamics of carcass decomposition and removal.

KEYWORDS: *Coragyps atratus*; caatinga; necrophagic agents.

RESUMO: As estradas desempenham um papel vital no desenvolvimento socioeconômico da sociedade moderna, facilitando o transporte de mercadorias e passageiros entre diferentes locais. No entanto, elas também são um dos principais fatores de perda de biodiversidade, principalmente devido ao impacto direto dos atropelamentos de animais. As carcaças resultantes desses acidentes são uma rica fonte de nutrientes para uma variedade de organismos decompositores, incluindo artrópodes, vertebrados, fungos e bactérias. O processo de decomposição de uma carcaça segue uma série de estágios distintos, influenciados por fatores abióticos e bióticos, como temperatura, umidade, presença de necrófagos e características da vegetação circundante. Necrófagos, como os urubus, são essenciais para a reciclagem de nutrientes e para a manutenção da saúde ambiental, ao prevenir a proliferação de organismos patogênicos. Este estudo de caso investigou a decomposição de uma carcaça de cavalo em um ambiente de Caatinga, observando a presença de necrófagos invertebrados e vertebrados. Os resultados indicaram que os urubus aceleraram significativamente o processo de decomposição, levando a carcaça ao estágio de decomposição esquelética em apenas alguns dias. Além disso, fatores ambientais locais, como temperatura e precipitação, desempenharam um papel importante na taxa de decomposição. Esses achados sugerem que, além de causar perda de biodiversidade, os atropelamentos podem ser um recurso valioso para necrófagos, influenciando a dinâmica da decomposição e remoção das carcaças.

PALAVRAS-CHAVE: *Coragyps atratus*; caatinga; agentes necrofágicos.

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INTRODUCTION

Roads are vital to the socioeconomic development of modern society, through the transportation of goods and passengers between different locations (Oliveira, 2013; Ribeiro; Laranja; Barbieri, 2022). However, roads are also a major driver of the loss of biodiversity, generating impacts through their construction, maintenance, and operation (Oliveira, 2013; Santos; Carvalho; Mira, 2011). Roadkill is the most obvious direct impact, which causes the loss of large numbers of individuals of many different animal species (Santos; Carvalho; Mira, 2011; Ratton; Secco; Rosa, 2014; Bezerra *et al,* 2018; Ferreguetti *et al*, 2020; Ribeiro; Laranja; Barbieri, 2022).

Animal carcasses are a potentially rich source of easily acquired nutrients for many organisms (Lira *et al*, 2020). These nutrients are released gradually during the decomposition process, which typically follows a standard pattern, beginning with the death of the animal, followed by the initial bloating of the carcass, and the arrival of detritivores, such as arthropods and vertebrates, as well as fungi and bacteria (Cruz; Vasconcelos, 2006; Hilal *et al*, 2021). While the stages of degradative succession tend to vary little, the velocity of this process will depend on the local environmental parameters, the condition of the carcass and the presence of decomposer organisms (Voss; Forbes; Dadour, 2008; Naves-Alegre *et al*, 2021).

Previous studies (Voss; Forbes; Dadour, 2008; Brooks; Sutton, 2018; Lira *et al*, 2020) have divided the decomposition process into five successive, and visually-identifiable stages: (1) fresh, from the death of the animal to the onset of bloating, (2) bloated, when the carcass swells due to the production of gases by the bacteria present in the animal, (3) humid decomposition, during which the skin ruptures and the liquid inside the carcass extravases, (4) dry decomposition, when the quantity of liquid and other soft tissue decreases abruptly, and the dry matter (skin, cartilage, and bone) predominates, and (5) skeletal decomposition, which is the final stage, when all soft tissue has been eradicated.

Abiotic parameters, such as the season, temperature, humidity, and precipitation (Voss; Forbes; Dadour, 2008; Naves-Alegre *et al*, 2021), as well as the characteristics of the road, such as the type of surface (paved, unpaved), traffic levels, and location (Ratton; Secco; Rosa, 2014), are all important determinants of the velocity of the decomposition of the carcasses of animals killed by traffic. Other factors, such as the size of the carcass, the presence and abundance of obligate and facultative necrophages (scavengers), predators, fungi, and bacteria, and the characteristics of the surrounding vegetation, all have a direct influence on the amount of time a roadkill carcass will persist on the road (Ratton; Secco; Rosa, 2014; Smith; Laatsch; Beasley, 2017; Naves-Alegre *et al*, 2021).

Scavengers are an essential component of any ecosystem, given that they contribute to nutrient recycling, as well as being sanitary agents, which inhibit the proliferation of opportunistic and potentially pathogenic organisms that may unbalance the system and impact the local human populations (O'Bryan *et al,* 2018; Choudhary; Chisthy; Bano, 2021; Turner; Conner; Beasley, 2021). One prominent example of this type of organism is the obligate avian scavengers (which depend on carrion), such as the New World vultures of the order Cathartiformes, specifically, the family Cathartidae (Naves-Alegre *et al*, 2021). These bird Family is highly efficient in the elimination of carcasses and tend to be dominant over most other scavengers in the acquisition of this resource (Olson; Bea; Rhodes, 2016; Lira *et al*, 2020). The presence of these obligate avian scavengers has a direct influence on the velocity at which the carcass is decomposed, due to their physiological adaptations for feeding on carrion, which enables them to consume larger amounts of this resource than invertebrate decomposers and facultative necrophages (Naves-Alegre *et al*, 2021).

The black vulture (*Coragyps atratus*) is an obligate necrophage (Ballejo *et al,* 2018), which has behavioral and morphological adaptations for the consumption of carrion, including an extremely acidic (low pH) stomach, urohidrosis for cleaning the legs, a lack of feathers on the head and neck, and relatively thick feathers at the base of the neck that are relatively impermeable to residues, in particular blood (Sick, 1997; Devault *et al*, 2016; Prusch *et al*, 2022). These vultures do not have a very well-developed olfactory system, however, and they forage for carrion primarily by flying at relatively high altitudes to maximize their field of vision, which enables them to spot potential feeding sites (Buckley, 1996). Black vultures are also synanthropic with humans, and inhabit open and semi-open areas (Martínez, 2019), where they take advantage of potential sources of nutrients made available by human activities (Ballejo *et al*, 2018).

Numerous studies have evaluated decomposition rates and the succession of the scavenging insect fauna, due primarily to the interest of forensic scientists in the decomposition rates of human corpses (e.g., Cruz; Vasconcelos, 2006; Voss; Forbes; Dadour, 2008; Pamponet *et al*, 2019; de Paula *et al,* 2020). Most of these studies have used pig (*Sus scrofa*) carcasses as models, given the physiological similarities of this animal with the human organism, to monitor the variation in the composition of the insect fauna over the course of the decomposition of the body, and define the stages in the degradation of the carcass. However, most of these studies overlook the participation of vertebrate scavengers, which may not only contribute to the decomposition of carcasses, but also compete with invertebrate decomposers (Inger *et al*, 2016; Lira *et al*, 2020). Decomposer vertebrates, such as scavenging birds that exhibit gregarious behavior and high population density, can influence the rate of decomposition of carcasses, which reduces the persistence time of carcasses in the environment and directly impacts the succession of the necrophagous invertebrate community (Lozano *et al,* 2019).

Given this, understanding the ecological roles and shifts in the community of scavenger organisms is important to determine how the variation in this community affects the

rate of removal of carcasses from the environment (Tobajas *et al,* 2021). However, relatively few data are available on the ecological role of obligate avian scavengers, and their contribution to carcass elimination rates, so the present study reports on the decomposition rates of the carcass of a horse (*Equus caballus*) over time, considering the presence of scavengers and decomposers, and in particular, black vultures, *C. atratus,* in an area of Caatinga dry forest, during the rainy season.

MATERIAL AND METHODS

The present case study took place on the Avenida do Contorno (-5.138154, -38.077464), a bypass highway located in the vicinity of the town of Limoeiro do Norte, in Ceará state, Brazil. This road has a total length of 13 km and is located within an area of Caatinga dry forest, in the São Francisco River Sertaneja Depression, and is characterized by a semi-arid climate with an average temperature of 28.5°C. The region experiences a rainy season from January to May and a dry season from July to December, with dense shrub vegetation (DNOCS, 2024; IPECE, 2024). The focus of the study was the carcass of a horse, which had died in a collision with traffic on April 29th, 2022. This carcass was found lying on the marginal bicycle lane and was thus outside the range of passing traffic.

The carcass was monitored by direct observation, with a 30-minute sample being obtained each day at 08:00 h, from 2 meters. This monitoring was conducted over a six-day period, from April 30th to May 5th, 2022, with an additional sample being collected seven days after the end of the initial period, on May 13th. All the information on temperature and precipitation was recorded in a spreadsheet and the carcass and associated fauna were photographed with a 48-megapixel cellphone camera, with a resolution of 720 x 1600 pixels (HD+).

The temperatures recorded on each day of the monitoring period were obtained from AccuWeather (www.accuweather.com/pt/br/brazil-weather) and the precipitation data were acquired from the Ceará State Foundation for Meteorology and Water Resources (FUNCEME - www.funceme.br) from the Limoeiro do Norte weather station (Table 1).

RESULTS AND DISCUSSIONS

The presence of scavenging insects found typically in decomposing carcasses was recorded throughout the decomposition process, which began on April 30th, when the carcass was still at the fresh stage, and ended on May 5th, when it was at the skeletal decomposition stage. These insects include various species of beetles (Coleoptera: Dermestidae, Scarabaeidae, and Silphidae), flies (Diptera: Sarcophagidae, Muscidae and Calliphoridae) and ants (Hymenoptera: Formicidae). The wake (flock) of *Coragyps atratus* was only present during the first three days of the monitoring period and the number of individuals present during the observation days ranged from nine to 13, however it is not known whether other local vertebrates visited the carcass at times outside the direct monitoring period, although several carnivores and facultative scavengers are known to inhabit the study area.

On April 30th, while the *E. caballus* carcass was still fresh, bloating had already begun, at a mean temperature of 27°C (Figure 1).

On May 1st (mean temperature = 28.5°C), a wake of *C. atratus* was observed feeding on the carcass, whose cranium was already partially exposed, and abdomen was perforated (Figure 2).

On May 2nd (mean temperature = 26°C), the carcass was already at the dry decomposition stage, with some remains of skin and hair, and exposed bones and with the extravasated stomach contents still moist (Figure 3).

The skull was the first part of the carcass to enter this phase (Figure 4).

During the final three days of monitoring, no vertebrate scavengers were observed visiting the carcass, despite the presence of the characteristic scavenging insect fauna mentioned above. On the final day (May 13th) in fact, no necrophagic activity was observed at the carcass and the stomach contents completely dried out. No major fragment of the carcass was removed from the site at any time during the monitoring period) (Figure 5).

Table 1. Ambient temperatures and precipitation recorded in Limoeiro do Norte, Ceará (Brazil), during the study period. Temperature data from AccuWeather (www.accuweather.com/pt/br/brazil-weather) and precipitation data from the Limoeiro do Norte weather station, Ceará Foundation for Meteorology and Water Resources (FUNCEME - www.funceme.br).

Day	Ambient temperature			Precipitation
	Minimum	Mean	Maximum	
30/04/2022	23°C	27.0°C	31°C	0,0 mm
01/05/2022	26°C	28.5°C	31°C	0,0 mm
02/05/2022	25°C	27.5°C	30°C	0,0 mm
03/05/2022	26°C	29.0°C	32°C	2.5 mm
04/05/2022	22°C	26.0°C	30°C	2,0 mm
05/05/2022	22°C	26.0°C	30°C	1,0 mm
13/05/2022	24°C	26.0°C	28°C	0,0 mm

Source: author's collection.

Figure 1. Initial scenario in the decomposition of the horse (*Equus caballus*) carcass on 04/30/2022, at the margin of the Avenida do Contorno, near Limoeiro do Norte, in Ceará state, northeastern Brazil. The carcass presents incipient bloating due to the production of gases by bacteria.

Source: author's collection.

Figure 2. Beginning of the humid decomposition stage of the *Equus caballus* carcass (05/01/2022), following the rupture of the skin and the release of the liquid contained in the body, with the presence of a wake of black vultures, *Coragyps atratus*.

Source: author's collection.

Figure 3. Dry decomposition in the horse carcass (05/02/2022), showing the reduction of the soft tissue and liquids. The red arrow indicates the stomach contents, which are still humid.

Source: author's collection.

Figure 4. Cranium of *Equus caballus* in the dry decomposition stage, with no liquid or residues of soft tissue, except for the skin.

Source: author's collection.

Figure 5. Skeletization stage of the *Equus caballus* carcass (05/13/2022), with no remaining liquid, and a complete absence of scavengers.

Indirectly, roads may often facilitate the access of scavengers to feeding resources, given their dependence on events of mortality to obtain nutrients. Roadkill may thus represent an extremely valuable resource for these species, given its relative abundance and predictability. However, carcass decomposition rates may vary according to the scavenger species that exploit this resource, in particular obligate necrophagous birds, as well as local environmental conditions. These processes are difficult to investigate in the case of roadkill events at sites that cannot be monitored daily.

The carcass of an animal is an extremely valuable nutritional resource in the natural environment and tends to become the focus of competitive interactions between vertebrate and invertebrate scavengers, which may be influenced by abiotic factors, such as ambient temperatures, relative humidity, and precipitation (Inger *et al*, 2016). Carcasses of large-bodied herbivores are an essential source of energy and nutrients for scavengers that recycle organic matter and contribute to the upkeep of ecosystems by cycling matter through the trophic web (Fielding *et al*, 2014). The results of the present study indicate that the skeletization of carcasses of large size may be relatively rapid due to the efficient behavior of avian scavengers, in contrast the action of invertebrate decomposers, where the decomposition process is more gradual, which are specialized for the detection and exploitation of this type of resource (Ballejo *et al,* 2018). These birds are able to maximize their exploitation of the resource and overcome the competition from other scavengers, due to the physiological adaptations for obligate necrophagy, associated with their flight capacity and acute vision, which not only facilitate the detection of carcasses, but also allow the bird to arrive rapidly at the feeding sites (Naves-Alegre *et al*, 2021). These adaptations are especially advantageous in open, anthropogenic landscapes (Hill *et al,* 2018). These vertebrates make the most of the resources, dominating the competition against other scavengers. The growth of these populations is associated with the availability and predictability of food due to anthropogenic actions, which corresponds with findings from other studies in the literature (e.g. Inger *et al*, 2016; Plaza; Lambertucci, 2018; Naves-Alegre *et al*, 2021).

In a study of the characteristic insect fauna associated with a pig (*S. scrofa domesticus*) carcass in a controlled environment, Cruz; Vasconcelos (2006) found that arthropods alone took approximately 30 days to reduce the carcass to the dry decomposition stage. Voss; Forbes; Dadour (2008) and Malainey; Anderson (2020), in turn, found that the decomposition of a pig carcass placed inside an automobile took three or four days less than the normal process, due to the higher temperature inside the vehicle, which favored the development of the insects. In this case, the carcass took 27 days to reach the skeletization stage. Santos; Carvalho; Mira (2011) observed that the persistence time of exposed carcasses on roads varied in accordance with the action of vertebrate scavengers (presence of obligate or facultative necrophages), the abiotic characteristics of the environment (temperature, precipitation, relative humidity), and the characteristics of the road (flow of traffic, type of surface [paved/unpaved], and visibility). Depending on the scenario, a carcass may decompose, be dismembered, or even removed completely.

In a study of the efficiency of the removal of carcasses of pigs by vertebrates, Lira *et al,* (2020) found that, while a carcass persisted for 8 days in the rainy season, it lasted 14 days in the dry season. Olson; Bea; Rhodes (2016) and Hill *et al,* (2018) found that the elimination rates of carcasses decreased in the absence of avian scavengers, despite the elimination of the competition presented by these birds. In the Cerrado savanna of central Brazil, Naves-Alegre *et al*, (2021) found that a majority of the carcasses were consumed by vertebrate scavengers, principally vultures, which were also the first animals to find the carcasses, as well as preferring carcasses of larger size. *Coragyps atratus* was also the most frequent species at carcasses and spent the most time feeding on these resources during the study. These findings are consistent with those of the present study, which showed that obligate avian scavengers increase the velocity of the elimination of a carcass, compared to a scenario without the presence of vertebrate decomposers.

Data from long-term studies in road ecology, in which the monitoring period is longer than the decomposition time of the carcasses, are extremely important for the understanding of decomposition patterns, and the potential for the disappearance of a carcass. This is because there can be significant loss in the count of road-killed animals, affecting the actual number of animals killed by vehicles. This information will contribute to data loss calculations and to define monitoring intervals for bodies of roadkill. Given this, it is essential to identify the factors that contribute to the disappearance of a carcass, which can vary considerably among different regions (Santos, 2011). This will be important for the establishment of standardized monitoring procedures that minimize the loss of information, as long as resources are available for the sampling activities, and logistic considerations do not constitute a limiting factor.

The present case study showed that a carcass of large size can be decomposed rapidly through the action of obligate avian scavengers during the rainy season of the semiarid Caatinga biome. In other words, variations in the composition of decomposer agents present in the environment, associated with abiotic factors, will affect the variations in the rate of decomposition according to each region.

CONCLUSIONS

Given the high temperatures and extreme seasonal variation in the Caatinga, future studies of the succession of the scavenging insect fauna and the competition for carcasses between this fauna and vertebrate scavengers may help to elucidate important issues. The activity of the entomofauna

characteristic of this environment may, under certain circumstances, surpass that of vertebrates, particularly during dry periods. Carcass partitioning between invertebrates and vertebrates may also be influenced by seasonal conditions, and in areas with higher traffic volumes, anthropogenic interference could favor invertebrates in the decomposition process. Additionally, temperature variation on asphalt may provide advantages to invertebrates, making them dominant in the carcass decomposition process.

The present study describes the relatively rapid decomposition of a horse carcass though the action of obligate avian scavengers (vultures) during the rainy season in the semiarid Caatinga biome of northeastern Brazil. Future studies that cover seasonal variation and the interaction between vertebrate and invertebrate scavengers should provide further insights into the dynamics of this process in different environments. Overall, the findings of the present study indicate that, in addition to the loss of biodiversity through collisions with traffic, studies in road ecology should also focus more systematically on the fauna that decomposes and removes carcasses, for the planning of more effective monitoring strategies and the development of adequate management measures.

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