Research Article

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Domestic dogs as a threat to sloths in Costa Rica: A clinical case report and review of the problem

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Abstract: Human-introduced predators, primarily the domestic dog (*Canis lupus familiaris*), and human-modified landscapes conjointly threaten wildlife across Costa Rica. For arboreal species, including the two-fingered sloth (*Choloepus hoffmani*), the impact of domestic dogs is amplified in areas of habitat fragmentation. In efforts to navigate discontinuous canopies associated with urban development and human encroachment, *C. hoffmani* is forced to utilize terrestrial locomotion. This unnatural behavior leaves sloths increasingly vulnerable to predation by domestic dogs, which occupy altered landscapes in high densities. In this report, we detail the ante and postmortem findings associated with *C. hoffmani* following an extensive attack by three large-breed dogs. The patient sustained severe and fatal polytraumatic injuries targeting the abdominothoracic region. Gross lesions were not readily evident, obscured by unique anatomical characteristics of the species. This report aims to highlight the threat imposed by dogs to sloths and the severity of injuries, with considerations for clinical management in light of *C. hoffmani* morphology. We review the scope of domestic dog–wildlife conflict in Costa Rica, and propose collaborative mitigation strategies including habitat preservation, domestic dog population control, installation of wildlife corridors, policy initiatives, and dog owner education and public outreach.

Keywords: sloth, *Choloepus hoffmanni*, invasive predator, anthropogenic disturbance, *Canis lupus familiaris*, necropsy

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1 Introduction

1.1 Domestic dogs as invasive predators in the Anthropocene

Anthropogenic disturbances represent increasingly pervasive threats to native fauna [1–6]. One of the most prominent drivers of biodiversity loss and homogenization is the introduction and establishment of invasive species [7,8]. Many domestic animals of non-native taxa serve as human-subsidized predators and cause substantial wildlife mortality annually [9–12]. Domestic dogs (*Canis lupus familiaris*) in particular, including owned and feral, threaten a wide variety of species globally [13–26]. These canids have become a notable and ubiquitous conservation challenge, ranking just below cats and rats as the third most-damaging invasive predator [8].

Urbanization is one of the most impactful anthropogenic activities and closely amalgamated with domestic dog–wildlife conflict [27–29]. The occurrence and density of dogs around native habitats are heavily influenced by surrounding urban development [30,31]. Human-modified landscapes that transect or edge wildlife zones often present a high abundance of feral and owned dogs [32,33]. In rural or peri-urban (i.e., urban-rural interface) landscapes bordering forests, dogs often roam freely regardless of ownership status [34,35]. Their presence in protected areas and extensive spatiotemporal range has been well documented [32,36–39]. Domestic dog occupancy is more geographically extensive and influenced to a greater degree by anthropogenic features than other invasive predators, including cats [40]. Human activity thus plays a significant role in the distribution of dogs in wildlife areas and represents a means of intervention when addressing the problem [10,41,42].

1.2 The impact of domestic dogs on wildlife

Domestic dogs threaten native fauna through both direct and indirect routes [11,43]. Indirect threats include

disease transmission [44–49], competition [18,50,51], and hybridization of [52–54] wildlife. Their presence alone may influence the vigilance [55], distribution and land use [56–59], reproduction [60], and feeding habits [55] of wild species. Although these indirect effects are non-negligible, predation continues to be the predominant threat imposed by dogs, and the prevalence of attacks on wildlife continues to rise [21,25,43,61–63]. Domestic dogs have aided 11 vertebrate extinctions and continue to threaten 188 other species, although the true impact is likely underestimated [11,64]. This predation is often recreational as it does not involve consumption of prey [65,66]. Cases of true predation by domestic dogs (i.e., wildlife is consumed) are typically driven by hunger and associated with underfeeding by owners. This scarcity of human-provided resources increases the probability of dog attacks on wildlife species [58].

Information regarding the density and distribution of domestic dogs is often lacking [67,68]. Globally, the population size is estimated to be over 700 million, ranking this species as the most abundant carnivore [11]. In Costa Rica, there were approximately 580,000 dogs in 2011, with an average of 20 dogs per 100 people [69]. A large portion of these dogs are allowed to roam freely, with only 3% living primarily indoors [69–71]. Despite the scale of the problem, and excluding the use of dogs for hunting by humans, there is limited literature documenting attacks on wildlife in Costa Rica [72–74]. Dog attacks on native Costa Rican species have been documented for Howler monkeys (*Alouatta palliata*) [75], birds [76], and sea turtles [77–80] in the country and the nine-banded armadillo [13], lowland tapir [13,81], and coati [21] in other geographic locations.

1.3 Domestic dog attacks on sloths

Domestic dogs present a considerable threat to sloths inhabiting Costa Rica, including the Hoffman's two-fingered (*Choloepus hoffmani*) and brown-throated three-fingered (*Bradypus variegatus*) sloth [82,83]. Numerous wildlife hospitals informally describe dog attacks as a leading cause of sloth intakes [84–88]; yet, literature documenting the phenomenon is sparse. *C. hoffmani* was reported as a victim to dogs in a 2017 publication, although details on the attack are not provided [83]. Likewise, another study reported local farmers identifying dogs as a predator to the species. This was followed by descriptions of two sloth carcasses that had been preyed upon, although the source of the attack is uncertain [82].

In the case of *C. hoffmanni*, loss of forest connectivity [89] in conjunction with the presence of domestic dogs has grave consequences [82]. Intact forests are an essential habitat component for this arboreal species, providing a means of locomotion, refuge, and nourishment [90–92]. In Costa Rica, anthropogenically changed landscapes have grown to unprecedented levels [93,94]. The negative effects of this tropical deforestation and habitat fragmentation have been documented for multiple sloth species, including *C. hoffmani*, in terms of altered dispersal, behavior, and survival [82,89,95–99].

As primary folivores, *C. hoffmani* maintains a niche diet that renders them highly dependent on available and accessible trees [100,101]. To satisfy these dietary requirements, sloths are both capable and willing to travel long distances to locate appropriate foliage [82]. Like other arboreal folivores, this characteristic leaves *C. hoffmanni* disproportionately susceptible to habitat loss, as they are unable to switch resources when their environment is degraded [102]. In the face of habitat fragmentation, food becomes diminished through loss of tree diversity and less accessible through reduced canopy connectivity [103,104]. As a result, *C. hoffmanni* is forced to travel further distances, enter unfavorable and novel environments, and modify their means of locomotion by climbing on the ground to navigate between trees [82,98].

In pristine forest, *C. hoffmani* historically avoids leaving the canopy, only descending to the forest floor once a week for elimination activities (i.e., urination, defecation) [105–107]. Descent to the ground, even in undisturbed forest, presents major predation risks to sloths by species including ocelots, jaguars, pumas, tayras, and spectacled owls [107,108]. However, the presence of domestic dogs in fragmented habitats makes the ground an increasingly dangerous place for sloths to navigate. This is due to both the abundance of dogs relative to elusive wildlife predators, and increased travel distance associated with transected habitats for sloths [10,82]. Unfortunately for *C. hoffmani*, the terrestrial locomotion of this species has been described as laborious and clumsy, rendering them exceptionally vulnerable to predators on the ground [90]. The complex mosaic of human-modified landscapes and human-subsidized predators as they relate to arboreal species must be considered in parallel. As human activity excessively fragments forest, sloths are forced to adapt unnatural ambulation (i.e., sternal crawling on the ground) where they are exposed to and attacked by domestic dogs [96,109].

1.4 Dog attack injuries: clinical considerations

The anatomical makeup of carnivores allows domestic dogs to inflict tremendous bite force through a combination of shearing, tensile, and compressive mechanisms [110–114]. Bites sustained from dogs therefore tend to be severe and often fatal, inciting crush, tear, and avulsion injuries [115,116]. Wounds sustained by companion species (i.e., other dogs and cats) are described as deceptive, with more damage occurring to deeper organs than the skin and subcutis [112,117–119]. Despite being common targets of attacks, there is little information available on the presentation of dog bite wounds in wild or exotic species [120,121]. This is significant given that predation by domestic dogs on wildlife is rarely observed [120]. Identifying these injuries in uncommon species may therefore be challenging, leading to an underestimated prevalence of these attacks and improper case management.

When wildlife requires medical care, rapid intake evaluation is vital in minimizing the stress and suffering of patients [122–124]. Deciding the fate of undomesticated animals should occur in a timely manner and obtaining a prompt clinical diagnosis is crucial in making said decision [123,125]. Documenting common presentations of wildlife injuries, such as dog attacks, in a taxonomic-specific context is therefore essential for improved recognition and management [120,126,127]. This is particularly important in the evaluation of morphologically unique species, where traditional information may not be extrapolatable [120,128,129].

Moreover, publications on the clinical nature of dog attack injuries in wildlife are limited. Variation in the presentation and topography of wounds across taxa is described in one study [130]. However, the incorporation of morphological information for each species is not described. A single report touches upon the clinical presentation of dog attacks in *C. hoffmani* specifically. Nonetheless, the information is limited due to the publication maintaining a broader focus on the species [83]. The lack of resources on traumatic dog attacks in sloths is especially unfavorable given the species' distinct anatomical makeup [131,132] as well as the upward trend in these events across sloths' ranges [63]. The purpose of this report is to describe the clinical presentation and postmortem lesions observed in *C. hoffmani* following an attack by dogs, with special consideration to morphology, behavior, and conservation of the species. In addition, this report aims to document the threat that domestic dogs pose to *C. hoffmani* and other wildlife in Costa Rica.

2 Case report

A subadult Hoffman's two-fingered sloth presented to The Sloth Institute (TSI) in June of 2022 following an attack by domestic dogs. TSI is a nonprofit wildlife rehabilitation and research center located in the Puntarenas Province of Costa Rica. The incident occurred on a nearby residential property, in the area of Manuel Antonio, Costa Rica (9.3923°N, 84.1370°W). A good Samaritan witnessed the attack and reported the involvement of three dogs, including two Doberman Pinschers and one Rottweiler. The dogs were seen mauling the sloth on the ground as it attempted to escape to a nearby tree. The dogs did not consume the sloth and eventually retreated after a prolonged period of attacking. Access to the injured animal was not possible until the following morning when the individual promptly retrieved the patient and contacted center staff. The sloth was found on the ground, in a curled resting position, and presumed dead (Figure 1).

Upon arrival, the patient was in lateral recumbency and did not resist being handled. Examination revealed that the patient was comatose, hypothermic, and apneic. Auscultation revealed absent lung sounds in all fields bilaterally despite having clear airways. The patient was bradycardic per species-specific parameters (<40 beats per minute) and had weak but synchronous femoral pulses. Dorsal pedal pulses were absent bilaterally. Throughout examination, the degree of bradycardia progressively worsened. The patient showed signs of impaired perfusion, demonstrated by pale mucous membranes, a prolonged capillary refill time, and cold extremities on palpation. Neurologic deficits were also evident. There was no indirect or direct pupillary light reflex, and the patient's pupils were

Figure 1: *C. hoffmani* immediately following attack by domestic dogs, assuming abnormal resting posture at the tree base. Typically, the species will quickly ascend back to the canopy following brief visits to the forest floor. Photograph taken by rescuer.

severely mydriatic. Menace and palpebral reflexes were diminished, and deep pain responses were impaired on all limbs. The patient was mildly dehydrated and had minor bilateral sinking of the eyes. The patient was in adequate body condition at 4.3 kg.

The patient's hair was wet but intact, with no obvious signs of injury visualized (Figure 2a). Parting of the hair and examination of the skin revealed soft tissue damage, including moderate bruising and superficial abrasions distributed around the cervical region, dorsum, and ventral abdomen (Figure 2b). Small puncture wounds (0.5–3 cm) were located around the left orbital cavity, left cervical spine, left abdomen, and dorsal pelvis. Petechiae were noted on both the left and right pinna. Ecchymoses were present along the ribs, entire dorsum, and proximal left fore and hindlimb. There was a large, irregular-shaped, and circumferential band of bruising on the distal neck, potentially compatible with being bitten in this region and shaken by the dogs during attack. Palpation of skeletal structures was unremarkable, with no obvious fractures or disarticulations noted and normal range of motion. The abdomen was soft on palpation, with no pronounced signs of organomegaly. All remaining structures were unremarkable on physical examination.

Attempts to stabilize the patient (i.e., airway establishment, fluid resuscitation, atropine administration) were underway while the patient was being evaluated initially. However, these efforts were discontinued shortly after the grave condition was recognized. While preparing for humane euthanasia, the patient died without medical assistance just minutes following arrival to the clinic. At that time, a pink frothy liquid was noted in the nares bilaterally.

Immediately following death, a modified abdominal and thoracic point of care ultrasound was performed for teaching purposes. There was a moderate volume of anechoic free peritoneal fluid present bilaterally. However, no fluid could be recovered via abdominocentesis. A mild

Figure 2: Postmortem images of *C. hoffmani* carcass following attack by domestic dogs. Pictured in (a) sternal recumbency with no discernible signs of traumatic injury and (b) lateral recumbency with hair parted to reveal moderate bruising along the dorsal thorax. Complete removal of the hair revealed (c) numerous lacerations, puncture wounds, and subcutaneous hemorrhage on the dorsum, as well as (d) extensive bruising on the left lateral thorax and proximal forelimb.

amount of free intraperitoneal air was also evident. Examination of the thorax revealed a small volume of anechoic pleural effusion. Multiple, adjacent hyperechoic pulmonary B-lines or lung rockets were noted as well.

The patient was preserved via refrigeration until radiographs could be obtained to further assess skeletal injury (Figure 3) and necropsy could be completed. Radiographs revealed no orthopedic injuries in the patient despite the degree of soft tissue injury and reported force of the attack. Open epiphyseal growth plates were noted bilaterally on the distal radius, denoting the sloth as a subadult. All other abnormalities were attributed to radiographic positioning or normal postmortem change.

On necropsy, the carcass was found to be in good postmortem and adequate nutritional condition. Upon removal of hair, extensive traumatic injury was evident (Figure 2c and d). Thirty-five variably sized (0.5–2 cm) surface abrasions, most elongated with opposite angular edges, were noted on the patient and distributed throughout the entire dorsum, ventral thorax, left axilla, left cervical, and left auricular area. Cutaneous ecchymosis was present in the left mammary region, with three linear to oblong-shaped lesions ranging from 3 to 6 cm in length. Linear bruising was present along the neck, extending dorsally to laterally. There were six small (0.5–3 cm), circular to elongated puncture wounds, lacerating both subcutaneous tissue and muscle. These wounds were noted on the left neck, lateral abdomen, and dorsal pelvis. Multiple hemorrhages and hematomas were found, with distribution on the lateral neck, entire thorax and abdomen, proximal left fore and hindlimb, and dorsal pelvis (Figure 4a).

Light pink froth was noted in the trachea and bronchi and a moderate volume of serosanguinous fluid was present in the pleural cavity (Figure 4c). The lungs were slightly enlarged, diffusely red, and mottled. Marked, locally extensive, dark red to purple hemorrhage was present on all surfaces and lobes (Figure 4e and f). Focal areas of yellow discoloration were noted on the caudal aspect of the right and left caudal lung lobes. The texture was generally soft, with multifocal spots of firmness felt on the left caudal lobe. There were moderate-sized (2 cm) emphysematous bullae noted focally on the dorsal surface of the right cranial lobe and ventral surface of the right caudal lobe. A moderate amount of hemorrhagic fluid was present in the pericardial sac (Figure 4b). The heart was firm and otherwise unremarkable.

A moderate amount of serosanguinous fluid was noted in the peritoneal cavity as well. The stomach was of normal size for the species and contained appropriate ingesta. There was locally extensive bruising over the ventral aspect of the fundic and cardiac region (Figure 4d). Two small puncture wounds (0.5 cm) were noted on the caudoventral aspect of the fundus with hemorrhagically infiltrated edges. All other gastrointestinal structures were unremarkable. The bladder wall was firm and thickened, with mild petechiae present on the external surface. Bladder mucosa was coated by flocculant exudate and infoldings were noted. A moderate amount of purulent, frothy, white to yellow fluid was likewise noted. Reproductive organs were unremarkable and consistent with the radiographic findings which had confirmed the sloth to be a sexually immature, or subadult, female. No skeletal abnormalities were evident, and no gross lesions

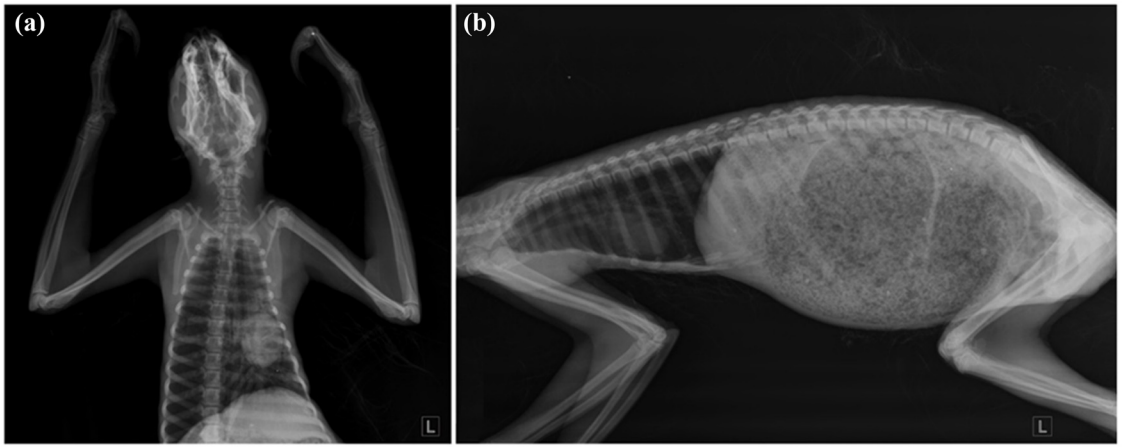

Figure 3: *C. hoffmani* radiographs obtained postmortem to assess for orthopedic injury. No skeletal injuries were noted on (a) dorsoventral or (b) left lateral views. All other findings are positional artifacts or attributable to postmortem change.

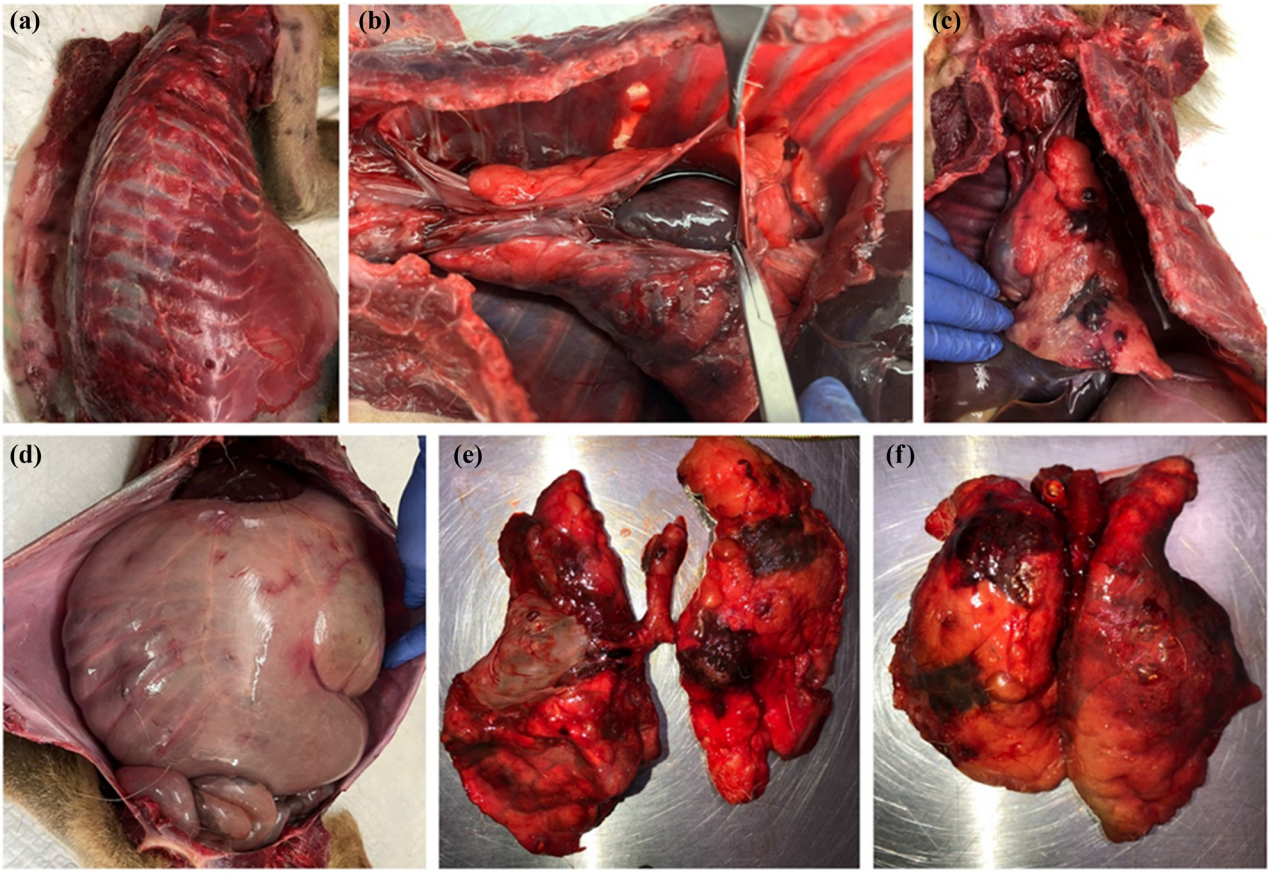

Figure 4: Gross pathological findings associated with *C. hoffmani* following attack by domestic dogs, including (a) subcutaneous hemorrhage and puncture wounds extending through gluteal muscle, presence of serosanguinous free fluid in the (b) pericardial and (c) pleural space, (d) contusions and puncture wounds on the ventral surface of the stomach, and hemorrhage and emphysema on (e) dorsal and (f) ventral views of the lungs.

were noted in the spinal region. Intracranial examination was not completed. All other findings were unremarkable.

Polytraumatic injury produced by repeated bites and blunt force associated with the attack was determined as the cause of death in this patient. Pleural and pericardial effusions, as demonstrated on necropsy, were presumed to cause the patient's apnea and impaired cardiopulmonary function. Severe hemorrhage and cavitary effusions suggest that the patient succumbed to hypovolemic shock. Substantial soft tissue injury was present, although penetrating wounds were minimal. The accumulation of blood under the skin and in muscle fascia suggests concurrent rupture of surrounding vasculature; however, the exact site of origin could not be identified. Finally, cystitis, as evident by signs of inflammation and infection in the bladder, was confirmed by necropsy. This may have been an inciting factor for the attack, precipitating the patient's descent from the tree to urinate despite unsafe conditions and the presence of dogs. Reviewing the timeline provided by the rescuer, it was determined that this sloth was attacked early in the evening and too weak to ascend back up the tree. The sloth likely remained stationary on the ground overnight where it slowly succumbed to its injuries before dying shortly after arrival to the clinic.

Ethical approval: The research related to animal use has been complied with all the relevant national regulations and institutional policies for the care and use of animals.

3 Discussion

3.1 Clinical management of *C. hoffmanni* following dog attacks

On initial examination, the extent of injury was not readily evident, given the coarse and thick nature of *C. hoffmanni* coat. The species maintains extremely dense

hair, which has been suggested to serve a variety of roles relevant to an arboreal lifestyle, including camouflage, thermal regulation, nutrient absorption, and redirection of water [133–137]. Likewise, a diverse microbial community of epibionts can be found in the coat, described as a "self-contained system of taxonomic diversity and trophic levels" [138]. Numerous algal, fungal, and bacterial organisms inhabit the hair of sloths and are believed to facilitate symbiosis with the species [136,138–140]. This morphology is important to consider clinically. Although this dense coat may mask the external injuries following attack, loss of hair may be detrimental to overall health and long-term survival [137]. This may likewise compromise a patient's suitability for release following recovery. Full body shaving of *C. hoffmanni* in this study was only conducted for research purposes and would rarely be appropriate premortem. Nonetheless, failure to recognize or treat dog-inflicted bite wounds without thorough evaluation may lead to infection, sepsis, and death. Although removal of the coat may be warranted at times to facilitate a more-thorough examination, shaving should be minimal in this species when possible.

The lack of external hemorrhage and minimal penetrating injury identified in the patient was unexpected given the length of time, number of dogs, and size of the breeds involved in the attack. Although dog bites are known to be deceptive in terms of skin and subcutaneous damage [119], reports of attacks with similarly sized species (i.e., large canids attacking small breed dogs and cats) often involve extensive deep wounds [141–143]. This finding is likely related to the excessively thick integument of *C. hoffmani*. Skin extends a depth of over 4 mm around the neck and throat, 3 mm on the dorsum, and 1–2 mm in other body regions [132]. To compare, the skin of a domestic canine may be as thin as 0.5 mm in dogs [144] and 0.4 mm in cats, although this is widely variable across breeds [145]. This composition may serve a protective role for *C. hoffmani* in terms of external trauma to the skin, although additional research is needed to support this hypothesis.

An almost complete absence of adipose tissue leaves the skin closely applied to the thick underlying musculature. Despite minimal subcutaneous and abdominal fat, including that of the omentum, adipose is present around renal structures and the spinal canal [132,135]. Contrastingly, abdominal organs, including a prominent stomach, sit closely against the body wall [83]. These structures may thus be more vulnerable to internal trauma than others, as demonstrated by this patient. Topographically, the sloth was targeted along the axial regions of the body, with appendages largely untouched. Likewise, the kidneys and vertebral regions were intact, with little visible damage on necropsy. This is likely related to both the distribution of adipose tissue and the form of locomotion adapted by *C. hoffmani* while on the ground (i.e., crawling in a sternal position).

Finally, no orthopedic injuries or long bone fractures were noted in the patient, despite limbs being a commonly reported site of dog attack injuries in other species [112]. The head was generally unscathed, and no skull injuries were evident. This may be related to the defensive mechanisms of *C. hoffmani*, which involve hissing, biting, and slashing with forelimb claws [146,147]. Unlike *Bradypus variegatus*, *C. hoffmani* possesses well-developed facial musculature and large, sharpened canines, allowing them to deliver forceful and damage-inflicting bites when threatened [83,131,148]. Although sloths demonstrate a reduction in muscle mass compared to other mammals, modified distal limb morphology grants them enhanced strength and endurance in their appendages [90,148–154]. These modifications support their suspensory posture and facilitate powerful flexor musculature [149], fatigue resistance [154], and grip strength exerted with minimal energy expenditure [155]. In addition, limbs lack bony processes, increasing mechanical advantage [151]. Compressive strength in the long bones of *C. hoffmani* is compromised. However, tensile strength is significantly enhanced to support suspensory function [156]. *C. hoffmani* may therefore be less susceptible to limb injuries inflicted by dog bites due to the strength and fluid nature of movement in these regions [83]. Predators may likewise avoid these areas during attack, given their potential to inflict damage. However, this is highly dependent on the nature of the bite inflicted [112]. Additional research is needed on the mechanics of *C. hoffmani* defense mechanisms to better understand the potential outcome.

These findings may be taken into consideration during evaluation of *C. hoffmanni* following traumatic dog attacks, with priority spots for examination involving the abdominothoracic region and underlying structures. Nevertheless, additional documentation of dog attacks is needed to determine patterns of injury for the species. The lack of marked external trauma, related to integument thickness and coat composition may lead practitioners to underestimate the magnitude of injuries. Additional diagnostic modalities were therefore of immense clinical value for this patient. Ultrasonography, radiology, and necropsy were essential in quantifying the extent of injury in *C. hoffmani*. Ultrasonography performed on the ventrum does not necessitate hair removal on this species, providing an excellent and truly noninvasive tool. Without these diagnostic aids and postmortem examination, this

patient's clinical presentation would have likely been deceiving. When available, these tools should be utilized for *C. hoffmani* patients following attack by domestic dogs to ensure timely premortem and accurate postmortem diagnosis.

3.2 Mitigating the impacts of dogs on sloths and other wildlife

Domestic dogs are understated threats to numerous wildlife species, including sloths, and the potential impacts are greater now than historically [157]. In the approaching decades, dog occupancy nearing natural habitats and attacks on wildlife are expected to increase in prevalence [9,11,19,31,43]. The status of Costa Rica as a biodiversity hotspot and rapidly urbanizing country makes this issue particularly critical [158,159]. Wildlife–dog conflict is well-documented as a consequence of anthropogenic origin and the socioecological components of this problem should be considered. It is essential that management strategies are attuned to cultural and regional values [160]. Likewise, a multifaceted approach must be maintained, given the issue's complexity. We discuss mitigation strategies, including (i) habitat preservation, (ii) domestic dog management and population control, (iii) wildlife corridors facilitating forest connectivity, (iv) owner education, and (v) government policy (Figure 5).

3.2.1 Habitat preservation

Mitigating wildlife–dog conflict begins with prevention in the context of global change [31,35]. Dynamic alterations in land use to accommodate urban infrastructure and agricultural expansion in Latin America have grown exponentially over the last decade. These changes continue to place pressure on wildlife [121,161–164]. Despite the success of national policies and programs enacted to preserve natural resources, Costa Rica still maintains the highest percentage of urban populations compared to other countries in Central America [93,165–171]. Manuel Antonio, the site in which this study occurred, holds the lowest rate of documented deforestation. However, over 90% of deforestation occurs in non-protected areas [170,172]. Numerous studies have demonstrated the value of protected areas and the restriction of dogs in these regions [31,56,172].

Although protected areas facilitate safer habitats for sloths and other wildlife, and reduced accessibility by dogs, this strategy alone is rarely effective [12,31,173]. Protected areas do not account for owner noncompliance, the movement of free-ranging dogs from adjacent lots, or the entry of wildlife onto residential property [28,38]. Likewise, the rate and magnitude of wildlife disturbance far exceeds the speed at which this strategy produces tangible results. Maintaining this strictly preservationist value (i.e., prohibiting human establishment near nature, solely focusing on pristine habitat preservation) is therefore of limited benefit to sloths and other wildlife in the Anthropocene. As urban expansion approaches a tipping point, a paradigm shift is essential [174,175]. Continued global change is inevitable and preserving habitats is crucial, but it must involve additional and complementary approaches [10,31,33,42,43,176–178].

3.2.2 Domestic dog management and population control

Traditional means of invasive predator management (i.e., physical removal, lethal control) have been highlighted as controversial, inhumane, and ineffective for domestic dogs, given their abundance and role as companion animals [179–181]. Nevertheless, addressing this issue represents a complex conservation challenge, given the interconnectedness of humans and dogs. The role and value of dogs in society, as companion animals and as working breeds, is not to be undermined [182,183]. When appropriately trained and supervised by human caretakers, dogs may have negligible, or even beneficial impacts on wildlife. This is demonstrated by their historical roles as conservation tools and livestock guardians [177,184–188]. Both positive and negative effects of domestic dogs must therefore be considered in an all-encompassing management approach [160].

The capture and transport of unsupervised free-ranging dogs to shelters has also been described as a canine-focused control strategy in some regions [189]. However, elimination of dogs without owners is unlikely to be successful in Costa Rica, given the overburdened and underfunded status of most humane organizations [69]. In addition, this does not target domestic dogs occupying less accessible regions of forest. Sterilization programs, residential fencing to restrict roaming, and barriers to prevent access to protected spaces have been suggested as the most effective canine control strategies [12,35,155]. Improved feeding and care of domestic dogs, through accessible and subsidized assistance, is also a means of mitigation [58,67]. However, even well-fed dogs pose a threat to wildlife. There are numerous reports of attack as a means of recreation for dogs rather than consumption [65,66]. TSI has never observed the consumption of

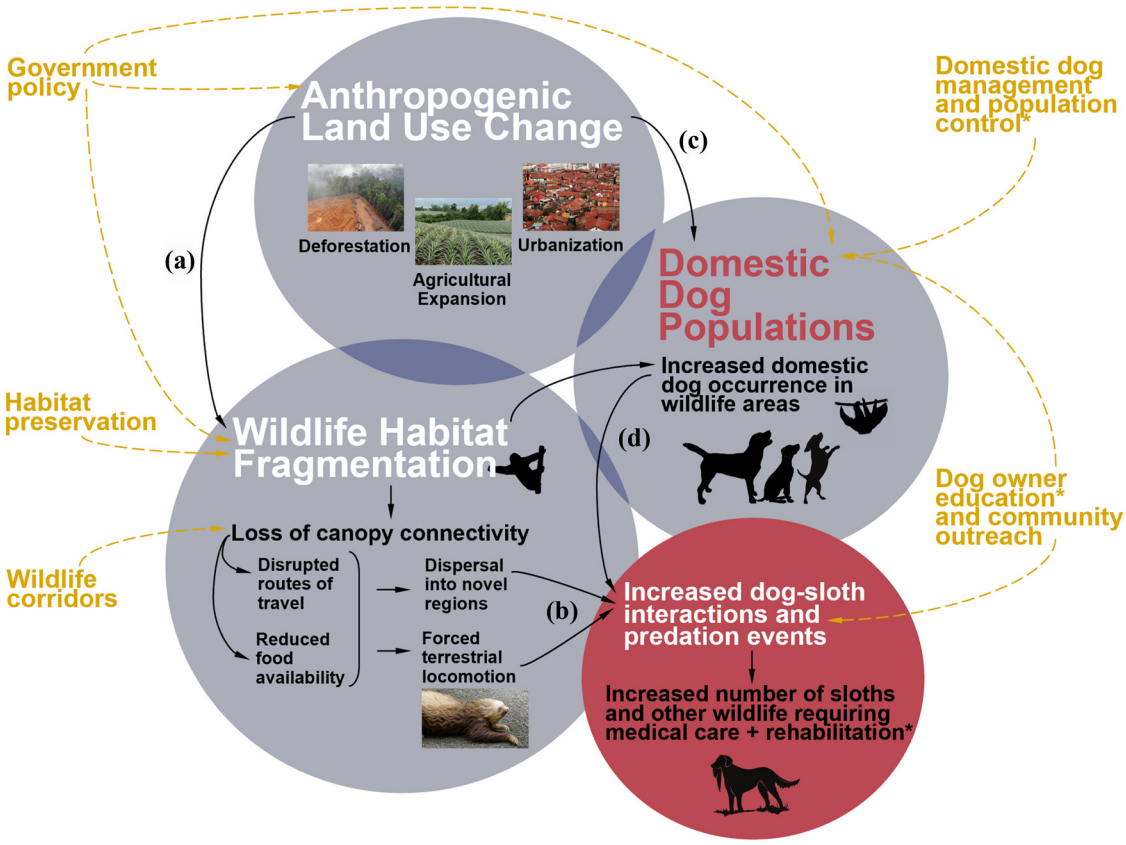

Figure 5: A collaborative approach to mitigate conflict between domestic dogs and sloths or other arboreal wildlife. Anthropogenic land use changes directly contribute to the degradation of wildlife habitats (a). Sloths are forced to enter novel environments in seek of resources and employ terrestrial locomotion in the face of discontinuous canopies (b). These land use changes likewise drive humans and their companion animals to forest edges or interiors (c), where domestic dog and sloths are then obliged to co-exist. The increased spatio-temporal overlap of dogs and sloths results in increased opportunities for predation (d) and resultant upticks of wildlife requiring medical care following these altercations. Addressing this problem requires a multifaceted approach, with target areas for intervention (yellow text and arrows) including habitat preservation, domestic dog management and population control, wildlife corridors facilitating forest connectivity, owner education, and government policy. Asterisks are used to denote interventions in which veterinary and other animal health professionals play a key role.

C. hoffmani or *B. variegatus* following attack. Other strategies for the control of domestic dogs have been suggested, but little research exists on intervention efficacy [9,41,160].

3.2.3 Wildlife corridors

Maintaining or restoring forest connectivity can substantially reduce the threats that domestic dogs pose to sloths and other arboreal species. Intact canopies provide safe routes for arboreal species to transverse and facilitate ease of movement between trees, eliminating unnecessary terrestrial locomotion [190–192]. When possible, the establishment or protection of natural canopy bridges should be pursued in areas with known wildlife–dog conflict. If canopy integrity cannot be naturally maintained, installation of artificial wildlife crossings should be completed [35,190,193–195]. Corridors in the form of rope bridges are a straightforward, inexpensive, and efficacious intervention [195–198]. Installation of these structures requires no specialized equipment, depending on tree height [196]. Rope of substantial thickness is typically utilized and securely placed between adjacent but disconnected trees [195–198].

These structures not only enable dog avoidance by sloths but also protect them from other anthropogenic threats such as electrocution or starvation due to the lack of tree access [35,194,199,200]. Corridors are also used to prevent vehicle collisions in areas where roads and other linear infrastructures transect vegetation [201,202]. The general success of these interventions in reducing wildlife mortality and use of corridors by animals in Costa has been

documented for a variety of native species [75,203,204]. Sloths, in particular, are frequent users of rope bridges [205,206]. Camera traps are often set up at artificial crossing sites to monitor animal use and for recreational viewing purposes [201].

As private lands intersect many natural habitats in the country [170], including that of sloths, outreach programs facilitating public willingness to allow these modifications are essential [40]. Contrarily, strategic tree trimming has been used for other species as a means to redirect and prevent access to certain areas [207]. There may be implications for this method in problem spots (i.e., fenced yards with dogs known to target wildlife) to deter use or congregation by sloths and other species. Additional research is needed to determine the efficacy of this strategy.

3.2.4 Owner education and veterinary engagement

The impact of domestic dogs on wildlife is highly dependent on responsible ownership and the key role of dog owners is highlighted in various studies [10,12,58]. Human behavior directly influences the movement and activity of dogs pertaining to wildlife [33,42,173,176]. Management strategies must therefore involve owner compliance [9,67]. Convincing owners to limit or restrict roaming and to provide proper nutrition is suggested as one straightforward management technique [10]. Other low-cost options include the implementation of stringent leash laws, although varying degrees of efficacy have been reported and with little effect on free-roaming populations [36,58,176].

Companion animal veterinarians and other veterinary staff play a key role in this mitigation approach. Client education is a critical and major part of small animal practitioners' everyday responsibilities [208,209]. This represents an important opportunity for veterinary staff in regard to wildlife. As credible sources of knowledge for their communities and through existing interactions with dog owners, veterinary staff may take the time to engage with clients about their pets' interactions with wildlife [210,211]. Likewise, they may help guide their clients toward appropriate resources when needed. This communication is important not only for dog–wildlife conflict and the benefit of wildlife but for companion animal health as well [212,213].

Non-veterinary-based education activities and community engagement are also essential in reducing the impact of domestic dogs on wildlife [40,67]. Outreach programs organized by wildlife groups or other relevant bodies should focus on responsible pet ownership and how to facilitate appropriate wildlife interactions [43,177,214,215]. Dog owners living near areas with a high abundance of wildlife should be provided information on the ways they can prevent attacks and who to contact should an attack occurs [9]. Training first responders in non-animal focused fields, such as law enforcement, may also be of value. These stakeholders often receive minimal training in regards to wildlife, yet are frequently contacted by the public in emergent animal situations. Specific training in wildlife handling for relevant organizations may therefore be advantageous in dog-wildlife response efforts. *C. hoffmani* is particularly difficult and dangerous to handle [83], and this task should be allotted to trained animal health professionals.

3.2.5 Government policy

Finally, policy and intergovernmental changes should be considered [43]. This may include the generation of standard operating procedures and management plans, amongst others. These plans may specify designated wildlife rescue centers, animal control staff, and veterinarians for response activities. Likewise, proper reporting systems should be in place to quantify the problem and identify key areas for invention [43]. Although community and national policy measures are essential in negating the problem of dog–wildlife conflict, various political, economic, and cultural issues prevent many governmental agencies from addressing the issue. Policy development on the topic has been described as highly unlikely at the national level [67]. Additional research and funding are therefore needed on the threat that domestic dogs pose to wildlife to determine the true scope of the problem and properly allocate resources.

4 Conclusions

In summary, our results suggest that domestic dogs in Costa Rica should be recognized as a conservation threat to sloths and other arboreal wildlife. Management of *C. hoffmani* following attack by domestic dogs involves careful clinical evaluation in the context of their unique anatomical makeup and ecological behavior. Preventing attacks on *C. hoffmani* and other species involves coordinated management efforts across the scientific disciplines, with emphasis on habitat preservation, domestic dog population control, installation of wildlife corridors, dog owner education, and policy changes. Additional research on domestic dog-wildlife conflict is required to

understand the true magnitude of impact, identify novel management approaches, and further evaluate the efficacy of mitigation strategies.

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