



Pablo Nascimento Martins
Instituto Nacional de Pesquisas da Amazônia
Programa de Pós Graduação em Ecologia
2025, Manaus - Amazonas



**EFEITO DO CLIMA E DO USO DO SOLO SOBRE O ATROPELAMENTO DE
VERTEBRADOS NA BR-319: NOVOS DESAFIOS PARA A FAUNA NA AMAZÔNIA
CENTRAL**

PABLO NASCIMENTO MARTINS

Manaus, Amazonas
2025

PABLO NASCIMENTO MARTINS

**EFEITO DO CLIMA E DO USO DO SOLO SOBRE O ATROPELAMENTO DE
VERTEBRADOS NA BR-319: NOVOS DESAFIOS PARA A FAUNA NA AMAZÔNIA
CENTRAL**

ORIENTADORA: CLARISSA ROSA

Manaus, Amazonas
2025

Aos meus pais, Munir Martins e Eloisa Winter Nascimento.

A minha irmã, Flora Nascimento Martins.

A todos os meus amigos, que me apoiaram nessa jornada.

A todos que participaram nesse esforço incrível de coleta de dados na BR-319.

Esse projeto não teria sido possível sem todos vocês.

SUMÁRIO

ÍNDICE DE FIGURAS.....	4
RESUMO.....	5
ABSTRACT.....	6
INTRODUÇÃO.....	7
Impactos de rodovias sobre ecossistemas e a biodiversidade.....	7
Rodovias e Amazônia.....	10
OBJETIVOS.....	13
REFERÊNCIAS.....	13
CAPÍTULO 1 - ARTIGO.....	17
CONSIDERAÇÕES FINAIS.....	67

ÍNDICE DE FIGURAS

Figure 1. Segment A of BR-319 (in red), representing the current study's area of interest. At the upper left corner, there is a general view of BR-319 in its entirety, starting in Manaus (north) and ending in Porto Velho (south), with each segment highlighted in distinct colors.....	27
Figure 2. Hotspots (including all faunal groups) along 'Segment A' of BR 319 in each year between 2017 and 2021 and multiple years. Hotspots which repeat along our study are colored in red and represent all areas which share a hotspot location for two or more years. All other hotspots are highlighted in distinct colors indicating the respective years in which they were found.....	31
Figure 3. Hotspots of amphibians along 'Segment A' of BR 319 in each year between 2017 and 2021 and multiple years. Hotspots which repeat along our study are colored in red and represent all areas which share a hotspot location for two or more years. All other hotspots are highlighted in distinct colors indicating the respective years in which they were found.....	32
Figure 4. Hotspots of reptiles along 'Segment A' of BR 319 in each year between 2017 and 2021 and multiple years. Hotspots which repeat along our study are colored in red and represent all areas which share a hotspot location for two or more years. All other hotspots are highlighted in distinct colors indicating the respective years in which they were found.....	33
Figure 5. Hotspots of birds along 'Segment A' of BR 319 in each year between 2017 and 2021 and multiple years. Hotspots which repeat along our study are colored in red and represent all areas which share a hotspot location for two or more years. All other hotspots are highlighted in distinct colors indicating the respective years in which they were found.....	34
Figure 6. Hotspots of mammals along 'Segment A' of BR 319 in each year between 2017 and 2021 and multiple years. Hotspots which repeat along our study are colored in red and represent all areas which share a hotspot location for two or more years. All other hotspots are highlighted in distinct colors indicating the respective years in which they were found.....	35
Table 1. Final models of climatic variables on the different groups analyzed. Variables of Rainfall and Temperature are in millimeters and Celsius respectively. Beta values determine the direction and intensity of the interaction found, and VIF values determine the variable's correlation coefficient.....	36

Table 2. Final models of landscape factors. Beta values determine the direction and intensity of the interaction found, and VIF values determine the variable's correlation coefficient..... 37

Table S1. Table of highest, lowest and average values found for each landscape type (water cover, farming land and wooded forest) within each individual buffer used. Highest and lowest values are in percentage of total area cover for the segment in which the value was located.... 52

Table S2. Complete list of species, as well as number of individual roadkill register of each species found, used in this study. All roadkill events within this list were registered along the 'Segment A' of BR-319, from October 2017 to September 2021. All common names in the register reference to the locally and most commonly used name for the species in Brazilian Portuguese. All names including the NID (Not identified) indicate that the individuals were not identified up to the level of species, but all were identified up to the lowest possible taxonomic level..... 54

Figure S1. Monthly values of the average temperature calculated for each month of our study period, from October 2017 to September 2021..... 59

Figure S19. Hotspot distribution of all roadkill events included in our study (all groups) for the first year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 76

Figure S20. Hotspot distribution of all roadkill events included in our study (all groups) for the second year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 76

Figure S21. Hotspot distribution of all roadkill events included in our study (all groups) for the third year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 77

Figure S22. Hotspot distribution of all roadkill events included in our study (all groups) for the fourth year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 77

Figure S23. Hotspot distribution of all roadkill events included in our study for amphibians for the first year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 78

Figure S24. Hotspot distribution of all roadkill events included in our study for amphibians for the second year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 78

Figure S25. Hotspot distribution of all roadkill events included in our study for amphibians for the third year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 79

Figure S26. Hotspot distribution of all roadkill events included in our study for amphibians for the fourth year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 79

Figure S27. Hotspot distribution of all roadkill events included in our study for birds for the first year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 80

Figure S28. Hotspot distribution of all roadkill events included in our study for birds for the second year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 80

Figure S29. Hotspot distribution of all roadkill events included in our study for birds for the third year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 81

Figure S30. Hotspot distribution of all roadkill events included in our study for birds for the fourth year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 81

Figure S31. Hotspot distribution of all roadkill events included in our study for mammals for the first year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 82

Figure S32. Hotspot distribution of all roadkill events included in our study for mammals for the second year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 82

Figure S33. Hotspot distribution of all roadkill events included in our study for mammals for the third year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL)

and lower limits (LCL) are represented by the orange and grey lines respectively..... 83

Figure S34. Hotspot distribution of all roadkill events included in our study for mammals for the fourth year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 83

Figure S35. Hotspot distribution of all roadkill events included in our study for reptiles for the first year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 84

Figure S36. Hotspot distribution of all roadkill events included in our study for reptiles for the second year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.....84

Figure S37. Hotspot distribution of all roadkill events included in our study for reptiles for the third year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 85

Figure S38. Hotspot distribution of all roadkill events included in our study for reptiles for the fourth year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively..... 85

RESUMO

As estradas causam grandes impactos na fauna, sendo o atropelamento de animais uma ameaça significativa para muitas espécies. Na Amazônia, as rodovias cortam ecossistemas ricos em biodiversidade, expondo mamíferos, aves, répteis e anfíbios ao risco de atropelamento. O aumento do tráfego e a expansão das redes rodoviárias têm contribuído para a diminuição das populações, influenciadas por características ambientais e condições sazonais de cada região. Nesse contexto, o objetivo do nosso estudo foi identificar a variação temporal dos pontos críticos de atropelamento e investigar sua relação com fatores climáticos (temperatura e precipitação) e da paisagem (cobertura florestal, agrícola e de áreas alagadas). Utilizamos um banco de dados de atropelamentos do primeiro trecho de 177,8 km da BR-319 (Manaus – Porto Velho) no período de 2017 a 2021 para avaliar as variações nos pontos críticos ao longo do tempo e investigar como os fatores climáticos e paisagísticos afetam os atropelamentos em diferentes buffers (500m, 1km, 5km e 10km). Registramos 673 incidentes de atropelamento (107 mamíferos, 251 répteis, 152 aves e 163 anfíbios). O estudo identificou padrões distintos de pontos críticos de atropelamento entre as diferentes classes de animais. Fatores climáticos e paisagísticos influenciaram significativamente as taxas de atropelamento, com temperaturas mais altas correlacionadas a mais atropelamentos, enquanto a precipitação geralmente reduziu os incidentes. Além disso, a maior cobertura de florestas e águas ajudou a reduzir os atropelamentos em várias espécies. Os resultados sugerem que fatores climáticos e paisagísticos desempenham papéis cruciais na formação dos padrões de atropelamento, ressaltando a necessidade de estratégias de conservação específicas para o contexto das rodovias. Concluímos que a mitigação dos atropelamentos ao longo da BR-319 exigirá abordagens integradas que considerem variáveis ambientais, gestão do tráfego e proteção de habitats para reduzir a mortalidade da fauna.

ABSTRACT

Roads have significant impacts on wildlife, with roadkill posing a major threat to many species. In the Amazon, highways cut through biodiversity-rich ecosystems, exposing mammals, birds, reptiles, and amphibians to roadkill risks. Increasing traffic and the expansion of road networks have contributed to population declines, influenced by environmental characteristics and seasonal conditions in each region. In this context, the objective of our study was to identify the temporal variation of roadkill hotspots and investigate their relationship with climatic (temperature and precipitation) and landscape (forest, agricultural, and wetland cover) factors. We used a roadkill database from the first 177.8 km of BR-319 (Manaus – Porto Velho) from 2017 to 2021 to evaluate variations in hotspots over time and investigate how climatic and landscape factors affect roadkills at different buffers (500m, 1km, 5km, and 10km). We recorded 673 roadkill incidents (107 mammals, 251 reptiles, 152 birds, and 163 amphibians). Our study identified distinct hotspot patterns among different animal classes. Climatic and landscape factors significantly influenced roadkill rates, with higher temperatures correlating with more roadkill, while precipitation generally reduced incidents. Additionally, higher forest and water cover helped reduce roadkill across various species. The results suggest that climatic and landscape factors play crucial roles in shaping roadkill patterns, highlighting the need for conservation strategies specific to the context of highways. We conclude that mitigating roadkill along BR-319 will require integrated approaches that consider environmental variables, traffic management, and habitat protection to reduce wildlife mortality.

INTRODUÇÃO

Impactos de rodovias sobre ecossistemas e a biodiversidade

A construção e manutenção de rodovias desempenham um papel essencial no desenvolvimento da sociedade, garantindo acesso a recursos necessários para o progresso e a sustentabilidade das comunidades humanas. No entanto, rodovias geram impactos químicos, físicos e biológicos no meio ambiente. Os impactos químicos incluem o aumento de poluentes como metais pesados, ozônio, moléculas orgânicas e poeira, que comprometem a qualidade do solo, da água e do ar ao redor das rodovias. Já os impactos físicos envolvem alterações nos sistemas de drenagem, que podem causar inundações, erosão do leito dos rios e sedimentação, além de aumentar a energia hidráulica dos sistemas fluviais, resultando em degradação ambiental adicional (Forman; Alexander, 1998; Trombulak; Frissel, 2000; Coffin, 2007; Laurance et al., 2009). Os impactos químicos e físicos frequentemente resultam em consequências biológicas indiretas, como, por exemplo, a mortalidade de peixes devido à poluição dos cursos d'água (Coffin, 2007; Laurance et al., 2009).

Outros impactos biológicos envolvem a supressão de áreas de floresta nativa, tornando as rodovias um dos principais agentes de fragmentação de habitats, com impacto direto na função e estrutura da paisagem local (Trombulak; Frissel, 2000). Além disso, a abertura de rodovias frequentemente favorece a ocupação humana e suas atividades associadas, ampliando ainda mais a fragmentação das áreas naturais (Forman; Alexander, 1998; Trombulak; Frissel, 2000). Essa dinâmica também intensifica os efeitos de borda, facilita a introdução de espécies exóticas invasoras, promove a disseminação de doenças, altera o comportamento das espécies e pode aumentar a pressão de caça, entre outros impactos negativos (Coffin, 2007; Forman; Alexander, 1998; Trombulak; Frissel, 2000). Entre esses impactos, os atropelamentos de fauna se destacam como um dos mais graves, devido à sua influência direta nas taxas de mortalidade das espécies, reduzindo populações e contribuindo para a extinção local em algumas regiões (Medrano-Vizcaíno et al., 2022).

Rodovias fragmentam habitats, criando barreiras físicas para o movimento de animais e isolando populações, ao mesmo tempo que aumentam a acessibilidade para atividades humanas (ex. caça furtiva), intensificando o risco de atropelamentos (Dixon et al., 2006). Os padrões de

atropelamentos de fauna são influenciados por fatores da paisagem (ex. proporção de cobertura florestal, presença de corpo d'água), climáticos (ex. temperatura e precipitação), estruturais da rodovia (ex. fluxo de veículos, velocidade permitida) e intrínsecos às espécies (ex. período de atividade, capacidade de deslocamento, etc.) (González-Suárez et al., 2018).

Mamíferos de médio e grande porte são frequentemente estudados em monitoramentos de atropelamentos de fauna no Brasil, devido à maior facilidade de detecção de suas carcaças na pista, em função do maior tamanho quando comparado a outros grupos de vertebrados (Coelho et al., 2008). Mamíferos de médio e grande porte apresentam elevada vulnerabilidade às pressões antrópicas, incluindo os atropelamentos, devido a fatores como áreas de vida extensas e a necessidade de atravessar rodovias em busca de recursos ou parceiros (Chiarello 1999; Galetti; Dirzo, 2013). Mamíferos de pequeno porte, por sua vez, são mais impactados quando rodovias atravessam suas áreas de vida ou pelos recursos disponíveis no entorno das estradas, que podem atraí-los (Laurance et al., 2009). Além disso, características da paisagem influenciam a dinâmica dos atropelamentos: áreas com maior cobertura florestal, por exemplo, tendem a registrar mais ocorrências envolvendo pequenos e médios mamíferos carnívoros, que utilizam esses ambientes para caça ou como parte de seu território (Grilo et al., 2009).

Alguns fatores mais específicos também agravam a vulnerabilidade das aves aos atropelamentos em comparação com outros animais. A disponibilidade de recursos, como o derramamento acidental de sementes nas rodovias utilizadas para o escoamento da produção agrícola regional, pode atrair espécies granívoras, tornando-as mais suscetíveis a colisões (Laurance et al., 2014). Aves necrófagas, como o urubu-de-cabeça-preta (*Coragyps atratus*) e o carcará (*Caracara plancus*), são atraídos para a pista pela carcaça de outros animais atropelados, ficando vulneráveis a colisões com veículos enquanto se alimentam ou tentam remover as carcaças da rodovia (Grilo et al., 2009). Além disso, aves com voo lento ou baixo são mais propensas a atropelamentos, enquanto aves com voo mais alto tendem a sofrer menos atropelamentos (Laurance et al., 2009).

Répteis e anfíbios apresentam vulnerabilidades distintas. Entre os anfíbios, fatores como a baixa capacidade de deslocamento, eventos de dispersão e recrutamento durante períodos reprodutivos são os mais frequentemente registrados (Trombulak; Frissel, 2000; Grilo et al.,

2011; Laurance et al., 2009). Para os répteis, a vulnerabilidade está associada ao comportamento de utilizar as pistas de rolamento para termorregulação, combinado à sua locomoção mais lenta (Laurance et al., 2009; Grilo et al., 2011). Adicionalmente, variáveis ambientais, como temperatura, precipitação, flutuações no nível da água e fotoperíodo, influenciam o comportamento desses animais que, por sua vez, influenciam as taxas de atropelamento (Orlowski et al., 2008).

Diante desse contexto e da rápida expansão das redes viárias globalmente, o estudo dos impactos causados por essas infraestruturas tornou-se uma prioridade. Foi esse cenário que deu origem à disciplina de Ecologia de Estradas no final do século passado (Forman; Alexander, 1998). Com origem nos Estados Unidos, Canadá e Europa por volta da década de 1930, chegando ao Brasil na década de 80 (Dornas et al., 2012), a Ecologia de Estradas busca compreender as interações entre as rodovias e os ecossistemas, bem como desenvolver estratégias para prevenir e mitigar os efeitos negativos da expansão rodoviária (Coffin, 2007; Laurance et al., 2009). Ao longo dos anos, o estudo dos impactos das rodovias sobre a fauna e a flora tem se consolidado como um campo interdisciplinar, que integra conhecimentos de diversas áreas, como ecologia, biologia da conservação e planejamento urbano, com o objetivo de entender e mitigar os efeitos das rodovias nas comunidades naturais (Coffin, 2007). Para uma compreensão mais profunda desses impactos, é fundamental realizar uma análise integrada que não apenas considere as características físicas das paisagens, como o tipo de vegetação, relevo e presença de recursos naturais, mas também as respostas comportamentais das espécies às rodovias, como alterações em padrões de movimento, estratégias de forrageamento e migração (JAEGER et al., 2005). Este tipo de abordagem permite identificar como as rodovias influenciam os ecossistemas e as populações, além de fornecer dados essenciais para o desenvolvimento de medidas eficazes de conservação e mitigação.

Rodovias e Amazônia

As rodovias na Amazônia desempenham um papel fundamental na dinâmica de ocupação e exploração do bioma e estão associadas a impactos ambientais significativos. Atualmente, a

região possui uma infraestrutura rodoviária limitada, com rodovias como a BR-319, BR-163 e a BR-230 (Transamazônica), muitas vezes em condições precárias, interligando áreas isoladas, mas também abrindo novas frentes de desmatamento e degradação ambiental. Historicamente, o bioma amazônico conta tradicionalmente com outros modais de transporte, como hidrovias, que são utilizados como vias naturais para o deslocamento de pessoas e mercadorias. A ausência de uma malha rodoviária densa tem contribuído para a conservação de extensas áreas de floresta, contrastando com outras regiões do Brasil que apresentam maior pressão antrópica devido à expansão de rodovias (Fearnside, 2006). A construção e pavimentação de rodovias na Amazônia frequentemente atuam como vetores de desmatamento, promovendo a expansão agrícola, madeireira e especulação fundiária (Grilo et al., 2020). Essa realidade ressalta a necessidade de considerar os impactos socioambientais das rodovias como parte de uma estratégia de desenvolvimento sustentável para a região.

Na Amazônia, as rodovias pavimentadas modernizam a malha viária, mas também facilitam o acesso a regiões florestais para exploração de recursos naturais. Essas estradas abrem caminho para caçadores, mineradores e grileiros de terra, especialmente em áreas remotas onde a aplicação das leis ambientais é limitada. Esse processo é intensificado por fatores socioeconômicos, como o crescimento populacional e econômico, que impulsionam atividades como extração de madeira, agronegócio, mineração e exploração de petróleo e gás. Além disso, financiadores internacionais e a expansão contínua de rodovias contribuem para acelerar essa dinâmica (Laurence et al., 2009; Laurance et al., 2014).

Nesse sentido, os impactos de rodovias podem ser ainda mais severos em regiões de alta biodiversidade e valor de conservação, como a Amazônia, que enfrenta um acelerado avanço nos projetos atuais e previstos da infraestrutura rodoviária (Laurance et al., 2014). Na Amazônia brasileira, a expansão de rodovias ocorre a uma média alarmante (Grilo et al., 2020), representando uma séria ameaça à biodiversidade e à estabilidade ambiental dos ecossistemas. Essa expansão intensifica problemas como a fragmentação de habitats, aumento de queimadas e morte direta de animais por atropelamento, colocando em risco a funcionalidade ecológica e os serviços essenciais fornecidos pela floresta (Medrano-Vizcaíno et al., 2022).

Embora os impactos de atropelamentos sejam amplamente documentados em diferentes biomas e regiões do mundo (Filius et al., 2020; Grilo et al., 2020; Schwartz et al., 2020), os estudos na Amazônia ainda são limitados (Filius et al., 2020; Medrano-Vizcaino et al., 2022; Vilela et al., 2020). Alguns trabalhos analisaram aspectos específicos, como o de Batista et al. (2022), que identificaram *hotspots* de atropelamento ao longo de trechos da BR-230 no Pará, e o de Santos et al. (2022), que investigaram padrões sazonais e variações na mortalidade de fauna em rodovias que cruzam áreas de floresta de terra firme no Mato Grosso. Além disso, há apenas alguns trabalhos isolados realizados no Pará (Batista et al., 2022) e Amazonas (Carvalho et al., 2015). Esses estudos contribuem para o entendimento de padrões locais, mas ainda são insuficientes para abranger toda a complexidade ambiental da Amazônia.

Análises que considerem fatores de paisagem em escalas mais amplas ou utilizem séries temporais extensas ainda são inexistentes na região, o que é uma lacuna relevante dado a heterogeneidade ambiental do bioma. Esta diversidade inclui diferentes tipos de floresta, áreas alagáveis e transições para outros biomas, como o Cerrado. Estudos focados em variáveis de paisagem, como cobertura do solo, proximidade de corpos d'água e uso da terra, são essenciais para o desenvolvimento de estratégias eficazes de mitigação e conservação (Laurance et al., 2014). No entanto, um desafio significativo para tais estudos é determinar a escala ideal para a coleta dessas variáveis, uma vez que as respostas das espécies são influenciadas por processos ecológicos em diferentes escalas, como dinâmica de metapopulação, dispersão e interações inter e intraespecíficas (Filius et al., 2020). Para superar esse desafio, é necessário identificar o efeito das variáveis em diferentes escalas, cujas respostas podem auxiliar no planejamento de medidas de mitigação a nível local e regional.

Quantificar os impactos na biodiversidade da Amazônia devido à expansão rodoviária é crucial para definir esforços de conservação que possam moderar a perda de biodiversidade (Van et al., 2015). A implementação de estratégias para mitigar os impactos causados por atropelamentos em rodovias é vasta e diversificada. No entanto, a eficácia dessas medidas depende de uma compreensão aprofundada das especificidades de cada espécie ou grupo taxonômico-alvo, além de fatores bióticos, abióticos, ecológicos e paisagísticos (Rytwinski et al., 2016). Medidas de mitigação devem ser aplicadas em locais estrategicamente selecionados,

considerando essas variáveis para maximizar sua eficiência (Glista et al., 2009; Bager; Rosa, 2010).

A BR-319, uma rodovia federal brasileira com 877 km de extensão, conecta Manaus (AM) a Porto Velho (RO), desempenha um papel estratégico na integração da região Norte com o restante do país. Construída durante a ditadura militar nos anos 1970 como parte de um ambicioso plano de integração nacional, a rodovia sofreu décadas de abandono após sua conclusão, resultando na deterioração de grandes trechos, especialmente no chamado "Trecho do Meio" (km 250 a 655,70). Atualmente, a BR-319 está dividida em quatro segmentos para fins de planejamento de expansão e licenciamento ambiental: segmento A (km 0 a 177,80), segmento C (km 177,80 a 250), "Trecho do Meio" e segmento B (km 655,70 a 877,40). O projeto atual de reabertura da rodovia prevê a pavimentação de 340 km em condições precárias e a manutenção contínua da rodovia.

A revitalização da BR-319 é cercada de controvérsias, pois a rodovia, além de desempenhar um papel essencial no transporte e na economia regional, atravessa áreas de grande relevância ambiental. O trajeto inclui a Reserva Biológica do Rio Trombetas e o Parque Nacional Mapinguari, além de passar próximo a terras indígenas, como as Terras Indígenas Tenharim Marmelos e Lago Capanã Grande (Costa et al., 2011). A pavimentação também ameaça importantes serviços ecológicos fornecidos pela região, como a regulação do ciclo hidrológico, a captura de carbono e a manutenção da biodiversidade, que são cruciais tanto local quanto globalmente (Fearnside, 2006). O cruzamento de rios essenciais, como o Rio Madeira e o Rio Purus, destaca ainda mais o impacto potencial da revitalização, pois esses rios são fundamentais para o transporte fluvial e para a conectividade ecológica na Amazônia. A reativação do tráfego regular, portanto, representa um risco significativo à biodiversidade, em uma área que abriga ecossistemas únicos e espécies endêmicas. Isso torna urgente a análise de fatores que contribuem para os atropelamentos de fauna ao longo da rodovia, a fim de orientar medidas de mitigação (González-Suárez et al., 2018).

Com planos para sua reconstrução, é esperado que agentes e processos de desmatamento se expandam para áreas conectadas a Manaus por vias terrestres, como o estado de Roraima, no norte da Amazônia, e a vasta área florestal no oeste do estado do Amazonas, que se tornariam

acessíveis por meio de rodovias planejadas para se conectarem à BR-319 (Fearnside et al., 2020). Essa expansão não apenas ameaça a biodiversidade, mas também facilita a exploração madeireira e a ocupação desordenada, agravando a pressão sobre os ecossistemas. Estudos sobre os impactos potenciais da pavimentação da BR-319 são fundamentais para embasar estratégias de mitigação eficazes, protegendo a fauna local e minimizando os impactos ambientais, especialmente em um bioma tão sensível quanto a Amazônia.

OBJETIVOS

Considerando o contexto da BR-319, nosso objetivo foi avaliar a variação temporal de *hotspots* de quatro grupo taxonômicos distintos - anuros, répteis, aves e mamíferos - ao longo do ‘Segmento A’ da BR-319 e investigar os fatores climáticos e de paisagem que afetam os eventos de atropelamentos no segmento. Especificamente avaliando os seguintes pontos:

- I. Identificar *hotspots* de atropelamento no trecho estudado e mudanças temporais na distribuição de *hotspots* ao longo de um período de quatro anos.
- II. Testar a influência de características climáticas - pluviosidade e temperatura - sobre o número de atropelamentos de fauna.
- III. Testar a influência da estrutura de paisagem em diferentes escalas sobre o número de atropelamentos dos grupos de fauna estudados.

REFERÊNCIAS

BAGER, A. & C. A. ROSA. Priority ranking of road sites for mitigating wildlife roadkill. *Biota Neotropica* 10:149–153. 2010.

BATISTA, G.; RASCON, N.; ROSA, C. Vertebrados Atropelados na BR-163, Entorno da Floresta Nacional do Tapajós, Pará: Influência dos Padrões Espaciais e Climáticos. *Biodiversidade Brasileira - BioBrasil*, v. 12, n. 1, p. 200–219, 18 jan. 2022.

CARVALHO, C. F.; CUSTÓDIO, A. E. I.; JUNIOR, O. M. Wild vertebrates roadkill aggregations on the BR-050 highway, state of Minas Gerais, Brazil. *Bioscience Journal*, v. 31, n. 3, p. 951–959, 2015.

- CHIARELLO, A. G. Effects of fragmentation of the Atlantic Forest on mammal communities in southeastern Brazil. *Biological Conservation* 89:71-82. 1999.
- COELHO, I. P., A. KINDEL & A. V. P. COELHO. 2008. Roadkills of vertebrate species on two highways through the Atlantic Forest Biosphere Reserve, southern Brazil. *European Journal of Wildlife Research* 54:689–699.
- COFFIN, A. W. From roadkill to road ecology: A review of the ecological effects of roads. *Journal of Transport Geography*, v. 15, n. 5, p. 396–406, set. 2007.
- COSTA, J. A. L., et al. Identificação do Desmatamento das Unidades Especiais na Área de Delimitação Provisória (ALAP) da BR-319. Anais XV Simpósio Brasileiro de Sensoriamento Remoto - SBSR, Curitiba, PR, Brasil, 30 de abril a 05 de maio de 2011, INPE p.4325.
- DIXON, J. D., et al. Two Florida Black Bear Populations. *Conservation Biology* 20:155–162. 2006.
- DORNAS, R. A. P; KINDEL, A.; BAGER, A.; FREITAS, S. R. Avaliação da mortalidade de vertebrados em rodovias. In: BAGER, A. (ed.) *Ecologia de Estradas: tendências e pesquisas*. Lavras: Ed. UFLA, p. 139-152. 2012.
- FEARNSIDE, P.; MAURÍCIO, P.; DE, L.; GRAÇA, A. Rodovia BR-319: O custo ambiental de ligar o arco do desmatamento ao coração da Amazônia. 2006.
- FEARNSIDE, P. M.; FERRANTE, L.; ANDRADE, M. B. T. BR-319 illegal side road threatens Amazon protected area, indigenous land (commentary). 2020.
- FILIUS, J. et al. Wildlife roadkill patterns in a fragmented landscape of the Western Amazon. *Ecology and Evolution*, v. 10, n. 13, p. 6623–6635, 20 jun. 2020.
- FORMAN, R.T.T. Road ecology: a solution for the giant embracing us. *Landscape Ecology*, v. 13, pag 3-5, 1998 .
- GALETTI, M. & R. DIRZO. Ecological and evolutionary consequences of living in a defaunated world. *Biological Conservation* 163:1–6. 2013.

GLISTA, D. J., T. L. DEVAULT & J. A. DEWOODY. A review of mitigation measures for reducing wildlife mortality on roadways. *Landscape and Urban Planning* 91:1–7. 2009.

GONZÁLEZ-SUÁREZ, M.; ZANCHETTA FERREIRA, F.; GRILO, C. Spatial and species-level predictions of road mortality risk using trait data. *Global Ecology and Biogeography*, v. 27, n. 9, p. 1093–1105, 2018.

GRILO, C.; BISSONETTE, J. A.; SANTOS-REIS, M. Spatial–temporal patterns in Mediterranean carnivore road casualties: Consequences for mitigation. *Biological Conservation*, v. 142, p. 301–313, 2009.

GRILO, C. et al. Do well-connected landscapes promote road-related mortality? *European Journal of Wildlife Research* 57:707–716. 2011.

GRILO, C. et al. Roadkill risk and population vulnerability in European birds and mammals. *Frontiers in Ecology and the Environment*, v. 18, n. 6, p. 323–328, 8 jun. 2020.

LAURANCE, W. F.; GOOSEM, M.; LAURANCE, S. G. W. Impacts of roads and linear clearings on tropical forests. *Trends in Ecology & Evolution*, v. 24, n. 12, p. 659–669, dez. 2009.

LAURANCE, W. F. et al. A global strategy for road building. *Nature*, v. 513, n. 7517, p. 229–232, 27 ago. 2014.

MEDRANO-VIZCAÍNO, P. et al. Roadkill patterns in Latin American birds and mammals. v. 31, n. 9, p. 1756–1783, 25 jun. 2022.

ORLOWSKI, G.; CIESIOLKIEWICZ, J.; KACZOR, M.; RADWANSKA, J.; ZYWICKA, A. Composição de espécies e correlatos de habitat de anfíbios atropelados em diferentes paisagens do sudoeste da Polônia. *Jornal Polonês de Ecologia*, v. 56, p. 659–671, 2008.

RYTWINSKI, T. et al. 2016. How effective is road mitigation at reducing road-kill? A meta-analysis. *PLoS ONE* 11:1–25.

SANTOS, E. et al. Hotspots and Season Related to Wildlife Roadkill in the Amazonia–Cerrado Transition. *Diversity*, v. 14, n. 8, p. 657, 14 ago. 2022.

SCHWARTZ, A. L. W.; SHILLING, F. M.; PERKINS, S. E. The value of monitoring wildlife roadkill. *European Journal of Wildlife Research*, v. 66, n. 1, 15 jan. 2020.

TROMBULAK, S. C.; FRISSELL, C. A. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology*, v. 14, p. 18-30, 2000.

VAN, R.; SMITH, D. J.; GRILO, C. *Handbook of road ecology*. Chichester, West Sussex: Wiley Blackwell, 2015.

VILELA, T. et al. A better Amazon road network for people and the environment. *Proceedings of the National Academy of Sciences*, 11 mar. 2020.

MARTINS, Pablo Nascimento; SAITO, Erica Naomi; FANTACINI, Felipe Moreli; ASSIS, André Ambrozio de; SILVA, Eduardo Araujo da; SILVA, André Luiz Ferreira da; SÁ, Guilherme Augusto Munhoz de; CARVALHO JUNIOR, Márcio Vieira de; SIDOSKI, Rodrigo; COSTA, José Roberto Nascimento da; GORDO, Marcelo; ROSA, Clarissa (2025) **Temporal variation in hotspots and the effects of climate and landscape on wildlife roadkill along the BR-319: conservation challenges in a high-biodiversity area in the Amazon**

Submetido a Nature Conservation

Temporal variation in hotspots and the effects of climate and landscape on wildlife roadkill along the BR-319: conservation challenges in a high-biodiversity area in the Amazon

Pablo Nascimento Martins¹, Erica Naomi Saito^{2,3}, Felipe Moreli Fantacini³; André Ambrozio-Assis^{3,4}; Eduardo Araujo da Silva⁴; André Luiz Ferreira da Silva⁵; Guilherme Augusto Munhoz de Sá; Márcio Vieira de Carvalho Junior⁴; Rodrigo Sidoski³; José Roberto Nascimento da Costa³; Marcelo Gordo⁶; Clarissa Rosa^{1,7}

Affiliation:

¹ Instituto Nacional de Pesquisas da Amazônia (INPA), Programa de Pós-Graduação em Ecologia., Av. André Araújo 2936, Petrópolis, 69055-010 Manaus, Amazonas, Brazil.

² Instituto de Biociências, Programa de Pós-Graduação em Ecologia, Universidade Federal do Rio Grande do Sul (UFRGS), Av. Bento Gonçalves 9500, Campus do Vale, 90650-001, Porto Alegre, Rio Grande do Sul, Brazil.

³ Rede Brasileira de Especialistas em Ecologia de Transportes (REET Brasil), Rua Corinto, 739, apt 13B, 05586-060, São Paulo, São Paulo, Brazil.

⁴ Ministério do Meio Ambiente e Mudança do Clima, Secretaria Extraordinária de Controle do Desmatamento e Ordenamento Ambiental Territorial, Bloco B, Eixo Monumental, Esplanada dos Ministérios, 70068-900, Brasília, Brazil.

⁵ Laboratório de Biodiversidade, Conservação e Ecologia de Animais Silvestres - LABCEAS, Departamento de Zoologia da Universidade Federal do Paraná/UFPR, Jardim das Américas, 82590-300, Curitiba, Paraná, Brazil.

⁶ Instituto de Ciências Biológicas, Universidade Federal do Amazonas (UFAM), Av. Jaury Marinho Coroado, 69080-005, Manaus, Amazonas, Brazil.

⁷ Instituto Nacional de Pesquisas da Amazônia (INPA), Coordenação de Biodiversidade, Av. André Araújo 2936, Petrópolis, 69067-375 Manaus, Amazonas, Brazil.

*The opinions expressed in this article are the sole responsibility of the author and do not necessarily reflect his official position at the Brazilian Ministry of Environment and Climate Change.

Abstract

Roads greatly impact wildlife, with roadkill posing a major threat to many species. In the Amazon, highways cut through biodiversity-rich ecosystems, exposing mammals, birds, reptiles, and amphibians to roadkill risks. Increasing traffic and expanding road networks drive population declines, influenced by environmental traits, traffic, and seasonal conditions. Our study aims to identify temporal variation on roadkill hotspots and investigate their relationship with climatic (temperature and rainfall) and landscape (forest, agricultural, and wetland cover). We used a roadkill database from the first 177.8 km of BR-319 (Manaus – Porto Velho) spanning 2017 to 2021 to evaluate variations in hotspots over time and investigate how climate and landscape factors affect roadkills across different buffers (500m, 1km, 5km, and 10km). We recorded 673 roadkill incidents (107 mammals, 251 reptiles, 152 birds, and 163 amphibians). Our study recorded 673 roadkill incidents along the first 177.8 km of BR-319, with amphibians, reptiles, birds, and mammals showing distinct hotspot patterns. Climate and landscape factors significantly influenced roadkill rates, with higher temperatures correlating with more roadkill, while rainfall generally decreased incidents, and increased forest and water cover helped reduce roadkill across most groups. Our findings suggest that both climatic and landscape factors play crucial roles in shaping roadkill patterns, highlighting the need for context-specific conservation strategies along highways. In conclusion, mitigating roadkill along BR-319 will require integrated approaches that consider environmental variables, traffic management, and habitat protection to reduce wildlife mortality.

Key-Word

Wildlife mortality, Wildlife-vehicle collisions, Road ecology, Amazon highways.

Introduction

Projections indicate that by 2050, an additional 25 million kilometers of paved roads will be constructed globally compared to 2010, representing more than 60% increase in global road coverage (Dulac 2013). While this expansion may boost economic development, it poses significant environmental risks, particularly in high-biodiversity and conserved regions, since roads directly contribute to habitat fragmentation and indirectly exacerbate activities such as logging and land occupation (Asher et al. 2020; Barrientos et al. 2021). For biodiversity, one of the most immediate effects is the increase in wildlife roadkill, which drives declines in numerous species' populations and ecosystems' functionality (Forman & Alexander 1998).

The dynamics of wildlife roadkill are shaped by environmental factors (e.g., forest cover, proximity to water bodies), road characteristics (e.g., number of lanes, speed limits), climatic variables (e.g., temperature, precipitation, seasonality), and species-specific traits (e.g., mobility, activity, and reproductive periods) (González-Suárez et al. 2018). These elements interact to create critical areas, or hotspots, with high concentrations of wildlife roadkill, which have been studied in both open and forested habitats across tropical and temperate zones to inform the placement of mitigation measures (e.g., Ha and Shilling 2018; Santos et al. 2022; Marques et al. 2022; PINTO et al. 2023). However, the temporal dynamics of these hotspots remain poorly understood. Seasonal events, such as migrations, reproductive periods, or fluctuations in water levels, can shift hotspot locations (Brum et al. 2017; Ferreguetti et al. 2020). Additionally, land-use changes, including deforestation or urbanization, may cause hotspots to emerge or disappear over time (Medrano-Vizcaíno et al. 2022; Grilo et al. 2011). Understanding the temporal fluctuations of hotspots is crucial for developing adaptive and effective mitigation strategies that account for dynamic ecological and environmental conditions.

Landscape composition and configuration play a critical role in shaping collision rates, either amplifying or reducing them (Grilo et al. 2011). Fragmented landscapes with dense road networks often experience higher collision rates due to increased animal movement between habitat fragments. For example, small felines are frequently road killed in agricultural regions, drawn by the abundance of prey in croplands (Caro et al. 2000). Amphibians are particularly vulnerable near water bodies, as road crossings become essential during reproductive periods

(Guter et al., 2006). Overall, the presence of dense forests, low vegetation, and agricultural areas affects the susceptibility of various faunal groups, including birds and mammals, to collisions (Medrano-Vizcaíno et al. 2022). The interaction between roads, landscapes, and wildlife-vehicle collisions also varies with the scale of observation, as species responses are shaped by ecological processes that operate at multiple scales (Jackson & Fahrig, 2015; Suárez-Castro et al., 2018). Identifying the optimal scale for analyzing landscape composition and configuration remains a challenge due to this multiscale complexity. To address this, a multiscale approach is needed to determine the specific scale at which each variable has the greatest effect in the wildlife roadkill (Jackson & Fahrig, 2015).

Climatic factors also influence collision rates, particularly in tropical regions. High temperatures and precipitation levels often increase the mobility of reptiles and amphibians, heightening their susceptibility to road mortality, especially during reproductive periods when their movement in search of mates or nesting sites intensifies (Carvalho et al. 2017; Medrano-Vizcaíno et al. 2023). In contrast, birds and mammals show an indirect relationship with climatic variables, as their collision rates are typically seasonal, often associated with reproductive periods and a higher presence of young, inexperienced individuals (Ferreguetti et al., 2020; Husby 2016). Rainfall can further influence collision rates by altering food availability, population abundance, and species movement patterns (Machado et al., 2015). While some studies have observed increased collisions during the rainy season (Seiler, 2001; Machado et al., 2015), this pattern is not universal. For instance, research conducted in the Carajás National Forest, northern Brazil, found no significant correlation between rainfall and wildlife roadkill (Gumier-Costa & Sperber, 2009).

While general patterns of wildlife-vehicle collisions are well-documented, local and regional factors play a crucial role, highlighting the need for mitigation strategies tailored to specific contexts. This issue is particularly urgent in the Amazon, a region known for its high ecological heterogeneity and exceptional biodiversity (Medrano-Vizcaíno et al. 2023). Most studies on wildlife roadkill have been conducted in temperate zones or tropical and subtropical areas that are either non-forested or heavily fragmented (Grilo et al. 2021; Jackson & Fahrig, 2015). Although some isolated studies in the Amazon have evaluated wildlife roadkill (Batista et al. 2022; Santos et al. 2022; Carvalho et al. 2015), a deeper understanding of roadkill patterns is

necessary to design effective conservation measures for the Amazon (Filius et al., 2020; Medrano-Vizcaíno et al. 2022). Quantifying the impacts of road expansion on Amazonian biodiversity is therefore critical for developing strategies to minimize biodiversity loss and safeguard the ecosystem services provided by the Amazon at both regional and global scales (Fearnside et al. 2021).

In this context, the BR-319 highway, which connects Manaus to Porto Velho, is a strategic road for Brazil's northern region, cutting environmentally sensitive areas, including protected areas and Indigenous lands (Fearnside et al. 2021). Its revitalization, including the paving of over 400 km cutting a highly rich biodiversity area, poses significant risks to biodiversity, especially as it traverses environmentally sensitive areas, such as biological reserves, national parks, and Indigenous lands (Ferrante et al. 2021). The associated increase in traffic and deforestation makes it urgent to investigate the factors contributing to wildlife roadkill in the region. So, our study aimed to investigate temporal changes in roadkill hotspots over four years along the BR-319 highway and identify the climatic factors (temperature and precipitation) and landscape characteristics (land cover measured at different scales) influencing roadkill events. We hypothesized that: (1) the dynamics of hotspots will vary annually, and (2) higher temperatures would increase roadkill involving mammals and reptiles, while (3) rainy periods would heighten collisions involving amphibians and reptiles flooded areas would increase roadkill involving amphibians and reptiles. For landscape, (4) agricultural areas would lead to higher roadkill numbers for birds and mammals, while (5) forest cover would positively influence roadkills for all taxa due to the species movement between both sides of the highway.

Methodology

Study Area

The road BR-319 is a federal highway in Brazil that connects the states of Amazonas (AM) and Rondônia (RO), serving as a strategic link between the northern region and the rest of the country. Spanning approximately 877 km, the highway starts in Manaus (AM) and ends in Porto Velho (RO), crossing regions of high environmental and socioeconomic importance in the

Amazon. Along its route, it intersects major rivers like the Madeira and Purus, which are critical for local biodiversity and fluvial transport. Additionally, the highway passes near protected areas such as the Rio Trombetas Biological Reserve and the Mapinguari National Park. Despite its strategic role, BR-319 faces challenges related to environmental conservation and road maintenance, particularly during the rainy season when unpaved sections become impassable (Fearnside et al. 2006).

Constructed in the 1970s as part of a national integration plan, BR-319 connects the "arc of deforestation" in the southern Amazon to Manaus, a central hub of the region (Fearnside et al. 2006). After partial abandonment in 1988, much of the highway became impassable, especially the "Middle Section" (km 250 to 655.7), characterized by a lack of paving and deteriorated conditions. In 2015, a maintenance program temporarily restored access to some parts during the dry season. Today, the highway is divided into four segments: the deteriorated "Middle Section", the Segment A (km 0 to 177.8) and Segment C (km 177.8 to 250), which are partially paved, and Segment B (km 655.7 to 877.4), which is fully paved. Our study focused on Segment A of BR-319, covering the first 177.8 km from Manaus to the municipalities of Careiro da Várzea and Manaquiri, in Amazonas (Figure 1).

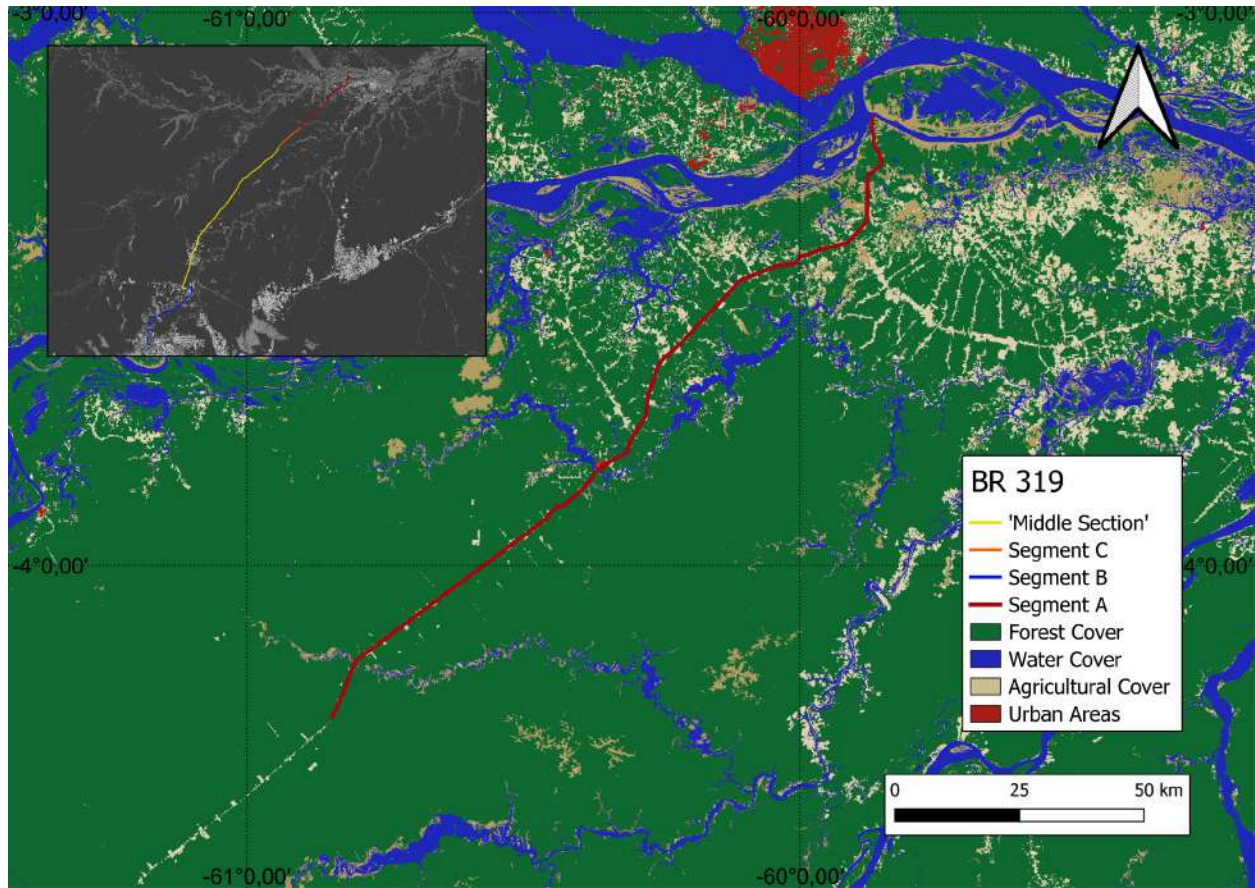


Figure 1. Segment A of BR-319 (in red), representing the current study’s area of interest. At the upper left corner, there is a general view of BR-319 in its entirety, starting in Manaus (north) and ending in Porto Velho (south), with each segment highlighted in distinct colors.

Fauna Roadkill Database

Our study utilized a roadkill database from BR-319, provided by the Brazilian National Department of Transport Infrastructure (DNIT). The database was developed based on monthly data collection conducted from October 2017 to September 2021, covering 48 months of sampling and spanning four annual seasonal cycles. The records include individuals identified, when possible, to the species level, and were grouped into four focal taxonomic groups for analysis: amphibians, reptiles, birds, and mammals. The database was compiled through roadkill monitoring using a vehicle traveling at an average speed of 40 km/h. Monitoring was carried out along the highway on one-way trips, with stops made to collect additional data whenever

carcasses or live animals were observed. All recorded carcasses were photographed, and those found on the road or its shoulders were classified as roadkill events. Identifications were performed, when possible, by specialist biologists in herpetology, ornithology, and mammalogy. Each carcass was georeferenced to obtain precise coordinates.

For this study, we selected only georeferenced records along Segment A of BR-319, specifically between kilometers 0 and 177.8 of the highway, focusing on the northern paved section. We included only records where identification was possible to at least the class level, which allowed classification within the analyzed taxonomic groups. Records of domestic or exotic species (e.g., *Canis familiaris*, *Equus caballus*, *Felis catus* and *Gallus domesticus*) were excluded to focus on the impacts of the studied factors on native fauna.

Climatic and Landscape Variables

We collected monthly accumulated precipitation and mean monthly temperature data from the Brazilian National Meteorological Institute (INMET) for station 82331 in Manaus, AM. We calculated the mean monthly temperature for each month between October 2017 and October 2021 based on daily mean temperatures.

For landscape variables, we assessed the coverage of flooded areas, forest cover, and agricultural areas surrounding the highway. We obtained the data using georeferencing techniques in QGIS (QGIS Development Team 2024) and surface maps with 15-meter resolution provided by the MapBiomias project (MapBiomias Project 2023). We divided the Segment A of the highway, spanning 177.8 km, into 1-km sections, and buffers of 500 m, 1000 m, 5000 m, and 10000 m were created around each section. Using these buffers, we calculated the percentage of coverage for each land cover type. This was done through vector area calculations in QGIS, with distinct color bands for each surface type. We identified these values for each year of the study to ensure that roadkill records were associated with temporally relevant and representative local landscape conditions.

Statistical Analyses

To analyze hotspots, we divided the 48 months of sampling into four 12-month periods, starting in October of the first year and ending in September of the following year, repeating the process for subsequent years. We performed analyses for all roadkill data combined and separately for each fauna group (birds, mammals, reptiles, and amphibians). We chose to analyze annual cycles of roadkill because this timeframe is typically used in both scientific literature (e.g., Mota et al. 2023; Santos et al. 2022) and to define roadkill hotspots for implementing mitigation measures in Brazil.

To identify roadkill hotspots, we applied the 2D Ripley K-statistics test using Siriema 2.0 software (Coelho et al., 2014), which evaluates aggregation intensity at different spatial scales through the $L(r)$ function. $L(r)$ values exceeding the upper confidence limit (UCL) indicate significant clustering, while values below the lower confidence limit (LCL) suggest significant dispersion. The test was configured with an initial radius of 500 meters, 500-meter increments, a 95% confidence level, and 999 simulations (Mota et al. 2023). These parameters were selected to correspond to relevant spatial scales for implementing effective mitigation measures along the studied segment and the entire BR-319 (Mota et al. 2023).

To identify segments with high concentrations of roadkill (hotspots), we used the 2D hotspot test in Siriema v2.0 (Coelho et al., 2014). This test evaluates the spatial distribution of events along the highway, using the Hotspot Score (HS) as a measure of aggregation intensity. Significant hotspots are identified by HS values above the UCL, while values within the confidence limits suggest random distribution. The test was performed annually for each fauna group to assess temporal variation in hotspots. The radius was set to 500 meters, with 1000 simulations and a 95% confidence interval.

To investigate the influence of climatic and landscape factors on roadkill, we performed generalized linear models (GLMs), initially adjusted for a Poisson distribution. In cases of overdispersion or multicollinearity in the initial GLMs, we adapted the models to a Quasipoisson distribution and applied necessary adjustments. Analyses were conducted in R software (R Core Team, 2024). We built separate models for climatic and landscape factors, with the number of roadkill events as the response variable (considering each fauna group separately). We tested all predictor variables for multicollinearity. For climatic models, we used mean monthly precipitation, mean monthly temperature, and their interaction as predictors variables. For

landscape models, we included the proportions of water, forest, and agricultural cover, along with their interactions, as predictor variables. We constructed models for each buffer (500 m, 1000 m, 5000 m, and 10000 m) to identify specific landscape influences on roadkill at different spatial scales.

Results

Our data comprised a total of 673 roadkill incidents, including 107 mammals, 251 reptiles, 152 birds, and 163 amphibians recorded over the 48-month data collection period in the Segment A of BR-319. The species with the highest number of roadkill events registered were *Rhinella marina* with 133 individuals, *Didelphis marsupialis* with 85 individuals and *Coragyps atratus* with 44 individuals. The highest average temperature recorded was 31.2°C in October 2018, while the lowest was 27.3°C in March 2021, with a monthly average of 28.8°C. Rainfall ranged from 19.5 mm in August 2018 to 589.3 mm in March 2021, with an overall average of 226.5 mm during the study period. Landscape analysis revealed a wide variety of vegetation cover types. Forest cover ranged from 38.4% to 98.9%, with the lowest percentages observed in the 5000m and 10000m buffers. Agricultural cover varied from 0% to 75%, showing the greatest variation in the 500m and 1000m buffers. Wetland coverage ranged from 0% to 37.7%, with minimal variation across the buffers (see supplementary material).

Roadkill Hotspots

For all wildlife groups combined, we observed a significant concentration of hotspots within the first 30 kilometers of the highway, which was the most consistently affected area throughout the analyzed periods. In year 1 (2017/2018), hotspots were located at kilometers 4, 7–9, 11–12, 14–15, 17, 19–21, 48, 58–59, and 81. In year 2 (2018/2019), hotspots occurred at kilometers 4, 6, 10, 12–16, 19, 43, 55–56, 59, 68, 80, 82–83, and 105. In year 3 (2019/2020), hotspots were identified at kilometers 3–4, 6–7, 9, 11–15, 25–26, 28–29, 34–35, and 44. In year 4 (2020/2021), hotspots were found at kilometers 0, 2, 4, 6, 8–9, 19, 28, 30, 32–33, 48, 55, 63,

and 71 (Figure 2). Over the years, the most consistent hotspots were at kilometers 4, 6, 19, and 48, which stood out for their recurrence across all monitoring periods.

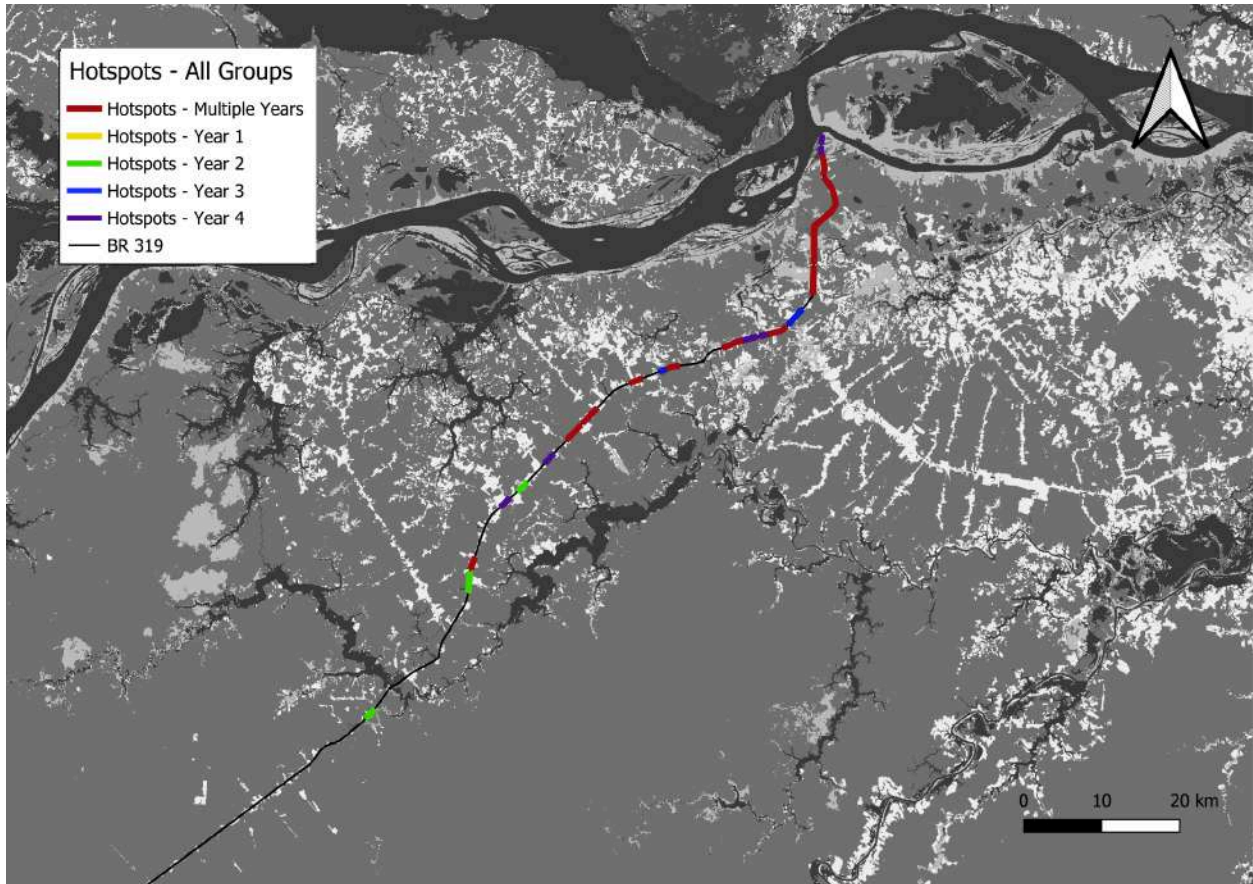


Figure 2. Hotspots (including all faunal groups) along ‘Segment A’ of BR 319 in each year between 2017 and 2021 and multiple years. Hotspots which repeat along our study are colored in red and represent all areas which share a hotspot location for two or more years. All other hotspots are highlighted in distinct colors indicating the respective years in which they were found.

For amphibians, hotspots were located at kilometers 9, 12, 19–20, 58–59, and 71 in year 1. In year 2, hotspots were recorded at kilometers 13, 17, 19, 41, 55–56, 59, 66, and 68. In year 3, hotspots occurred at kilometers 7, 9, 11, 18, 28–29, 35, 37, 44, 48, and 69. In year 4, a single

hotspot was identified at kilometer 1 (Figure 4). The most consistent hotspots over the years were at kilometers 9, 19, and 59, which appeared in at least two of the four periods analyzed.

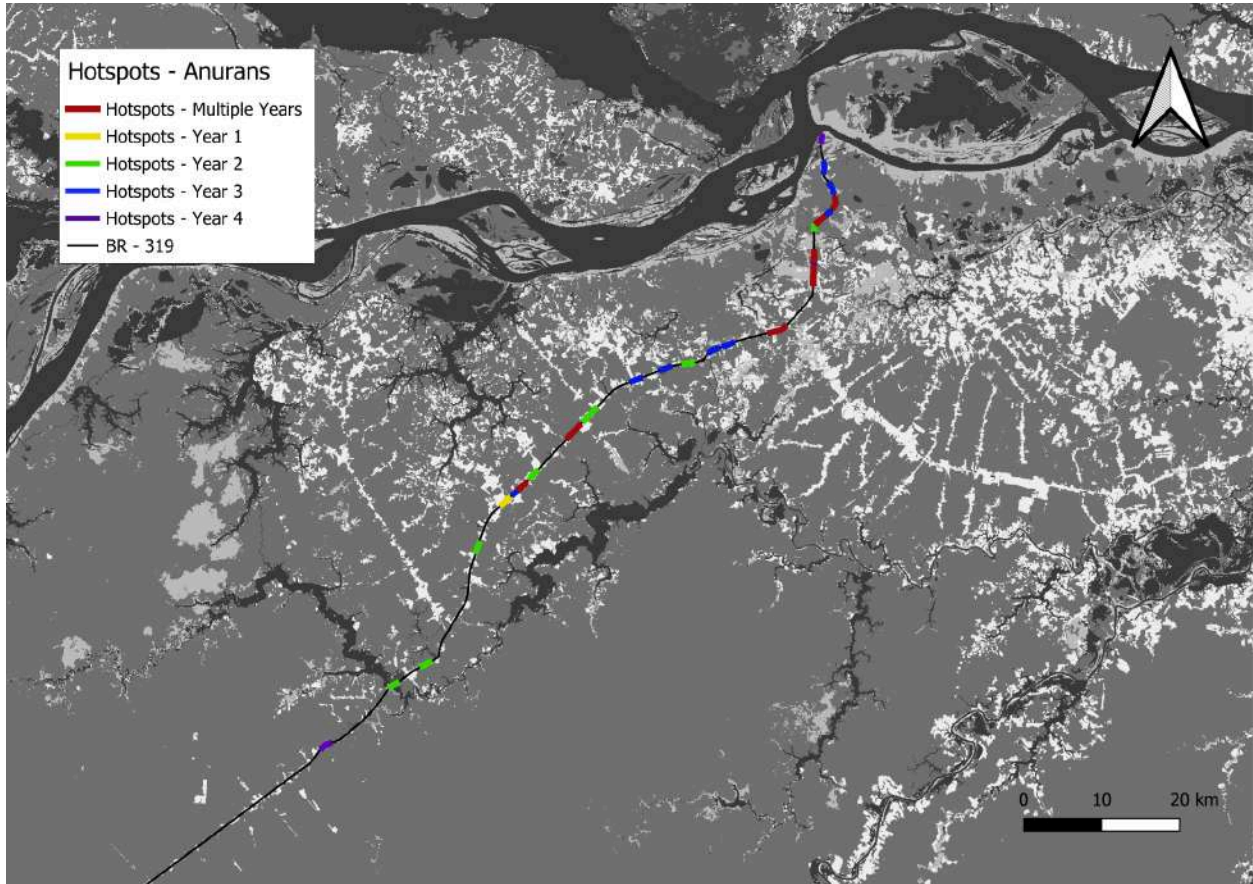


Figure 3. Hotspots of amphibians along ‘Segment A’ of BR 319 in each year between 2017 and 2021 and multiple years. Hotspots which repeat along our study are colored in red and represent all areas which share a hotspot location for two or more years. All other hotspots are highlighted in distinct colors indicating the respective years in which they were found.

For reptiles, annual variation in hotspot location patterns was relatively low, with over 95% of hotspots concentrated between kilometers 3 and 30. In year 1, hotspots were identified at kilometers 5, 8, 11, 14–17, 38, 51, and 83. In year 2, hotspots were recorded at kilometers 4–5, 10, 13–16, and 22. In year 3, hotspots occurred at kilometers 2–3, 6–7, 9, 12–15, 19–20, 26, 29, and 44. In year 4, hotspots were found at kilometers 2, 4, 6–9, 12–14, 28, 33, and 55 (Figure 5).

The most consistent hotspots over the years were at kilometers 2, 4, 6, 12, and 14, which appeared in at least three of the four periods analyzed.

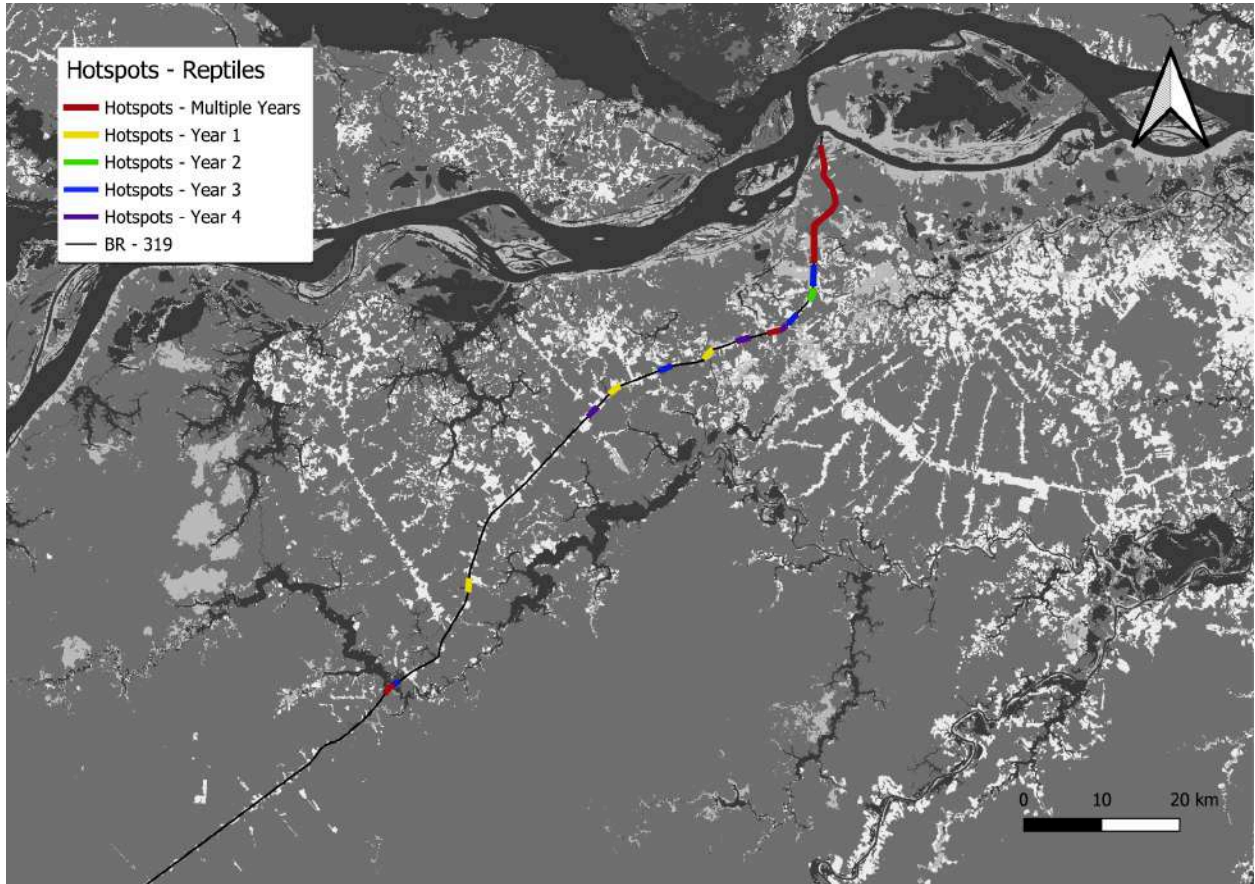


Figure 4. Hotspots of reptiles along ‘Segment A’ of BR 319 in each year between 2017 and 2021 and multiple years. Hotspots which repeat along our study are colored in red and represent all areas which share a hotspot location for two or more years. All other hotspots are highlighted in distinct colors indicating the respective years in which they were found.

For birds, we observed a significant variation in hotspot distribution patterns across annual monitoring cycles. In year 1, hotspots were located at kilometers 19, 48, 80, and 84. In year 2, hotspots occurred at kilometers 6, 14, 43, 55, 68, 70, and 82. In year 3, hotspots were identified at kilometers 25, 34, 36, and 44. In year 4, hotspots were at kilometers 1, 19, 30, 48, and 75 (Figure 3). The most consistent hotspots over the years were at kilometers 19 and 48, appearing in three of the four periods analyzed.

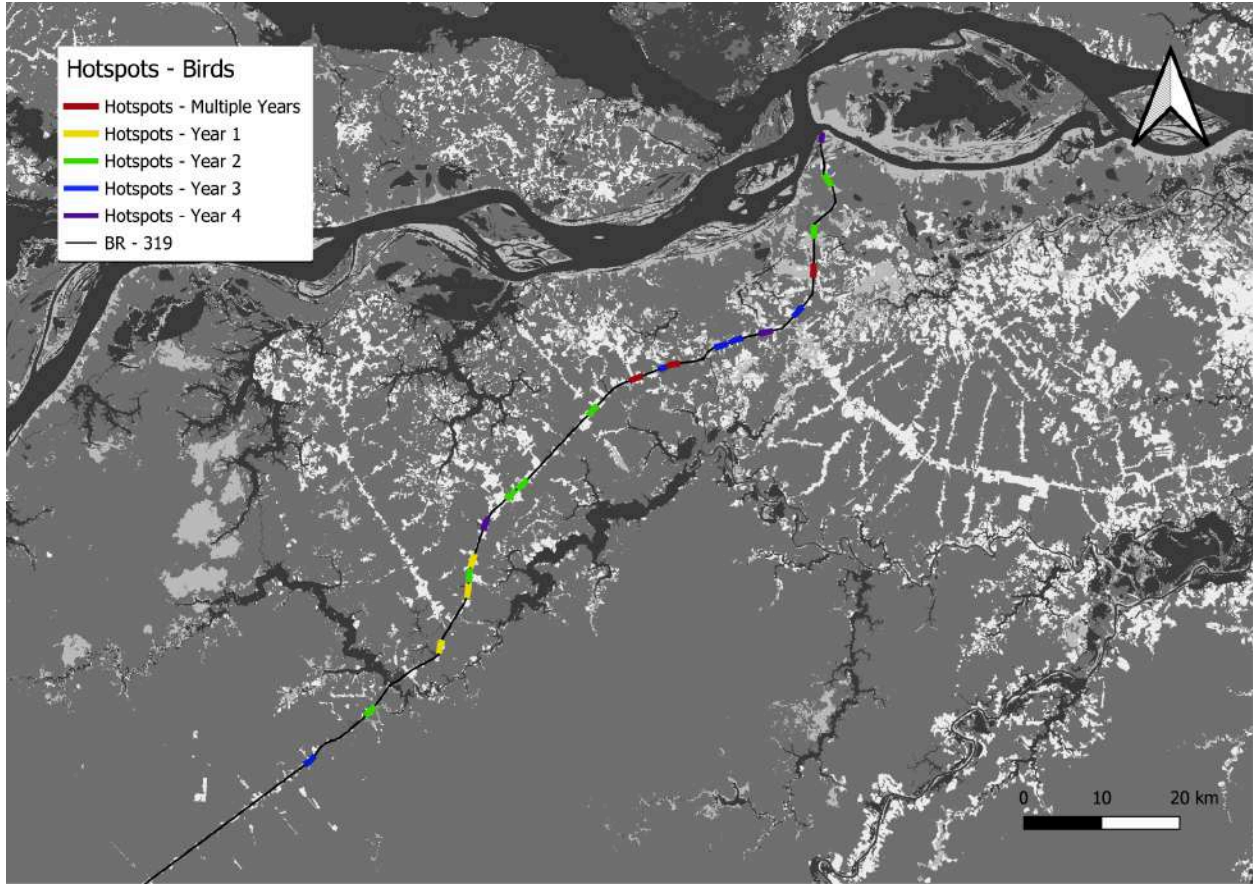


Figure 5. Hotspots of birds along ‘Segment A’ of BR 319 in each year between 2017 and 2021 and multiple years. Hotspots which repeat along our study are colored in red and represent all areas which share a hotspot location for two or more years. All other hotspots are highlighted in distinct colors indicating the respective years in which they were found.

Mammals exhibited the most distinct aggregation pattern among the taxonomic groups studied. While variation in hotspot locations was relatively small over the analyzed periods, mammal hotspots were less frequent compared to other groups. In year 1, hotspots were recorded at kilometers 76, 80, and 94. In year 2, they were at kilometers 63, 80, and 107. In year 3, hotspots were located at kilometers 11, 28, and 99. In year 4, hotspots occurred at kilometers 9 and 32 (Figure 6). The most consistent hotspots were at kilometers 80 and 107, appearing in two consecutive periods.

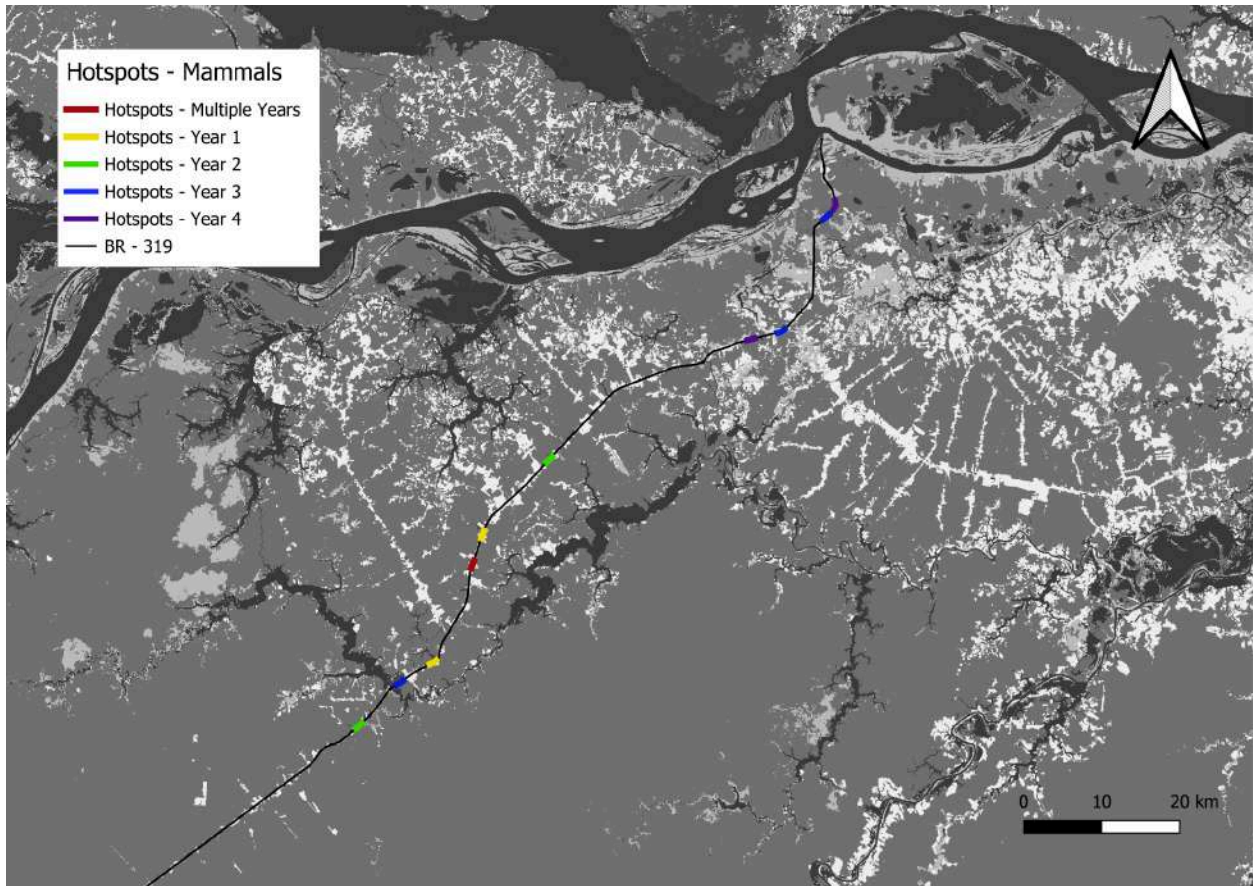


Figure 6. Hotspots of mammals along ‘Segment A’ of BR 319 in each year between 2017 and 2021 and multiple years. Hotspots which repeat along our study are colored in red and represent all areas which share a hotspot location for two or more years. All other hotspots are highlighted in distinct colors indicating the respective years in which they were found.

Climate Factors

Models assessing the influence of climatic conditions on roadkill revealed similar patterns across the groups. Both temperature and precipitation were found to influence roadkill, with all groups showing a positive correlation between higher temperatures and an increase in roadkill incidents. In contrast, a negative correlation between rainfall and roadkill was observed, indicating that higher rainfall decreased roadkill across all groups (Table 1).

Table 1. Final models of climatic variables on the different groups analyzed. Variables of Rainfall and Temperature are in millimeters and Celsius respectively. Beta values determine the direction and intensity of the interaction found, and VIF values determine the variable's correlation coefficient.

Group	Final Model	Variables	Beta	P-value	VIF
Anurans	Rainfall(mm) + Temperature(C)	Rainfall(mm)	-0.001511	3.30e-05	1.612
		Temperature(C)	0.738469	<2e-16	1.612
Reptiles	Rainfall(mm) + Temperature(C)	Rainfall(mm)	-0.001309	0.0237	1.591
		Temperature(C)	0.414551	1.10e-07	1.591
Birds	Rainfall(mm) + Temperature(C)	Rainfall(mm)	-0.001802	0.0165	1.553
		Temperature(C)	0.132322	0.2179	1.553
Mammals	Rainfall(mm) + Temperature(C)	Rainfall(mm)	-0.000016	0.9856	1.578
		Temperature(C)	0.3026	0.0197	1.578

Landscape Factors

Our adjusted models evaluating the impact of landscape factors on roadkill numbers revealed some common patterns across all studied groups. In buffers of 500m, 1000m, and 5000m, all groups showed a negative relationship between water and forest cover, meaning that an increase in the proportion of these landscape types consistently led to a reduction in roadkill numbers across all groups within these buffers (Table 2).

Amphibians and reptiles exhibited lower roadkill in segments with higher water, forest, and agricultural cover in buffers ranging from 500m to 5,000m for amphibians and from 500m to 10,000m for reptiles. However, the interaction between forest and water covers increased amphibian roadkill in the 500m buffer. At the 5,000m buffer, interactions between forest and agricultural cover led to an increase in amphibian roadkills, while at the 10,000m buffer, interactions between water and agricultural cover were associated with higher roadkill rates. For

reptiles, the interaction between water and either forest or agricultural cover, depending on the buffer scale, was linked to increased roadkill (Table 2).

For bird roadkill models, an increase in water, forest, and agricultural cover reduced roadkills in all buffers below 10,000m. However, the interaction between forest and agricultural cover had a positive effect on bird roadkills in the 1,000m and 5,000m buffers. At the 10,000m buffer, roadkill rates were higher in areas with greater water and agricultural cover. Mammal roadkill decreased with higher water and forest cover in all analyzed buffers. However, roadkill also decreased with higher agricultural cover in the lowest and highest buffers analyzed (500m and 10,000m). The interaction between agriculture and forest cover increased mammal roadkill at the 1,000m and 5,000m buffers, while the interaction between forest and water cover increased roadkill at the 5,000m and 10,000m buffers (Table 2).

Table 2. Final models of landscape factors. Beta values determine the direction and intensity of the interaction found, and VIF values determine the variable's correlation coefficient.

Buffer	Final Model	Variable	Beta	P-value	VIF
ANURANS					
500m	Water% * Forest% + Water% + Forest% + Farming%	Water%	-21.7463	5.33E-05	6.95172
		Farming%	-1.6147	0.001895	1.917455
		Forest%	-3.9207	2.88E-12	2.345862
		Water%: Forest%	51.5117	0.000114	6.836359
1000m	Water% + Forest% + Farming%	Water%	-7.5614	0.0013	1.38471
		Farming%	-1.7397	0.01161	1.9823
		Forest%	-3.7708	1.05E-12	1.902177
5000m	Water% + Forest% + Farming% + Forest%:Farming%	Water%	-8.447	0.000379	3.976797
		Farming%	-15.729	0.001005	28.408446
		Forest%	-7.603	1.68E-08	6.731983

		Forest%: Farming%	20.832	0.001125	16.679164
		Forest%	-1.6125	0.02514	2.270518
10000m	Forest% + Water%:Farming% + Forest%:Farming%	Water%: Farming%	82.611	7.42E-05	2.186837
		Forest%: Farming%	5.0727	0.00517	1.057216
REPTILES					
		Water%	-20.6889	3.83E-07	5.507039
		Farming%	-3.9067	2.12E-05	5.890916
500m	Water% * Forest% + Forest% * Farming%	Forest%	-3.7996	2.60E-15	3.158706
		Water%: Forest%	22.3236	0.03157	5.12831
		Forest%: Farming%	-6.8554	0.00496	4.455429
		Water%	-19.2198	2.13E-13	2.286869
1000m	Water% * Farming% + Forest%	Farming%	-8.951	<2e-16	2.04495
		Forest%	-6.1661	<2e-16	1.463817
		Water%: Farming%	79.7469	0.00277	2.225765
		Water%	-22.7703	<2e-16	11.843587
5000m	Water% * Forest% + Farming%	Farming%	-12.3421	<2e-16	3.298776
		Forest%	-12.0117	<2e-16	3.292301
		Water%: Forest%	23.6916	8.05E-06	9.173043
		Water%	-6.012	0.021387	14.067148
10000m	Water% * Farming% + Forest%	Farming%	-8.305	0.000531	7.263759
		Forest%	-6.843	9.70E-07	13.61752
		Water%: Farming%	96.25	2.71E-10	2.058495

BIRDS					
500m	Water% + Farming% + Forest%	Water%	-4.585	0.046	1.39641
		Farming%	-0.9395	0.0791	1.943157
		Forest%	-3.1872	3.78E-10	1.799457
1000m	Water% + Farming% + Forest% + Farming%:Forest%	Water%	-6.3727	0.01121	1.567648
		Farming%	-5.026	0.01348	11.861648
		Forest%	-4.9968	3.31E-08	3.509808
		Farming%: Forest%	9.0213	0.01963	8.015893
5000m	Water% + Farming% + Forest% + Farming%:Forest%	Water%	-5.597	0.040945	4.52805
		Farming%	-11.346	0.028166	29.97342
		Forest%	-5.585	0.000267	7.78822
		Farming: Forest%	16.873	0.011852	16.53537
10000m	Water% + Farming%	Water%	4.573	1.37E-05	1.114696
		Farming%	6.1599	2.81E-10	1.114696
MAMMALS					
500m	Water% * Forest%	Water%	-14.6222	0.009368	6.8865
		Forest%	-1.9201	0.000646	1.493346
		Water%: Forest%	53.8061	0.000242	6.874451
1000m	Water% * Forest% + Forest% * Farming%	Water%	-30.585	0.00591	16.158736
		Farming%	-11.417	0.001407	19.879832
		Forest%	-5.139	0.000211	4.464162
		Water%: Forest%	65.265	0.000772	14.637192
		Forest%: Farming%	21.157	0.000431	13.904734
5000m	Water% * Forest% + Forest% * Farming%	Water%	-21.573	0.00601	18.711745
		Farming%	-23.806	0.003355	44.039104

		Forest%	-5.397	0.008825	7.920169
		Water%: Forest%	35.625	0.004276	15.541902
		Forest%: Farming%	34.531	0.000484	27.239535
		Water%	-27.9559	1.78E-06	11.61376
10000m	Water% * Forest%	Forest%	-3.1046	0.000639	2.022671
		Water%: Forest%	61.5738	1.52E-08	9.000986

Discussion

The temporal variation of roadkill hotspots along BR-319 confirms the complexity of factors influencing wildlife mortality on highways. Our results largely support the initial hypothesis that roadkill hotspots would vary annually, with high roadkill areas not remaining constant over time. However, certain locations, such as kilometers 4, 6, 19, and 48, emerged as recurring hotspots across multiple groups. Those hotspots are located in significantly fragmented areas, which border, and partially include, the outer region of the city of Manaus. Even in smaller spatial scales, the environment around those kilometers shows a strong urban and agricultural presence, which indicates they may also be located in particularly heavy traffic areas. Three of those points are also located before and relatively nearby to the Araçá river bridge, a road feature which could serve as a wildlife attractive and influence roadkill patterns alongside nearby areas (Fraga et al. 2022).

The variation in most of the hotspot locations across taxonomic groups could be related to the ecology of the species. While mammals and birds have more dispersed hotspots that vary over the years, anurans and reptiles show more consistency in their hotspot locations. This is likely because anurans and reptiles move less across the landscape compared to birds and mammals and tend to be more faithful to their breeding areas (Taylor et al. 2020; Thais Almeida-Corrêa et al. 2020; Fischer 2023). The consistency of hotspots in certain sections aligns with the behavior of these species, which tend to concentrate in specific areas due to microclimatic conditions (Fischer 2023; Inman et al. 2022), where they are more vulnerable to

roadkill (Costa and Gomides 2024; Gomes et al. 2023). In contrast, mammals, with their broader movement patterns, exhibit roadkill fluctuations as they cover larger areas and have overlapping territories across different segments of the road (Teitelbaum and Mueller 2019). This explains why mammal hotspots are more dispersed and less consistent over the years compared to other groups. Even indirectly related events, such as changes in road traffic during the COVID-19 pandemic (Naveca et al. 2021), can impact highly responsive species. The pandemic caused frequent reductions in traffic, particularly in heavily affected areas like Amazonas (Naveca et al. 2021). Studies show these reductions had a varied effect on wildlife-vehicle collisions, sometimes increasing roadkills, but in other cases, having little or even a negative impact (Pokorny et al. 2022).

The hotspots are shaped by a dynamic interplay of climatic factors, landscape characteristics and animal behavior (Taylor et al. 2020) and we show that hotspot distribution in BR-319 is influenced by both microclimatic and landscape conditions, which shape roadkill patterns. These findings align with studies highlighting the influence of these factors on roadkill patterns (Bueno and Almeida 2019; Batista et al. 2022; Grilo et al. 2009; Medinas et al. 2021). Amphibians and reptiles exhibited a negative correlation with rainfall, contrary to our initial hypothesis. One possible explanation is the increased frequency of adverse weather events along BR-319, particularly during the rainy season, which reduces traffic flow (Li et al. 2022). The road's limited infrastructure and occasional flooding may exacerbate these effects by deteriorating road conditions and slowing down vehicles, further influencing wildlife mortality. Even though the section we studied is already paved, the lack of paving in other sections may inhibit the overall use of the road. Additionally, heavy rainfall may lead to carcass washout or accelerated decomposition, especially among smaller species (Rosa et al., 2012). Both amphibians and reptiles also showed higher roadkill numbers with increased temperatures, aligning with previous studies on reptiles, particularly those exhibiting thermoregulatory behavior (Laurance et al. 2009; Grilo et al. 2011). However, this pattern was less evident in amphibians, likely due to the unique seasonal dynamics of the Amazon. The Amazonian summer (June to November) is characterized by a pronounced dry season, followed by intense rainfall during the Amazonian winter (December to May), which may counteract the effects of persistently high temperatures. In this region, the interaction between temperature and rainfall is

complex. During the dry season, high temperatures coincide with much lower rainfall, creating a distinct microclimate with reduced soil moisture and humidity (Löbs et al. 2020). This differs from subtropical and temperate regions, where increased temperatures alone drive more predictable seasonal roadkill patterns, particularly when combined with summer rainfall. In the BR-319 region, amphibians may be less susceptible to higher roadkill rates during hot months because their activity is influenced by additional factors, such as lower humidity or reduced availability of suitable breeding sites in the landscape (Taylor et al. 2020).

For mammals and birds, climatic influences are often more species-specific, which has led to studies where aggregating species within broader groups fails to identify environmental causes for increased roadkill or only reveals correlations between roadkill patterns and species-specific physical or behavioral traits (Medrano-Vizcaíno et al. 2022; Rowe et al. 2015; Kent et al. 2021). However, some studies have also linked roadkill in both groups to higher rainfall and temperatures, suggesting that the composition of these groups can significantly impact their interactions with the local environment (Carvalho et al. 2015; Santana 2012).

Our results also reveal that forest cover consistently reduces roadkill across all species groups and spatial scales. This suggests that forested areas act as natural barriers, potentially limiting wildlife movement near roads and thereby decreasing the likelihood of roadkill. This finding contrasts with research from other regions, where forest cover has been linked to higher roadkill rates due to enhanced connectivity (Batista et al. 2022; Filius et al., 2020; Medrano-Vizcaíno et al. 2022). In more fragmented landscapes, wildlife often faces an increased need to move across roads in search of resources, leading to higher roadkill rates (Almeida-Corrêa et al. 2020; Fraga et al. 2022). Conversely, in well-preserved areas, like ecosystems along BR-319, animals are less likely to need extensive movement to fulfill their resource needs, which may reduce their exposure to roads. Similarly, wetland and agricultural areas were generally associated with lower roadkill rates across most species groups, which could suggest a general effect of non-urban areas creating a ‘safety buffer’ along the road.

Amphibians and reptiles, which are particularly sensitive to microclimatic shifts, experienced higher roadkill rates near areas where wetlands and agricultural land intersect, especially in the more urbanized zones along the first third of the road. This trend, evident only

within the 500m buffer scale, aligns with findings from previous studies, which identified roadkill patterns in these groups predominantly within smaller spatial scales, especially in amphibians (Laurance et al. 2014; Kouris et al. 2024). This can be attributed to their limited locomotion, reliance on specific microclimates, and preference for smaller landscape structures (Gonçalves et al. 2023; Kouris et al. 2024; Medrano-Vizcaíno et al. 2022; Taylor et al. 2020). Supporting this observation, our results show that the influence of wetlands and agricultural areas on roadkill rates in amphibians diminishes at larger spatial scales, vanishing entirely at the largest scale of 10,000m.

However, it is important to remember that effects of scale can vary across groups, species and populations, emphasizing that landscape influences on roadkill are region-specific and may depend on local ecological conditions (Freitas et al. 2013). For birds, for example, we have found the most distinct interaction at the 10,000m scale, in which both wetlands and agricultural coverage were found associated with an increased roadkill count. The majority of birds roadkills identified in this study were scavenger species of vultures (*Coragyps atratus*), which could indicate attraction to areas where other species suffered larger roadkill rates, such as we observed for amphibians around the paired wetlands and agricultural areas (Medrano-Vizcaíno et al. 2022).

Our study offers valuable insights into the spatiotemporal patterns of wildlife roadkill along BR-319. We find that preserving forest cover is the most effective strategy for mitigating roadkill in highly conserved areas like the Amazon, though this is challenging given that roads are major drivers of habitat fragmentation. It further underscores the critical importance of the political debate surrounding the paving of the BR-319 highway. Researchers have consistently warned that this project should not proceed without the prior establishment of robust governance policies to prevent deforestation and illegal occupation in the region (Fearnside et al. 2020). Our results also underscore the need for targeted conservation measures, such as wildlife corridors and ecological barriers, particularly in areas where fragmented landscapes intersect with high levels of human activity. These strategies are crucial for mitigating roadkill in the Amazon, a region characterized by unique and delicate ecosystems. The findings also emphasize the importance of considering both climatic and landscape factors in conservation planning, as these variables interact in complex ways that can influence wildlife mortality. By integrating these

considerations into road planning and conservation efforts, we can better safeguard biodiversity and reduce the negative impact of infrastructure on wildlife in the Amazon.

Acknowledgements

We thank Brazil's Departamento Nacional de Infraestrutura e Transportes (DNIT) for sharing the data used in this research. Furthermore, we express our deep gratitude to all of the professional researchers and consultants involved in the field collection effort and data analysis for all their hard work, which made this research possible. We also would like to extend our thanks to the Brazilian National Meteorological Institute for their efforts in collecting and making publicly available all the climate data for the variables used in the analysis for this study.

References

Almeida-Corrêa T, Frazão L, Costa DM, Menin M, Kaefer IL (2020) Effect of environmental parameters on squamate reptiles in an urban forest fragment in central Amazonia. *Acta Amazonica* 50: 239–245. <https://doi.org/10.1590/1809-4392201904423>

Asher S, Garg T, Novosad P (2020) The Ecological Impact of Transportation Infrastructure*. *The Economic Journal* 130: 1173–1199. <https://doi.org/10.1093/ej/ueaa013>

Barrientos R, Ascensão F, D'Amico M, Grilo C, Pereira HM (2021) The lost road: Do transportation networks imperil wildlife population persistence? *Perspectives in Ecology and Conservation* 19. <https://doi.org/10.1016/j.pecon.2021.07.004>

Batista G, Rascon N, Rosa C (2022) Vertebrados atropelados na BR-163, entorno da floresta nacional do Tapajós, Pará: influência dos padrões espaciais e climáticos. *Biodiversidade Brasileira* 12: 200–219. <https://doi.org/10.37002/biodiversidadebrasileira.v12i1.1802>

Brum FT, Graham CH, Costa GC, Hedges SB, Penone C, Radeloff VC, Rondinini C, Loyola R, Davidson AD (2017) Global priorities for conservation across multiple dimensions of mammalian diversity. *Proceedings of the National Academy of Sciences* 114: 7641–7646. <https://doi.org/10.1073/pnas.1706461114>

Bueno C, Almeida PJAL (2019) Sazonalidade de atropelamentos e os padrões de movimentos em mamíferos na BR-040 (Rio de Janeiro-Juiz de Fora). *Revista Brasileira de Zoociências* 12. Available from: <https://periodicos.ufjf.br/index.php/zoociencias/article/view/24467>

Caro TM, Shargel JA, Stoner CJ (2000) Frequency of MediumSized Mammal Road Kills in an Agricultural Landscape in California. *The American Midland Naturalist* 144: 362–369. <https://doi.org/10.2307/3082943>

Carvalho CF, Custódio AEI, Junior OM (2015) Wild vertebrates roadkill aggregations on the BR-050 highway, state of Minas Gerais, Brazil. *Bioscience Journal* 31: 951–959. <https://doi.org/10.14393/bj-v31n3a2015-27468>

Carvalho CF, Elizabeth A, Marçal Júnior, Oswaldo (2017) Influence of climate variables on roadkill rates of wild vertebrates in the cerrado biome, Brazil. *Biosci. j. (Online)* 33: 1632–1641. Available from: <https://pesquisa.bvsalud.org/portal/resource/pt/biblio-966527>

Costa ACG de L, Gomides SC (2024) Disentangling drivers of vertebrate roadkill in a protected area in the Amazon rainforest. *Austral Ecology* 49. <https://doi.org/10.1111/aec.13571>

Dulac J (2013) Estimating road and railway infrastructure capacity and costs to 2050 INFORMATION PAPER. Available from: https://www.ctc-n.org/sites/default/files/resources/transportinfrastructureinsights_final_web.pdf

Fearnside PM, Lima PM, Graça A (2006) RODOVIA BR-319: O CUSTO AMBIENTAL DE LIGAR O ARCO DO DESMATAMENTO AO CORAÇÃO DA AMAZÔNIA. Available from:

https://philip.inpa.gov.br/publ_livres/Preprints/2006/BR-319%20Sci%20American%20Brasil-3.pdf

Fearnside PM, Ferrante L, Andrade MBT (2020) BR-319 illegal side road threatens Amazon protected area, indigenous land (commentary). Available from: https://philip.inpa.gov.br/publ_livres/2020/Illegal_road_branching_off_BR-319_invades_protected_area.pdf

Ferrante L, Andrade MBT, Leite L, Junior CAS, Lima M, Junior MGC, Neto ECS, Campolina D, Carolino K, Diele-Viegas LM, Pereira EJAL, Fearnside PM (2021) Brazils Highway BR-319: The road to the collapse of the Amazon and the violation of indigenous rights. DIE ERDE · 152: 2021. <https://doi.org/10.12854/erde-2021-552>

Filius J, Hoek Y, Jarrín-V P, Hooft P (2020) Wildlife roadkill patterns in a fragmented landscape of the Western Amazon. Ecology and Evolution 10: 6623–6635. <https://doi.org/10.1002/ece3.6394>

Fischer EK (2023) Form, function, foam: evolutionary ecology of anuran nests and nesting behaviour. Philosophical Transactions of the Royal Society B 378. <https://doi.org/10.1098/rstb.2022.0141>

Forman RTT, Alexander LE (1998) ROADS AND THEIR MAJOR ECOLOGICAL EFFECTS. Annual Review of Ecology and Systematics 29: 207–231. <https://doi.org/10.1146/annurev.ecolsys.29.1.207>

Fraga LP, Maciel S, Zimbres BQC, Brandão RA, Rocha CR, Carvalho PJ (2022) Differences in Wildlife Roadkill Related to Landscape Fragmentation in Central Brazil. Anais da Academia Brasileira de Ciências 94. <https://doi.org/10.1590/0001-376520220220041>

Freitas SR, Sousa COM, Bueno C (2013) Effects of Landscape Characteristics on Roadkill of Mammals, Birds and Reptiles in a Highway Crossing the Atlantic Forest in Southeastern Brazil. Trb.org. Available from: <https://trid.trb.org/view/1345840>

Gomes DF, Bueno C, Pinna PH, Voitovicz-Cardoso M, Passos P (2023) March or Die: road-killed herpetofauna along BR-040 highway, an ancient road on the Atlantic Forest from Southeastern Brazil. *Biota Neotropica* 23. <https://doi.org/10.1590/1676-0611-bn-2022-1454>

Gonçalves LO, Brack IV, Zank C, Beduschi J, Kindel A (2023) Spatially prioritizing mitigation for amphibian roadkills based on fatality estimation and landscape conversion. *Frontiers in Ecology and Evolution* 11. <https://doi.org/10.3389/fevo.2023.1123292>

González-Suárez M, Ferreira FZ, Grilo C (2018) Spatial and species-level predictions of road mortality risk using trait data. *Global Ecology and Biogeography* 27: 1093–1105. <https://doi.org/10.1111/geb.12769>

Grilo C, Bissonette JA, Santos-Reis M (2009) Spatial–temporal patterns in Mediterranean carnivore road casualties: Consequences for mitigation. *Biological Conservation* 142: 301–313. <https://doi.org/10.1016/j.biocon.2008.10.026>

Grilo C, Ascensão F, Santos-Reis M, Bissonette JA (2011) Do well-connected landscapes promote road-related mortality? *European Journal of Wildlife Research* 57: 707–716. <https://doi.org/10.1007/s10344-010-0478-6>

Grilo C, Borda-de-Água L, Beja P, Goolsby E, Soanes K, Roux A, Koroleva E, Ferreira FZ, Gagné SA, Wang Y, González-Suárez M (2021) Conservation threats from roadkill in the global road network. *Global Ecology and Biogeography* 30: 2200–2210. <https://doi.org/10.1111/geb.13375>

Ha H, Shilling F (2018) Modelling potential wildlife-vehicle collisions (WVC) locations using environmental factors and human population density: A case-study from 3 state highways in

Central California. Ecological Informatics 43: 212–221.
<https://doi.org/10.1016/j.ecoinf.2017.10.005>

Husby M (2016) Factors affecting road mortality in birds. 212-224 93. Available from:
<https://nordopen.nord.no/nord-xmlui/handle/11250/2434867>

Inman RD, Esque TC, Nussear KE (2022) Dispersal limitations increase vulnerability under climate change for reptiles and amphibians in the southwestern United States. *The Journal of Wildlife Management* 87. <https://doi.org/10.1002/jwmg.22317>

INMET Instituto Nacional de Meteorologia. Instituto Nacional de Meteorologia. Available from:
<https://portal.inmet.gov.br>.

Kent E, Schwartz ALW, Perkins SE (2021) Life in the fast lane: roadkill risk along an urban–rural gradient. *Journal of Urban Ecology* 7. <https://doi.org/10.1093/jue/juaa039>

Kouris AD, Christopoulos A, Vlachopoulos K, Christopoulou A, Dimitrakopoulos PG, Zevgolis YG (2024) Spatiotemporal Patterns of Reptile and Amphibian Road Fatalities in a Natura 2000 Area: A 12-Year Monitoring of the Lake Karla Mediterranean Wetland. *Animals* 14: 708–708.
<https://doi.org/10.3390/ani14050708>

Laurance WF, Goosem M, Laurance SGW (2009) Impacts of roads and linear clearings on tropical forests. *Trends in Ecology & Evolution* 24: 659–669.
<https://doi.org/10.1016/j.tree.2009.06.009>

Laurance WF, Clements GR, Sloan S, O’Connell CS, Mueller ND, Goosem M, Venter O, Edwards DP, Phalan B, Balmford A, Van Der Ree R, Arrea IB (2014) A global strategy for road building. *Nature* 513: 229–232. <https://doi.org/10.1038/nature13717>

Li X, Hu Z, Tseng Y, Liu Y, Liang P (2022) A Historical Perspective of the La Niña Event in 2020/2021. *Journal of Geophysical Research: Atmospheres* 127. <https://doi.org/10.1029/2021jd035546>

Löbs N, Walter D, Barbosa CGG, Brill S, Alves RP, Cerqueira GR, Sá MO, Araújo AC, Oliveira LR, Ditas F, Moran-Zuloaga D, Florentino APP, Wolff S, Godoi RHM, Kesselmeier J, Oliveira SM, Andreae MO, Pöhlker C, Weber B (2020) Microclimatic conditions and water content fluctuations experienced by epiphytic bryophytes in an Amazonian rain forest. *Biogeosciences* 17: 5399–5416. <https://doi.org/10.5194/bg-17-5399-2020>

MapBiomas Project (2024) Plataforma - MapBiomas Brasil. [Mapbiomas.org](https://plataforma.brasil.mapbiomas.org). Available from: <https://plataforma.brasil.mapbiomas.org>.

Marques I, Ferreira MS, Lacet C, Bueno C (2022) Spatial patterns of carnivore roadkill in a high-traffic-volume highway in the endangered Brazilian Atlantic Forest. *Mammalian biology* 102: 477–487. <https://doi.org/10.1007/s42991-022-00247-1>

Medinas D, Marques JT, Costa P, Santos S, Rebelo H, Barbosa AMárcia, Mira A (2021) Spatiotemporal persistence of bat roadkill hotspots in response to dynamics of habitat suitability and activity patterns. *Journal of Environmental Management* 277: 111412. <https://doi.org/10.1016/j.jenvman.2020.111412>

Medrano-Vizcaíno P, Grilo C, Brito-Zapata D, González-Suárez M (2023) Landscape and road features linked to wildlife mortality in the Amazon. *Biodiversity and Conservation* 32. <https://doi.org/10.1007/s10531-023-02699-4>

Medrano-Vizcaíno P, Grilo C, Campos F, Douglas W, Melinski RD, Schultz ED, González-Suárez M (2022) Roadkill patterns in Latin American birds and mammals. *Global Ecology and Biogeography* 31: 1756–1783. <https://doi.org/10.1111/geb.13557>

Mota L, Alves C, Secco H, Edson N (2023) Hotspots and hotmoments of wildlife roadkills along a main highway in a high biodiversity area in Brazilian Amazonia. *Acta Amazonica* 53: 42–52. <https://doi.org/10.1590/1809-4392202201871>

Naveca FG, Nascimento V, de Souza VC, Corado A de L, Nascimento F, Silva G, Costa Á, Duarte D, Pessoa K, Mejía M, Brandão MJ, Jesus M, Gonçalves L, Costa CF, Sampaio V, Barros D, Silva M, Mattos T, Pontes G, Abdalla L (2021) COVID-19 in Amazonas, Brazil, was driven by the persistence of endemic lineages and P.1 emergence. *Nature Medicine* 27: 1230–1238. <https://doi.org/10.1038/s41591-021-01378-7>

Pinto T, Santos SM, Mira A, Sillero N (2023) Importance of water availability for amphibian roadkill in a mediterranean landscape. *Biodiversity and Conservation* 32: 2513–2537. <https://doi.org/10.1007/s10531-023-02616-9>

Pokorny B, Cerri J, Bužan E (2022) Wildlife roadkill and COVID-19: A biologically significant, but heterogeneous, reduction. *Journal of Applied Ecology* 59. <https://doi.org/10.1111/1365-2664.14140>

QGIS Development Team (2024) QGIS Geographic Information System. Available from: www.qgis.org.

R Core Team (2024) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Available from: <https://www.r-project.org/>.

Rowe KC, Rowe KMC, Tingley MW, Koo MS, Patton JL, Conroy CJ, Perrine JD, Beissinger SR, Moritz C (2015) Spatially heterogeneous impact of climate change on small mammals of montane California. *Proceedings of the Royal Society B: Biological Sciences* 282: 20141857. <https://doi.org/10.1098/rspb.2014.1857>

Salazar BC, Montoya LR (2020) Population viability analysis of common marsupials, *Didelphis marsupialis* and *Didelphis virginiana*, in a scenario of constant loss of native vegetation. *Mammalia* 84: 475–482. <https://doi.org/10.1515/mammalia-2019-0130>

Santos E, Cordova M, Rosa C, Rodrigues D (2022) Hotspots and Season Related to Wildlife Roadkill in the Amazonia–Cerrado Transition. *Diversity* 14: 657. <https://doi.org/10.3390/d14080657>

Taylor EN, Diele-Viegas LM, Gangloff EJ, Hall JM, Halpern B, Massey MD, Rödder D, Rollinson N, Spears S, Sun B, Telemeco RS (2020) The thermal ecology and physiology of reptiles and amphibians: A user’s guide. *Journal of Experimental Zoology Part A: Ecological and Integrative Physiology* 335: 13–44. <https://doi.org/10.1002/jez.2396>

Teitelbaum CS, Mueller T (2019) Beyond Migration: Causes and Consequences of Nomadic Animal Movements. *Trends in Ecology & Evolution* 34: 569–581. <https://doi.org/10.1016/j.tree.2019.02.005>

Supplementary Files

Table S1. Table of highest, lowest and average values found for each landscape type (water cover, farming land and wooded forest) within each individual buffer used. Highest and lowest values are in percentage of total area cover for the segment in which the value was located.

Buffer	Highest Value (%)	Lowest Value (%)	Average (%)
Water Cover			
500m	25.10	0.00	2.41
1000m	39.20	0.00	2.14
5000m	37.80	0.00	2.93
10000m	39.00	0.00	4.84
Farmland			
500m	75.40	0.00	25.25
1000m	68.70	0.30	18.15
5000m	39.50	0.50	9.96
10000m	33.00	0.40	8.71
Forest Cover			
500m	94.90	10.60	54.73
1000m	96.20	17.20	67.17
5000m	98.40	28.90	79.57
10000m	98.90	37.20	78.34

Table S2. Complete list of species, as well as number of individual roadkill register of each species found, used in this study. All roadkill events within this list were registered along the ‘Segment A’ of BR-319, from October 2017 to September 2021. All common names in the register reference to the locally and most commonly used name for the species in Brazilian Portuguese. All names including the NID (Not identified) indicate that the individuals were not identified up to the level of species, but all were identified up to the lowest possible taxonomic level.

Scientific Name	Common Name	Number of Individuals
Amphibians		
<i>Anura</i> NID	Anuro	14
<i>Boana lanciformes</i>	Perereca-cabrinha	2
<i>Hylidae</i> NID	Perereca	5
<i>Leptodactylus macrosternum</i>	Gia	3
<i>Leptodactylus pentadactylus</i>	Rã-pimenta	1
<i>Leptodactylus</i> sp.	Rã	4
<i>Rhinella marina</i>	Sapo-cururu	133
<i>Siphonops</i> sp.	Cecília	1
Birds		
<i>Agamia agami</i>	Garça-da-mata	1
<i>Agelaioides badius</i>	Asa-de-telha	1
<i>Ardea alba</i>	Garça-branca-grande	1
<i>Ardea cocoi</i>	Garça-moura	2
<i>Ardeidae</i> NID	Garça	1

<i>Athene cunicularia</i>	Coruja-buraqueira	1
Bird NID	Ave	12
<i>Brotogeris versicolurus</i>	Periquito-de-asa-branca	1
<i>Bubulcus ibis</i>	Garça-vaqueira	1
<i>Caprimulgidae</i> NID	Bacurau	2
<i>Caracara plancus</i>	Carcará	1
<i>Cathartes</i> sp.	Urubu	16
<i>Chloroceryle americana</i>	Martim-pescador-pequeno	1
<i>Chloroceryle inda</i>	Martim-pescador-da-mata	2
<i>Coccyzua minuta</i>	Chincoã-pequeno, chincoãzinho	1
<i>Columbidae</i> NID	Pomba	1
<i>Columbina minuta</i>	Rolinha-de-asa-canela	1
<i>Columbina talpacoti</i>	Rolinha-roxa	1
<i>Coragyps atratus</i>	Urubu-de-cabeça-preta	44
<i>Crotophaga ani</i>	Anu-preto	9
<i>Crotophaga major</i>	Anu-coroça	1
<i>Crypturellus cinereus</i>	inambu-pixuna	1
<i>Elaenia</i> sp.	Guaracava	2
<i>Emberizoides herbicola</i>	Canário-do-campo	1
<i>Jacana jacana</i>	Jaçanã, piaçoca, narceja	1
<i>Megaceryle torquata</i>	Martim-pescador-grande	1
<i>Megascops choliba</i>	Corujinha-do-mato	4
<i>Mesembrinibis cayennensis</i>	Coró-coró	2
<i>Milvago chimachima</i>	Gavião-carrapateiro	1

<i>Myiozetetes cayanensis</i>	Bem-te-vizinho	1
<i>Nannopterum brasilianus</i>	Biguá, Mergulhão	1
<i>Paroaria gularis</i>	Cardeal-da-amazônia	1
<i>Passeriformes</i> NID	Pássaro	7
<i>Ramphocelus carbo</i>	Pipira-vermelha	5
<i>Rupornis magnirostris</i>	Gavião-carijó	2
<i>Sporophila</i> sp.	Caboclinho	3
<i>Stelgidopteryx ruficollis</i>	Andorinha-serradora	2
<i>Strigiformes</i> NID	Coruja nid	1
<i>Sturnella militaris</i>	Polícia-inglesa-do-norte	1
<i>Tangara episcopus</i>	Sanhaçu-da-amazônia	2
<i>Thraupis palmarum</i>	Sanhaçu-coqueiro	1
<i>Troglodytes musculus</i>	Curuíra	1
<i>Tyrannus melancholicus</i>	Suiriri	5
<i>Tyrannus savana</i>	Tesourinha	3
<i>Volatinia jacarina</i>	Tiziu	2
Mammals		
<i>Cabassous unicinctus</i>	Tatu-de-rabo-mole	1
<i>Chiroptera</i> NID	Morcego-insetívoro	1
<i>Coendou prehensilis</i>	Ouriço-cacheiro	3
<i>Dasyopus</i> sp.	Tatu	2
<i>Didelphis marsupialis</i>	Mucura	85
<i>Echimyidae</i> NID	Rato-de-espinho	1
<i>Eira barbara</i>	Irara	3

<i>Lontra longicaudis</i>	Lontra	1
<i>Mammalia</i> NID	Mamífero de porte médio	2
<i>Tamandua tetradactyla</i>	Tamanduá-mirim	8
Reptiles		
<i>Alligatoridae</i> NID	Jacaré	54
<i>Ameiva ameiva</i>	Calango	10
<i>Amphisbaena fuliginosa</i>	Cobra-cega, Cobra-de-duas-cabeças	1
<i>Anilius scytale</i>	Falsa-coral	1
<i>Boa constrictor</i>	Jiboia	9
<i>Caiman crocodilus</i>	Jacaretinga	33
<i>Chironius exoletus</i>	Cobra-cipó	1
<i>Chironius multiventris</i>	Cobra-cipó	1
<i>Chironius scurrulus</i>	Surucucu-fogo, cobra-cipó	1
<i>Chironius</i> sp.	Cobra cipó	8
<i>Crocodylus amazonicus</i>	Lagarto-jacareana	1
<i>Drepanoides anomalus</i>	Cobra-vermelha, falsa-coral	3
<i>Epicrates cenchria</i>	Jiboia-arco-íris	2
<i>Erythrolamprus reginae</i>	Cobra-d'água	1
<i>Eunectes murinus</i>	Sucuri	8
<i>Helicops angulatus</i>	Cobra-d'água	1
<i>Helicops leopardinus</i>	Cobra-d'água	1
<i>Hydrodynastes gigas</i>	Cobra-d'água-grande	30
<i>Hydrops triangularis</i>	Cobra-d'água	1
<i>Iguana iguana</i>	Iguana	27

<i>Imantodes cenchoa</i>	Dormideira	1
<i>Mastigodryas boddaerti</i>	Corredeira	1
<i>Micrurus spixii</i>	Cobra-coral	1
<i>Oxybelis aeneus</i>	Cobra-bicuda	1
<i>Oxybelis fulgidus</i>	Cobra-bicuda	3
<i>Oxyrhopus melanogenys</i>	Falsa-coral	1
<i>Paleosuchus palpebrosus</i>	Jacaré-pedra	1
<i>Paleosuchus</i> sp.	Jacaré	3
<i>Paleosuchus trigonatus</i>	Jacaré-coroa	1
<i>Podocnemis unifilis</i>	Tracajá	1
<i>Reptilia</i> NID	Réptil NID	2
<i>Serpentes</i> NID	Serpente NID	25
<i>Spilotes pullatus</i>	Caninana	9
<i>Teiidae</i> NID	Teiu	1
<i>Testudines</i> NID	Quelônio NID	1
<i>Tupinambis teguixin</i>	Jacuraru	5

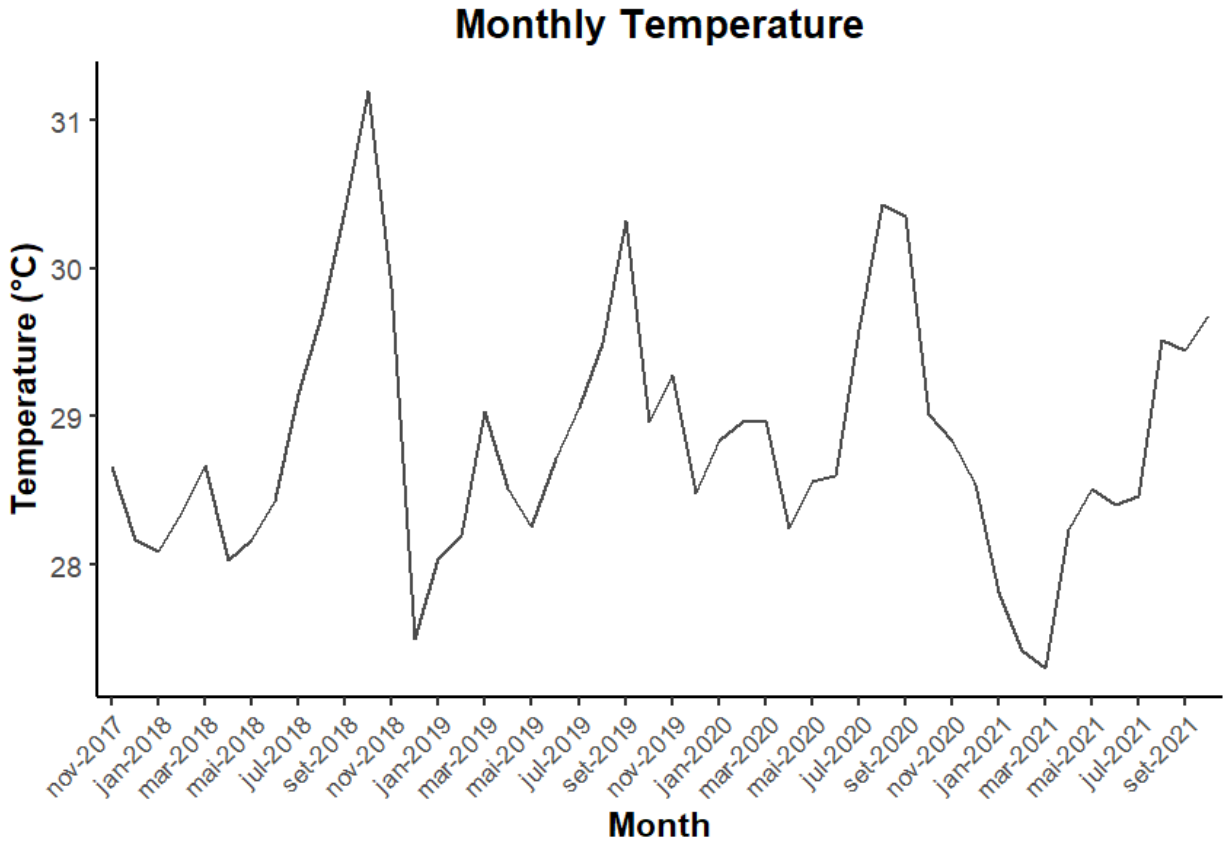


Figure S1. Monthly values of the average temperature calculated for each month of our study period, from October 2017 to September 2021.

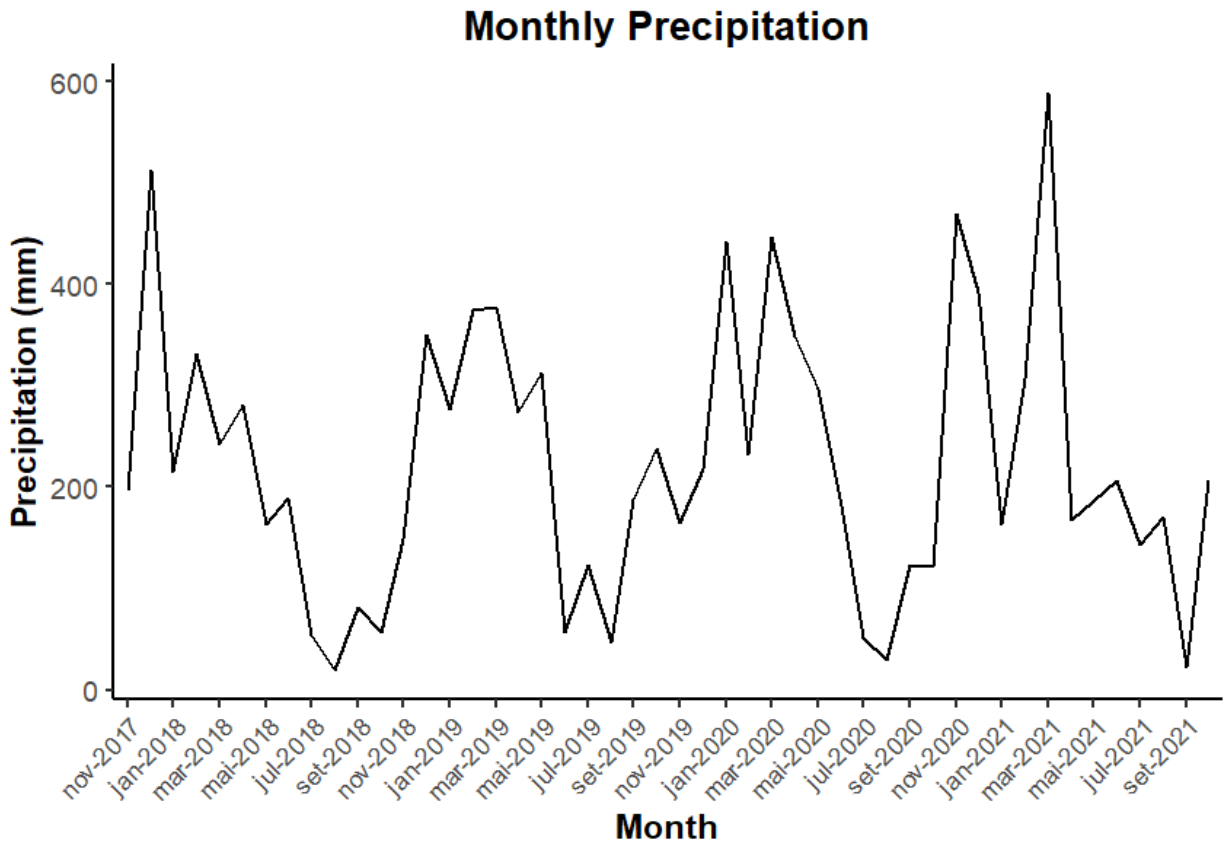


Figure S2. Monthly values of the total accumulated precipitation for each month of our study period, from October 2017 to September 202

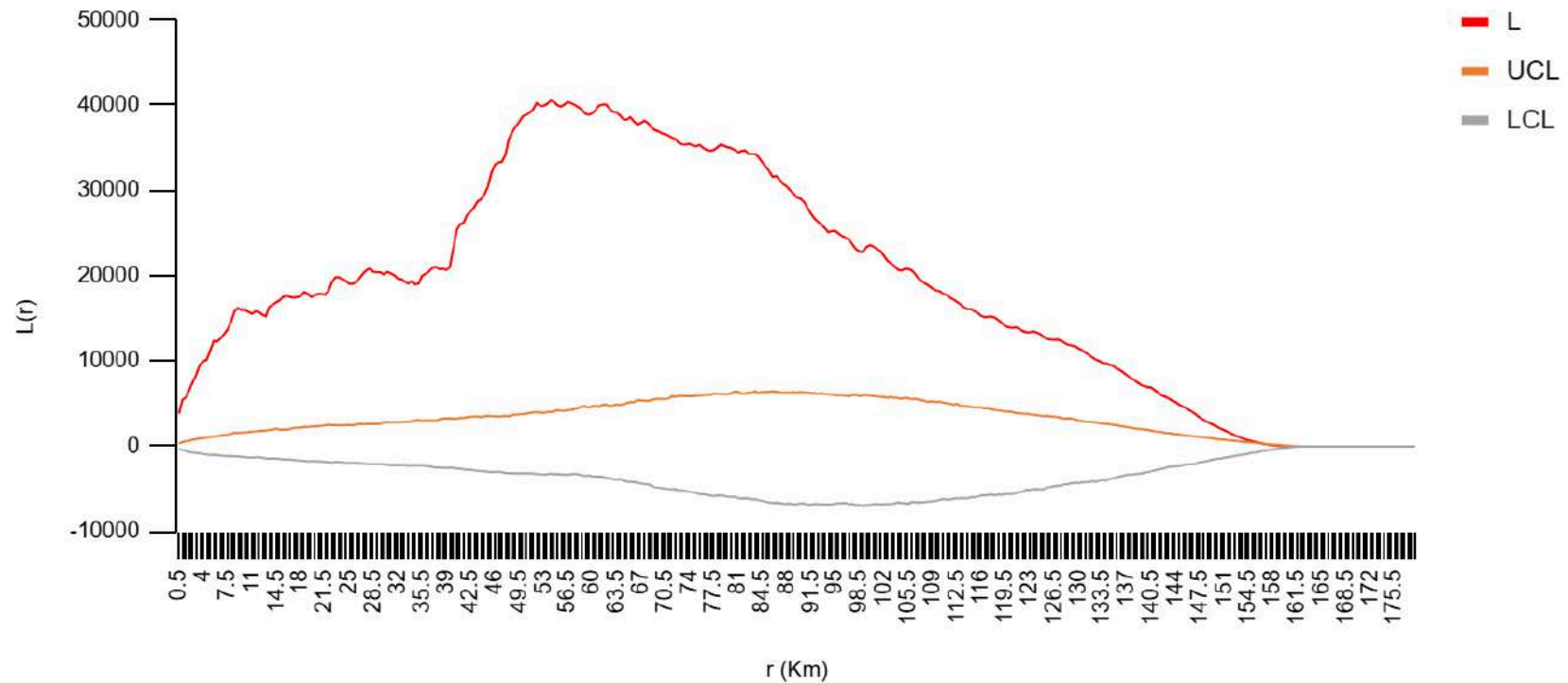


Figure S3. Roadkill aggregation graphs for amphibians in accordance with the 500m radius used in our analysis for the first year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

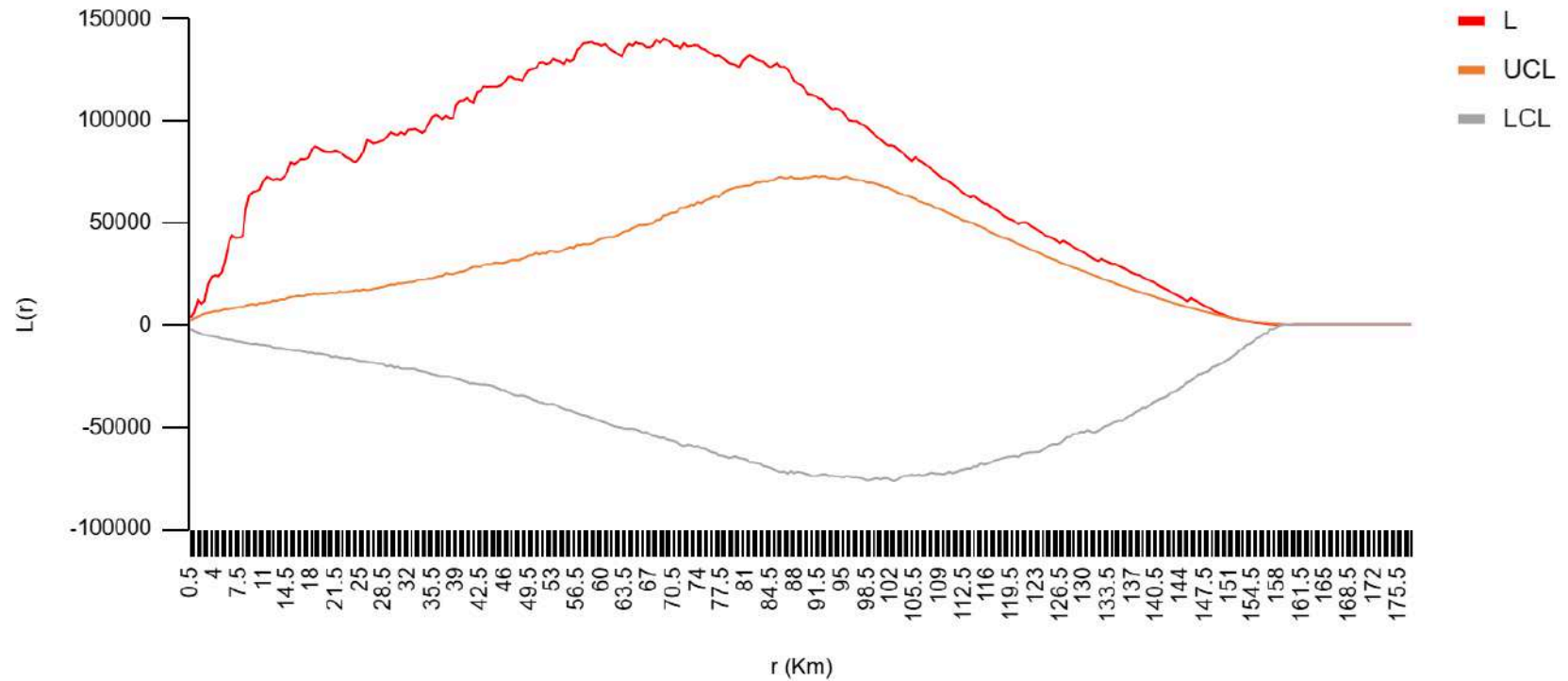


Figure S4. Roadkill aggregation graphs for amphibians in accordance with the 500m radius used in our analysis for the second year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

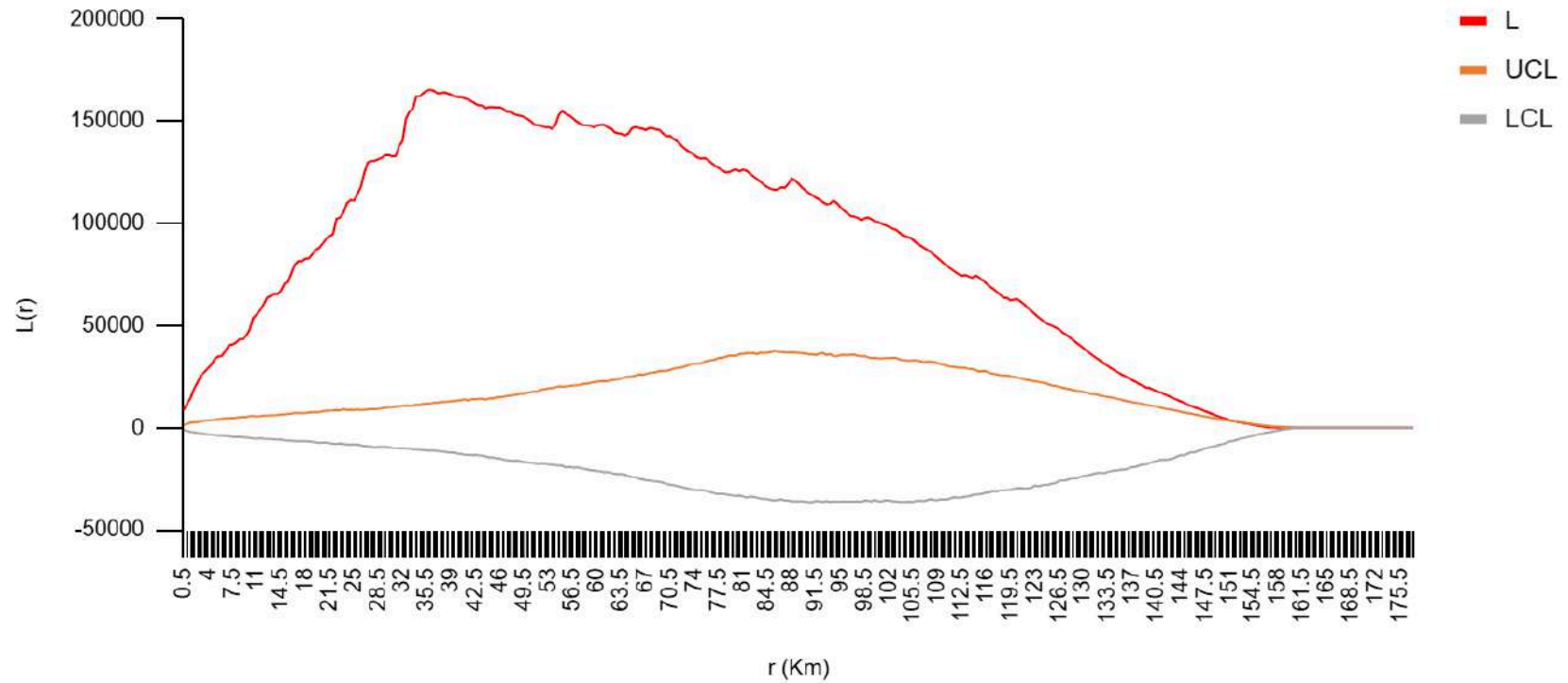


Figure S5. Roadkill aggregation graphs for amphibians in accordance with the 500m radius used in our analysis for the third year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

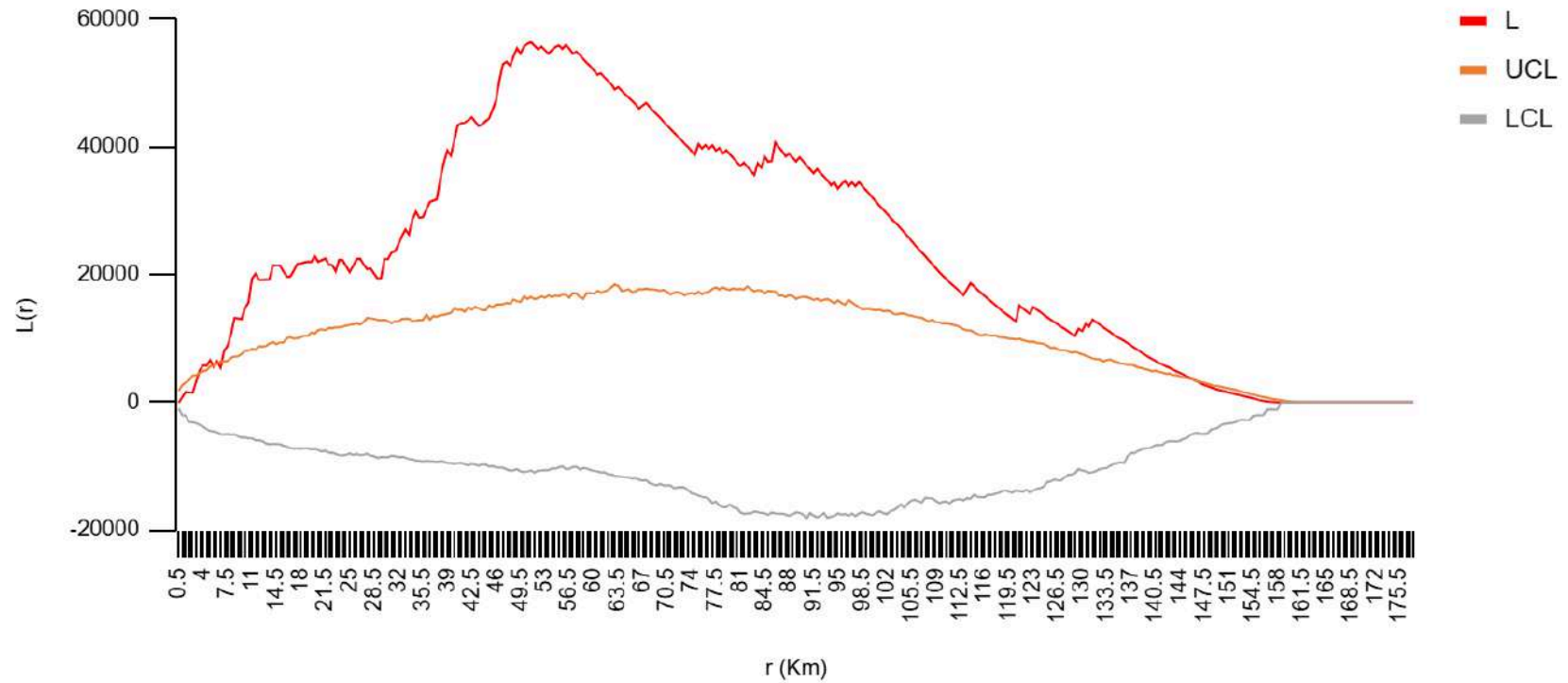


Figure S6. Roadkill aggregation graphs for amphibians in accordance with the 500m radius used in our analysis for the fourth year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

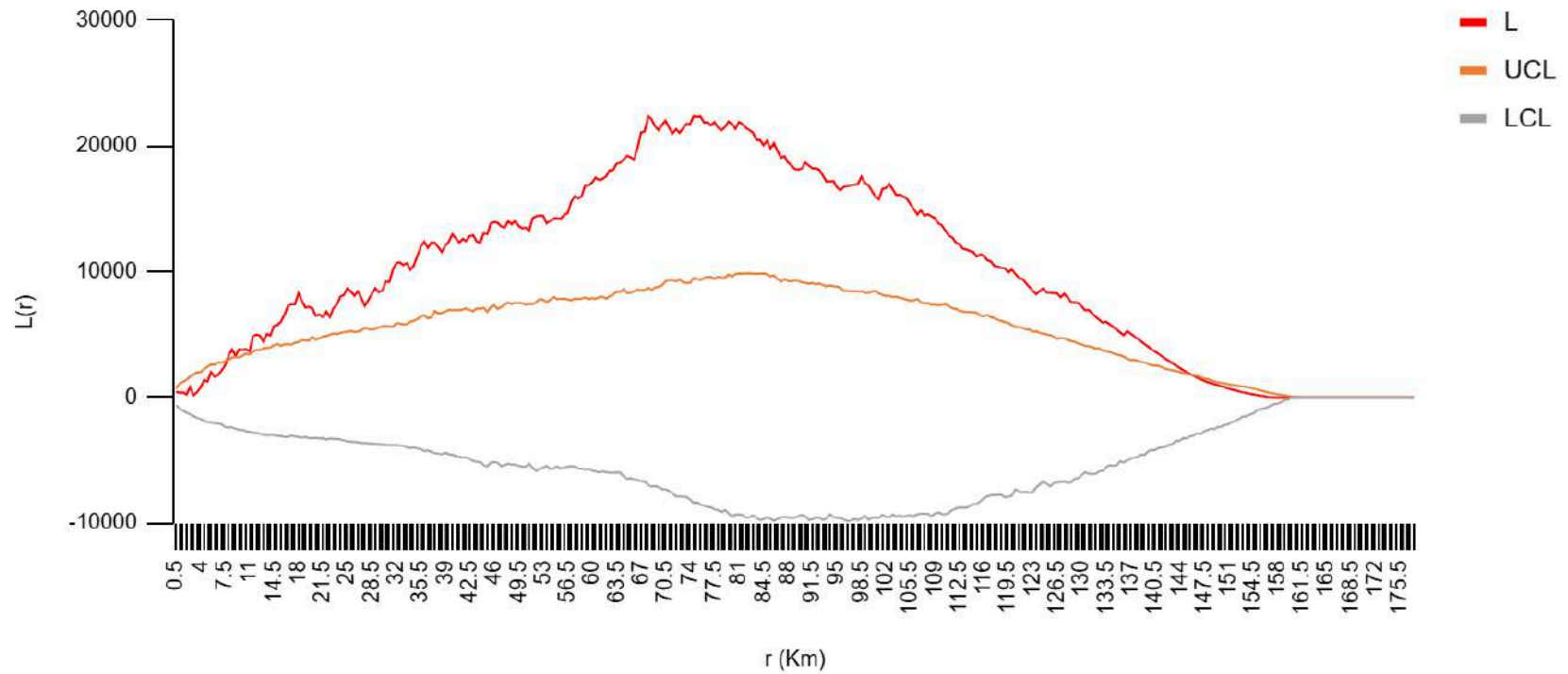


Figure S7. Roadkill aggregation graphs for birds in accordance with the 500m radius used in our analysis for the first year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

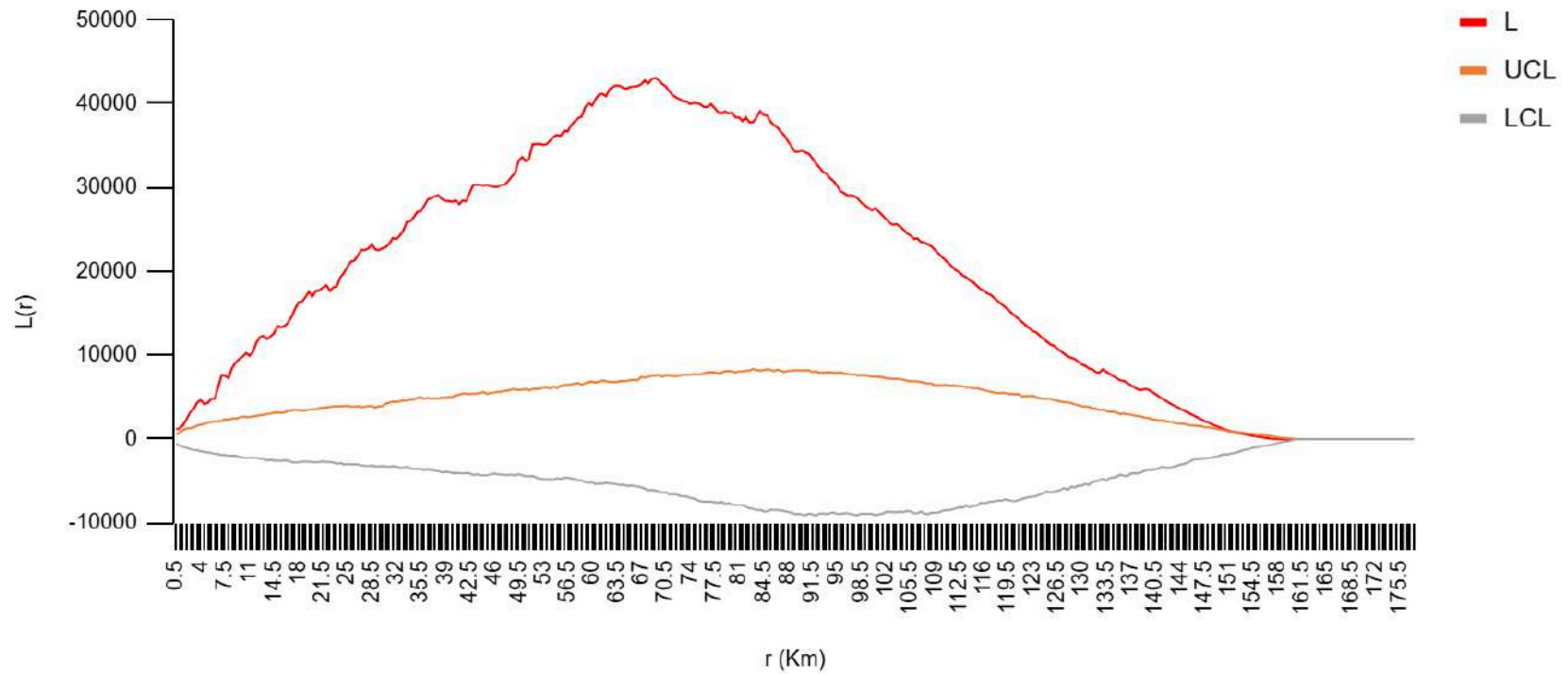


Figure S8. Roadkill aggregation graphs for birds in accordance with the 500m radius used in our analysis for the second year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

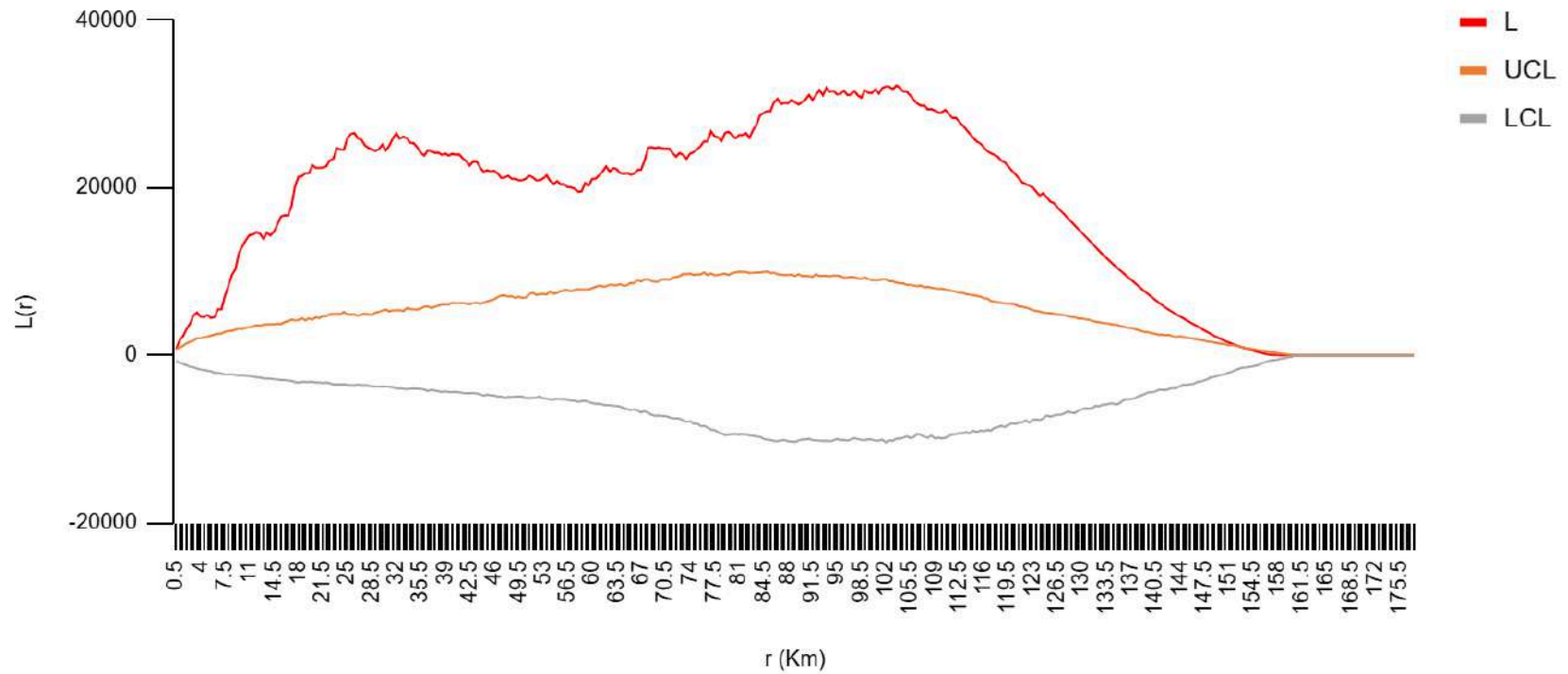


Figure S9. Roadkill aggregation graphs for birds in accordance with the 500m radius used in our analysis for the third year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

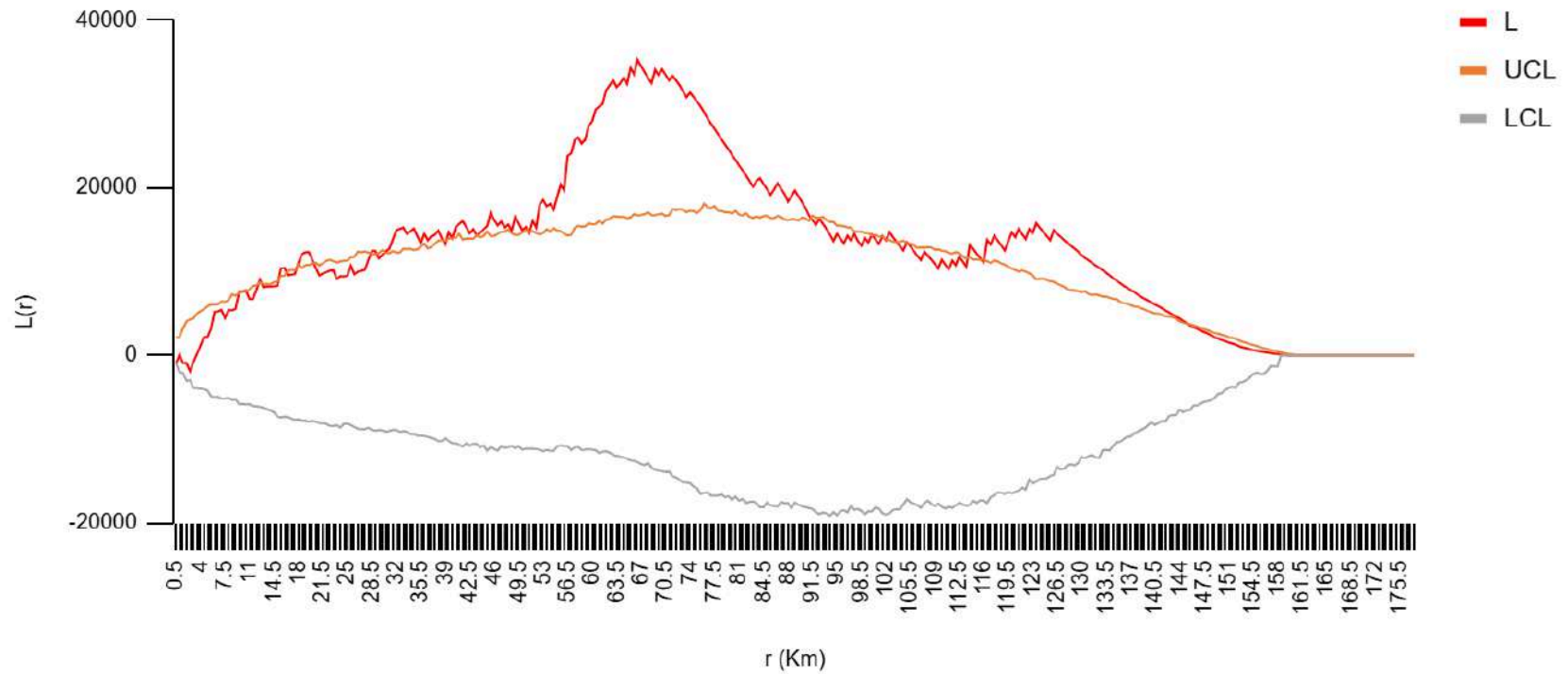


Figure S10. Roadkill aggregation graphs for birds in accordance with the 500m radius used in our analysis for the third year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

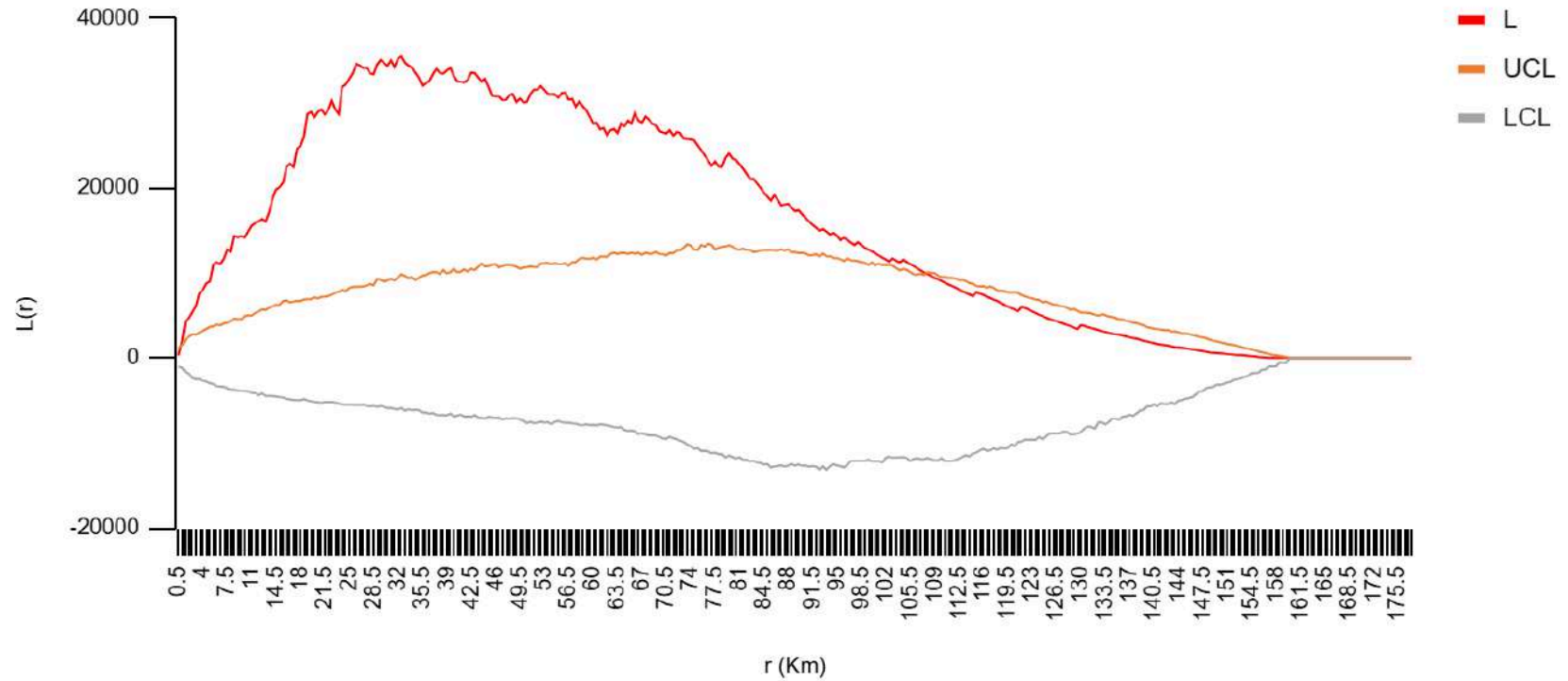


Figure S11. Roadkill aggregation graphs for mammals in accordance with the 500m radius used in our analysis for the first year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

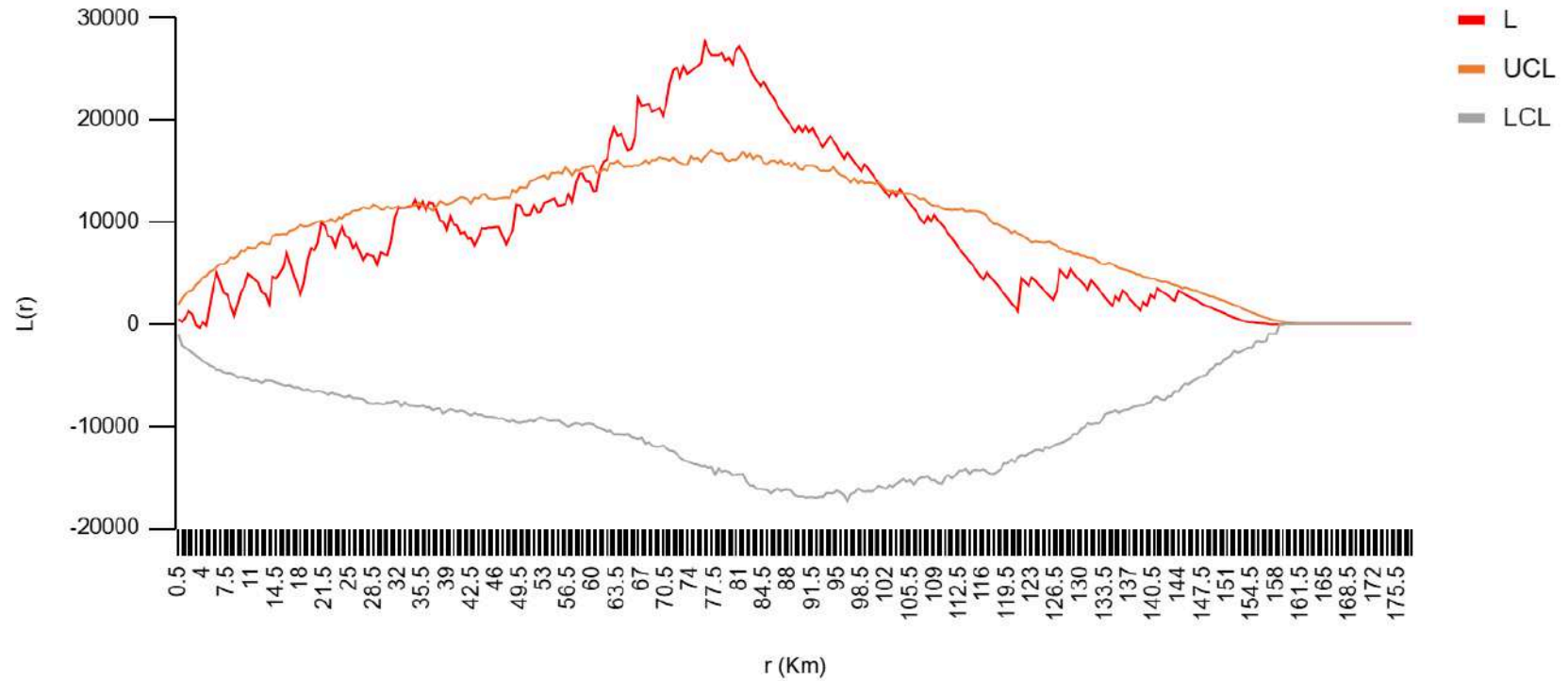


Figure S12. Roadkill aggregation graphs for mammals in accordance with the 500m radius used in our analysis for the second year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

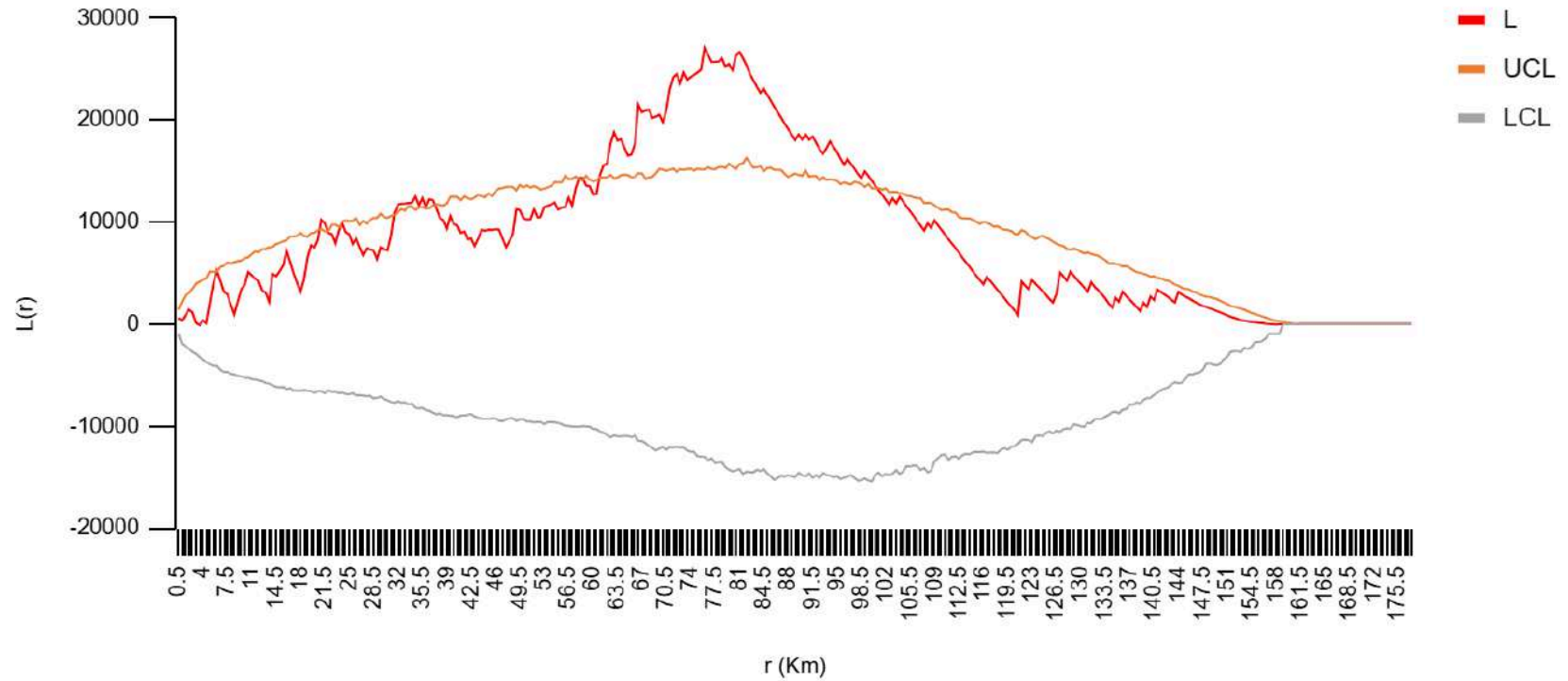


Figure S13. Roadkill aggregation graphs for mammals in accordance with the 500m radius used in our analysis for the third year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

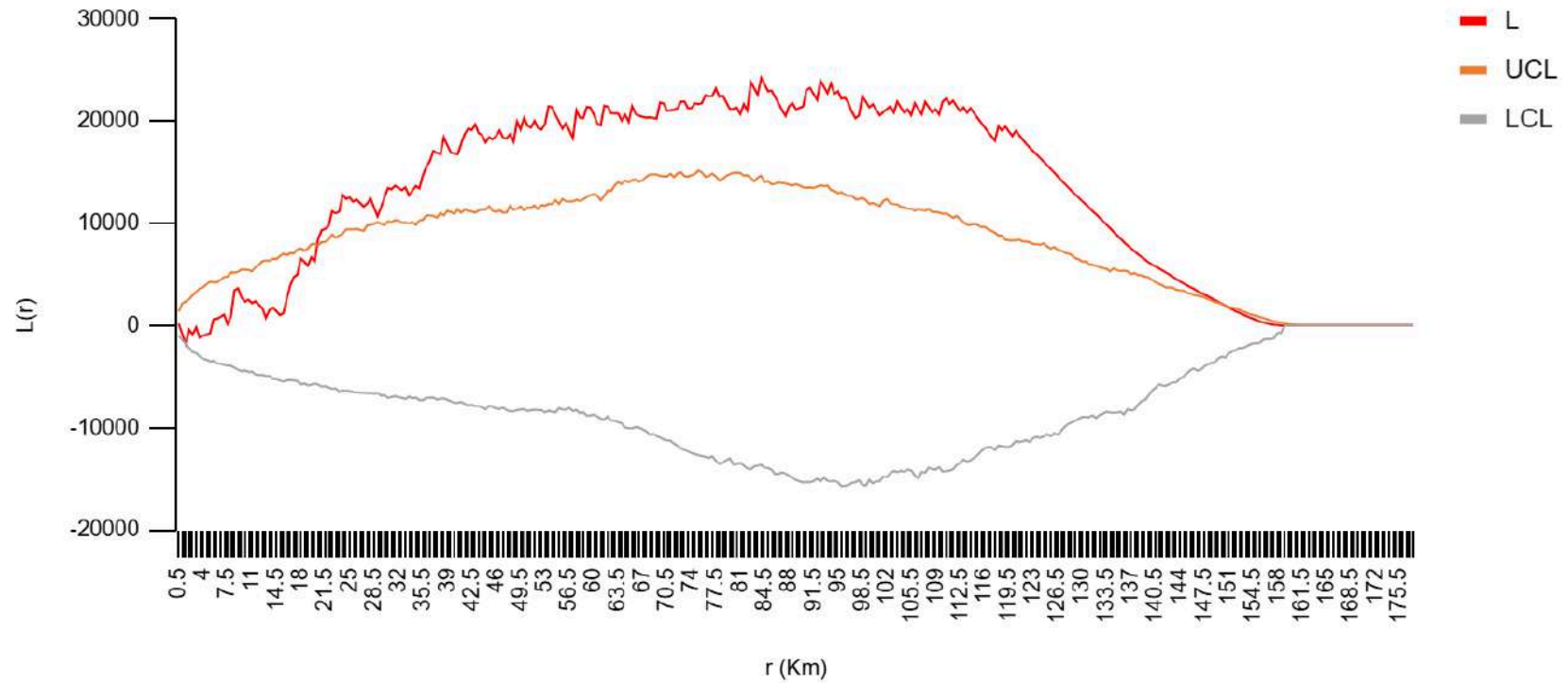


Figure S14. Roadkill aggregation graphs for mammals in accordance with the 500m radius used in our analysis for the fourth year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

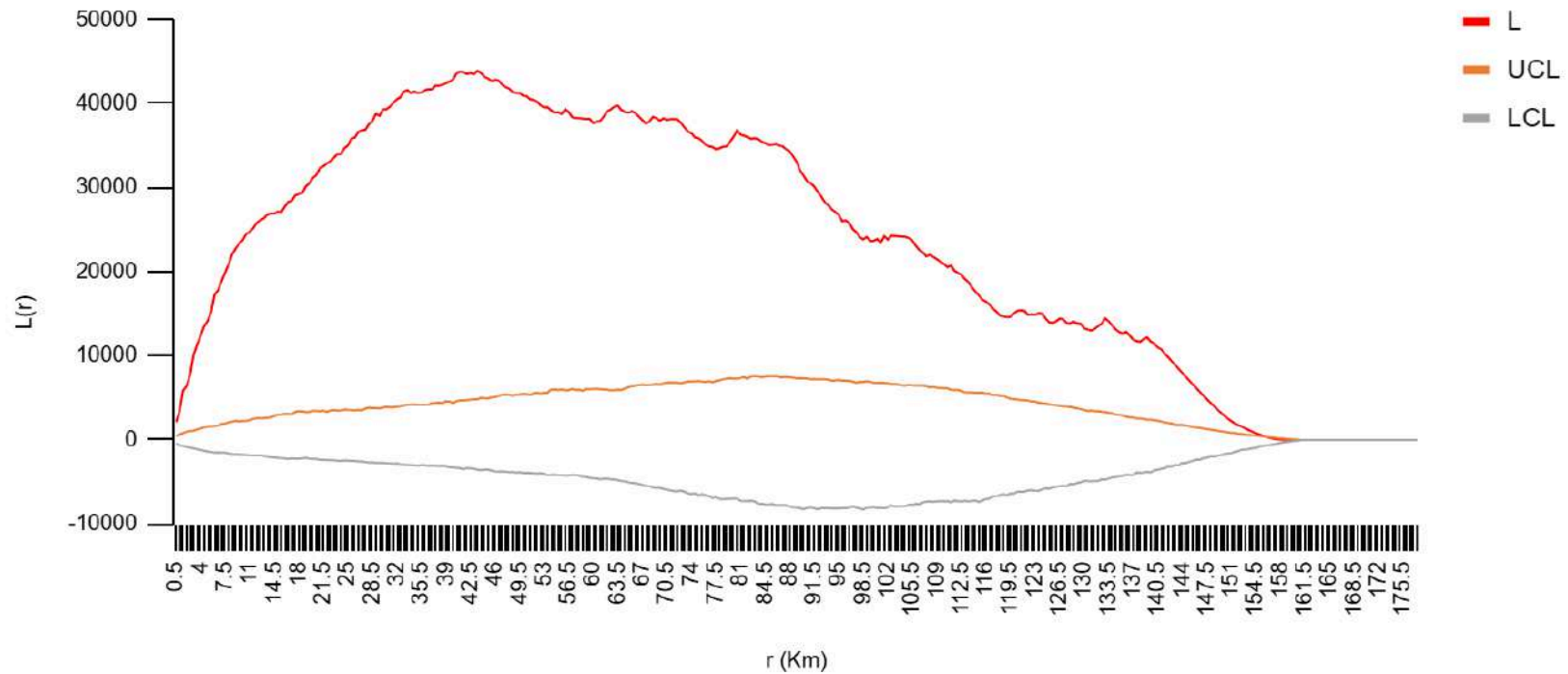


Figure 156. Roadkill aggregation graphs for reptiles in accordance with the 500m radius used in our analysis for the first year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

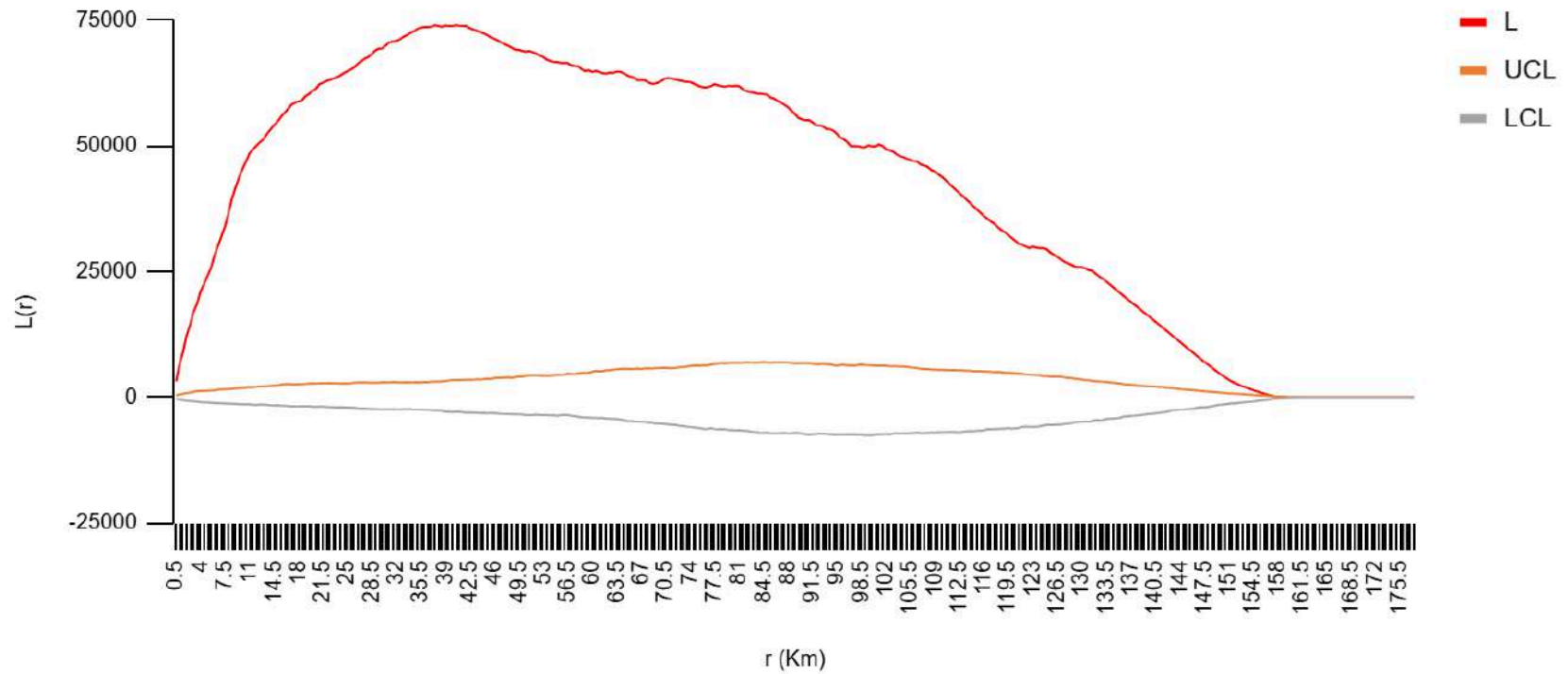


Figure S16. Roadkill aggregation graphs for reptiles in accordance with the 500m radius used in our analysis for the second year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

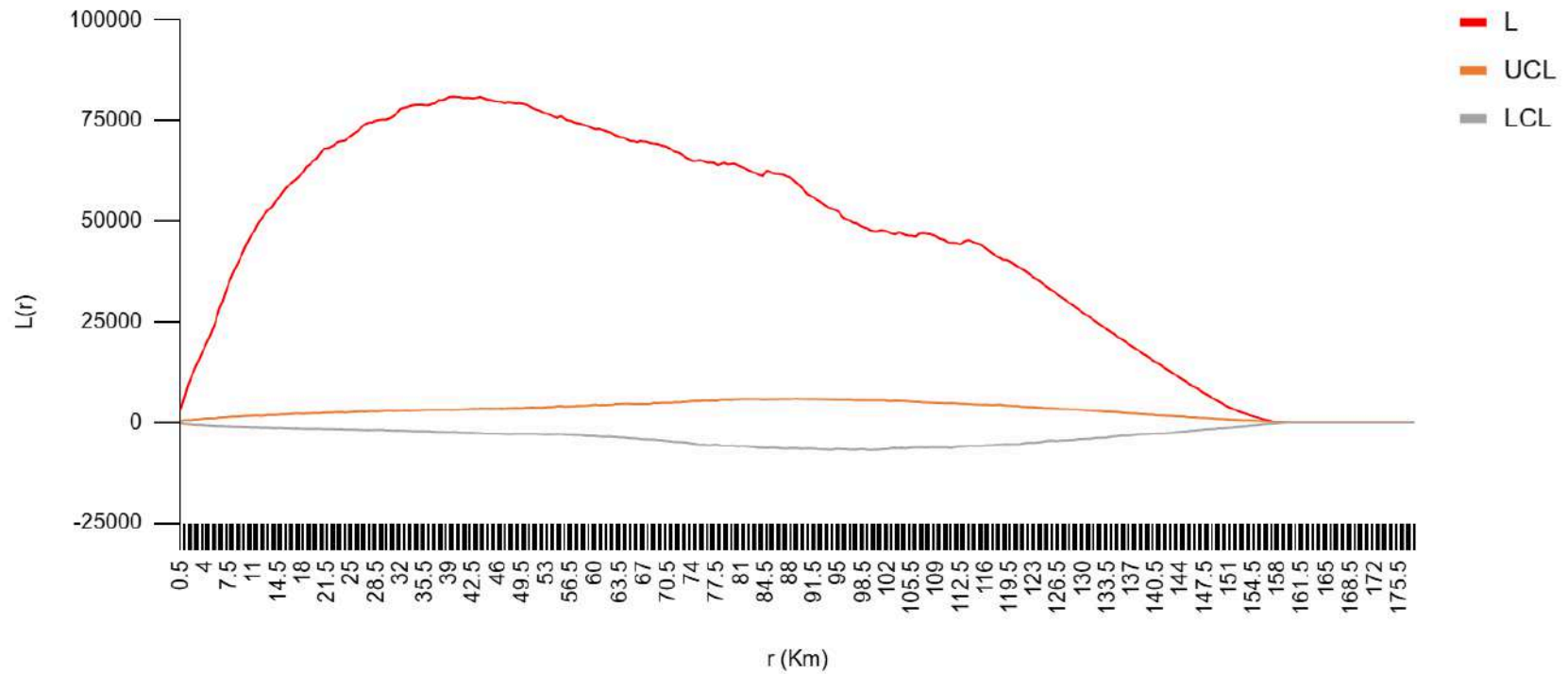


Figure S17. Roadkill aggregation graphs for reptiles in accordance with the 500m radius used in our analysis for the third year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

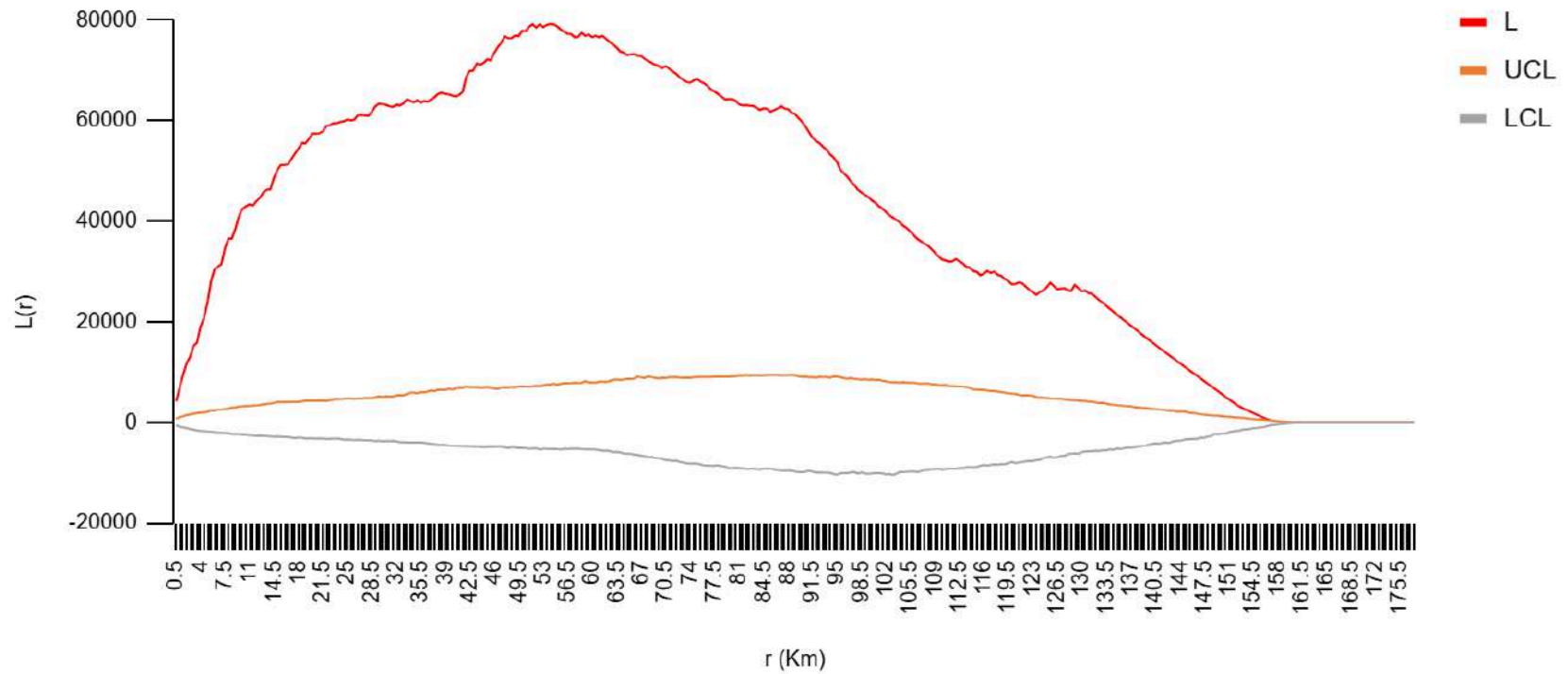


Figure S18. Roadkill aggregation graphs for reptiles in accordance with the 500m radius used in our analysis for the fourth year of study. The $L(r)$ function is indicated by the red line, while the upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines, respectively.

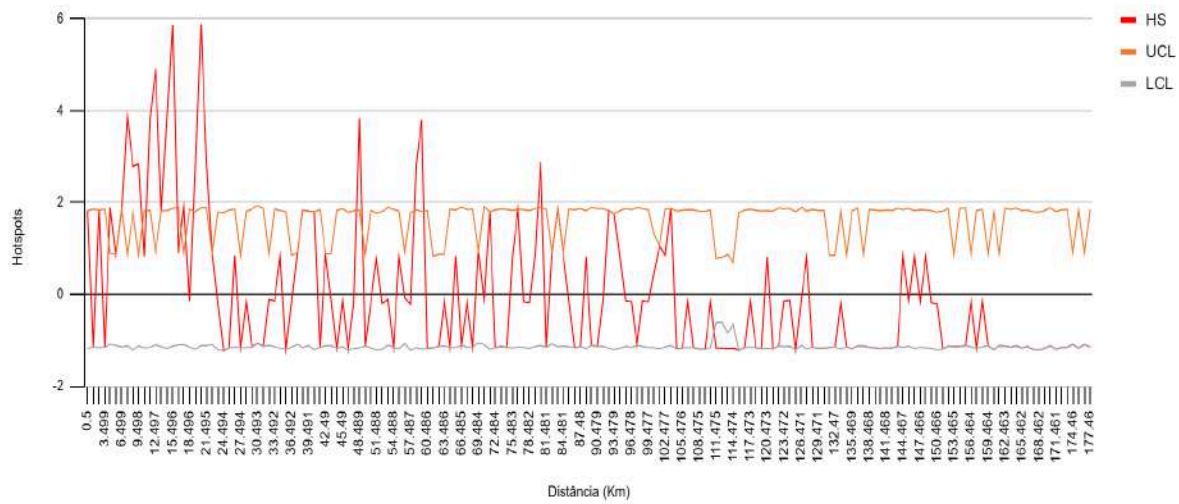


Figure S19. Hotspot distribution of all roadkill events included in our study (all groups) for the first year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

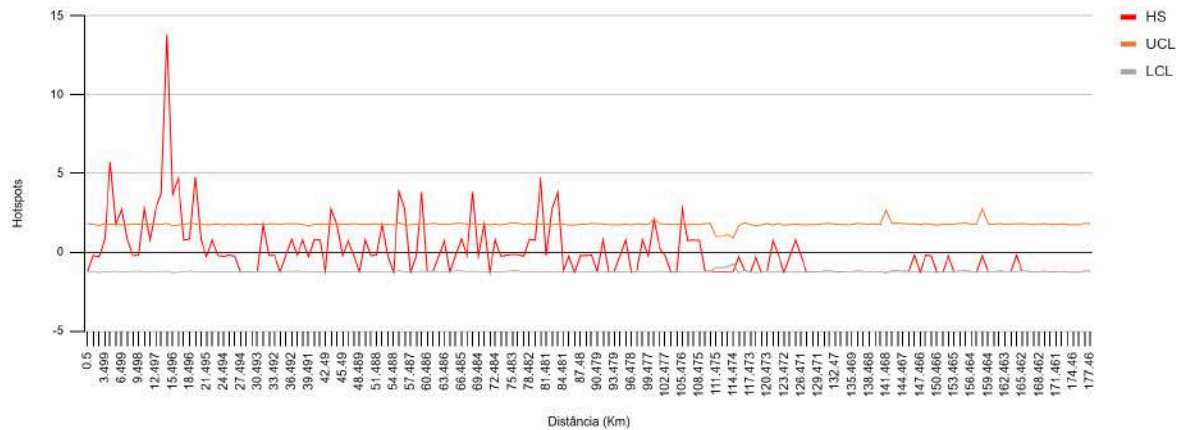


Figure S20. Hotspot distribution of all roadkill events included in our study (all groups) for the second year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

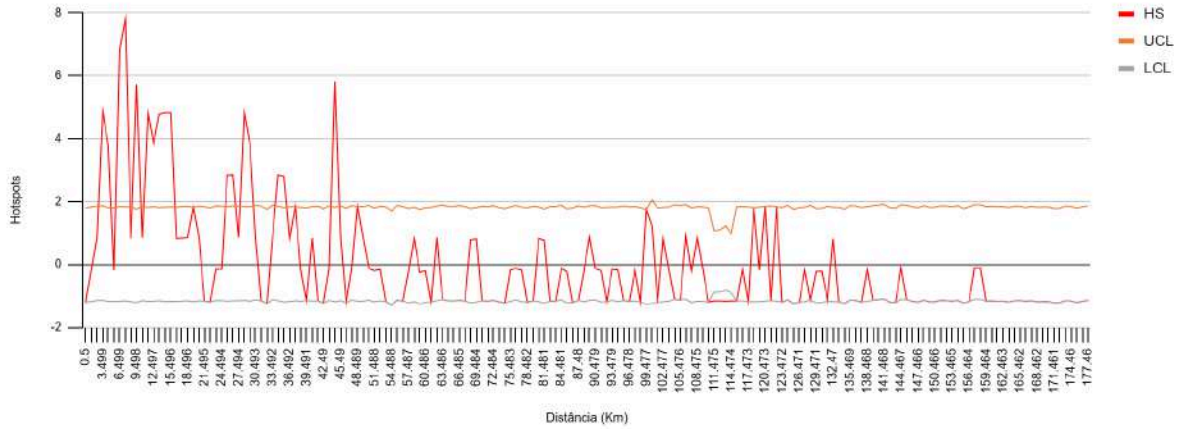


Figure S21. Hotspot distribution of all roadkill events included in our study (all groups) for the third year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

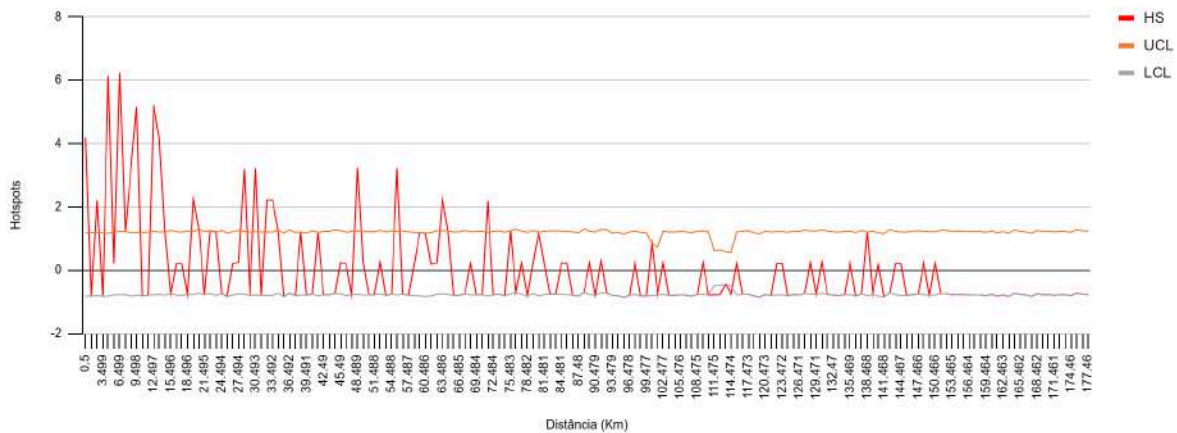


Figure S22. Hotspot distribution of all roadkill events included in our study (all groups) for the fourth year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

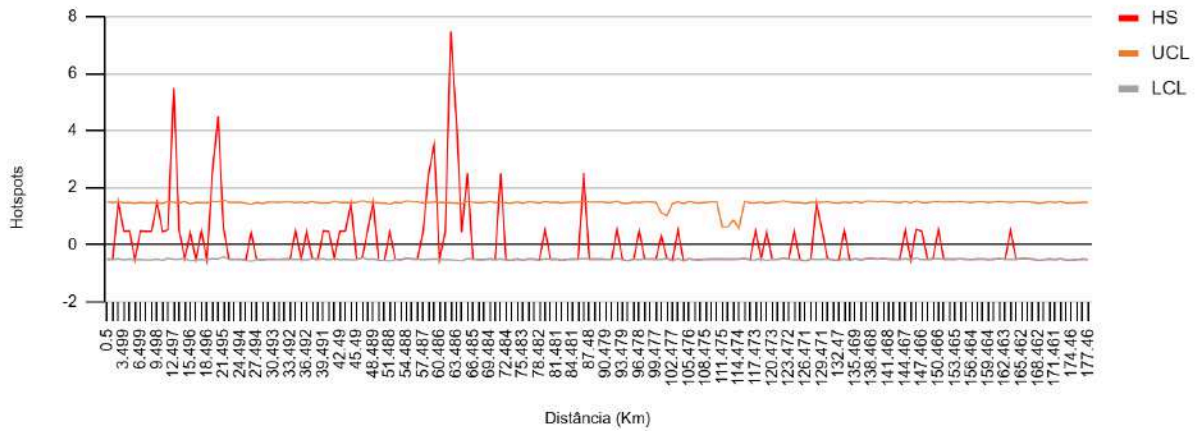


Figure S23. Hotspot distribution of all roadkill events included in our study for amphibians for the first year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

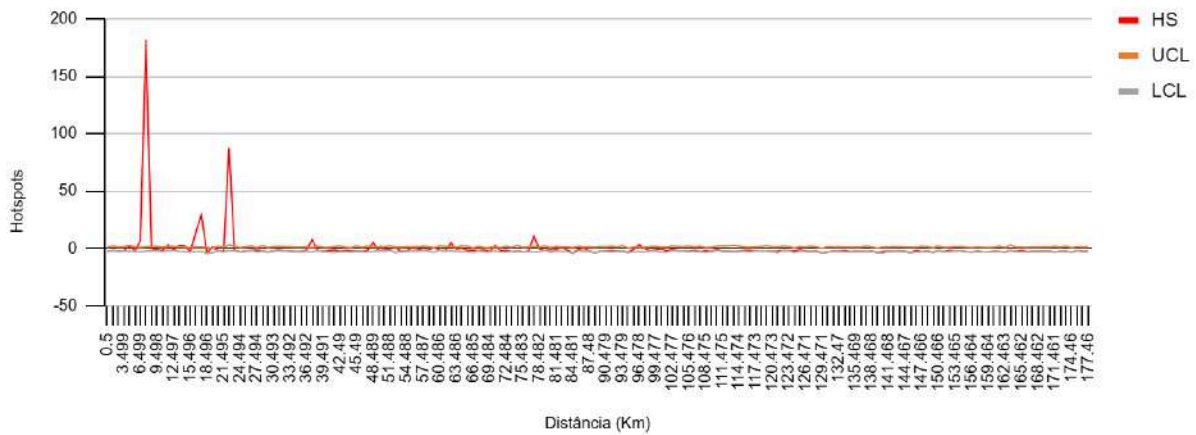


Figure S24. Hotspot distribution of all roadkill events included in our study for amphibians for the second year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

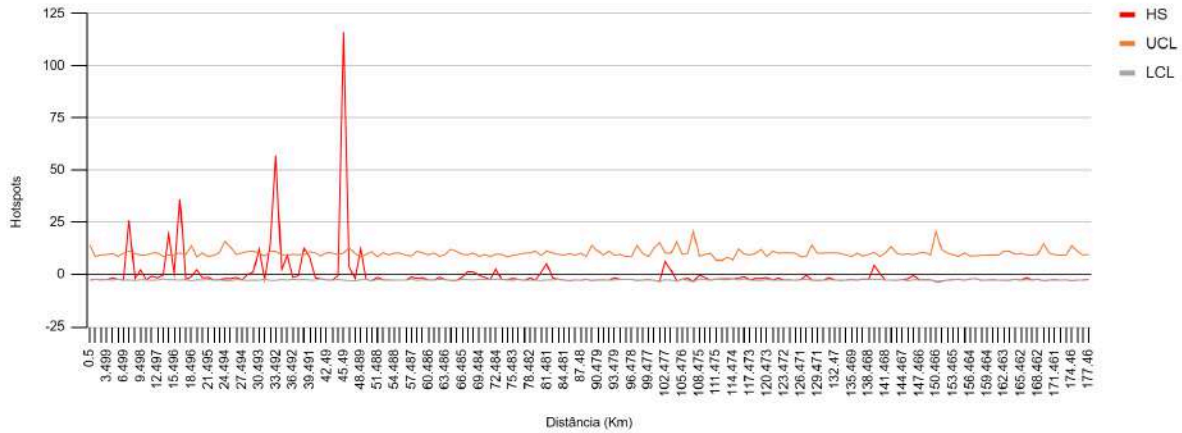


Figure S25. Hotspot distribution of all roadkill events included in our study for amphibians for the third year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

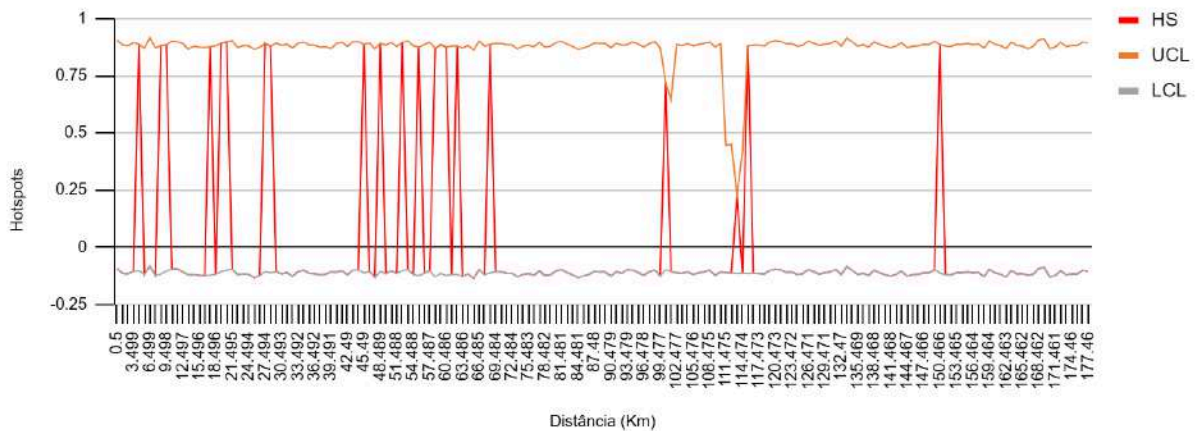


Figure S26. Hotspot distribution of all roadkill events included in our study for amphibians for the fourth year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

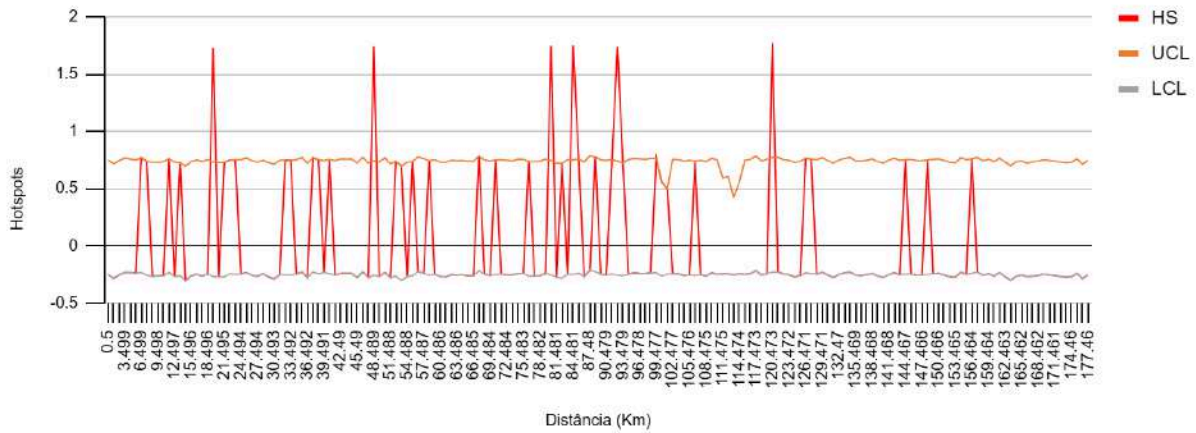


Figure S27. Hotspot distribution of all roadkill events included in our study for birds for the first year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

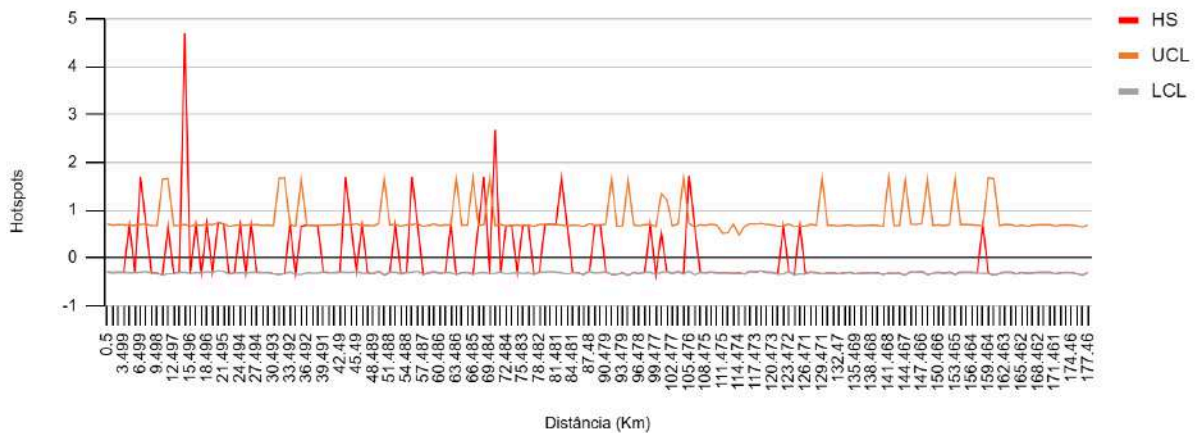


Figure S28. Hotspot distribution of all roadkill events included in our study for birds for the second year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

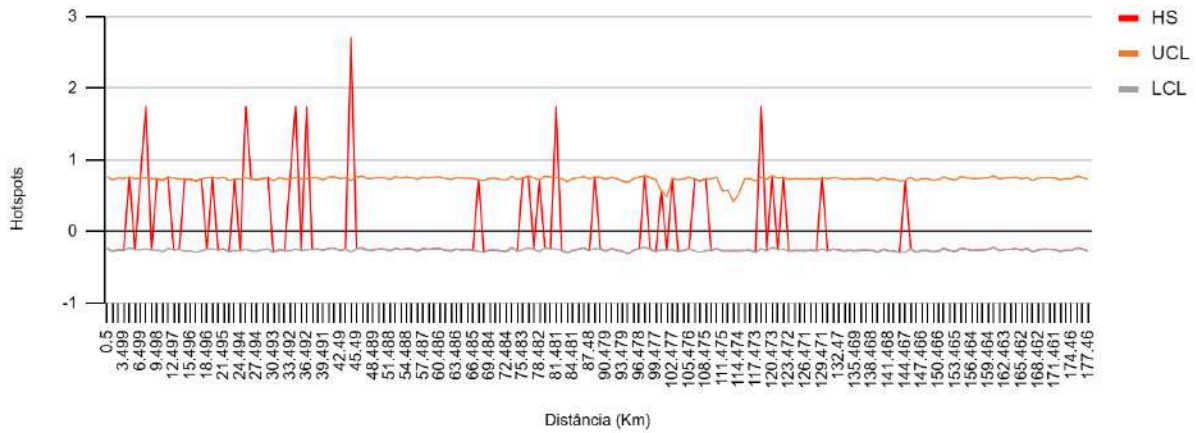


Figure S29. Hotspot distribution of all roadkill events included in our study for birds for the third year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

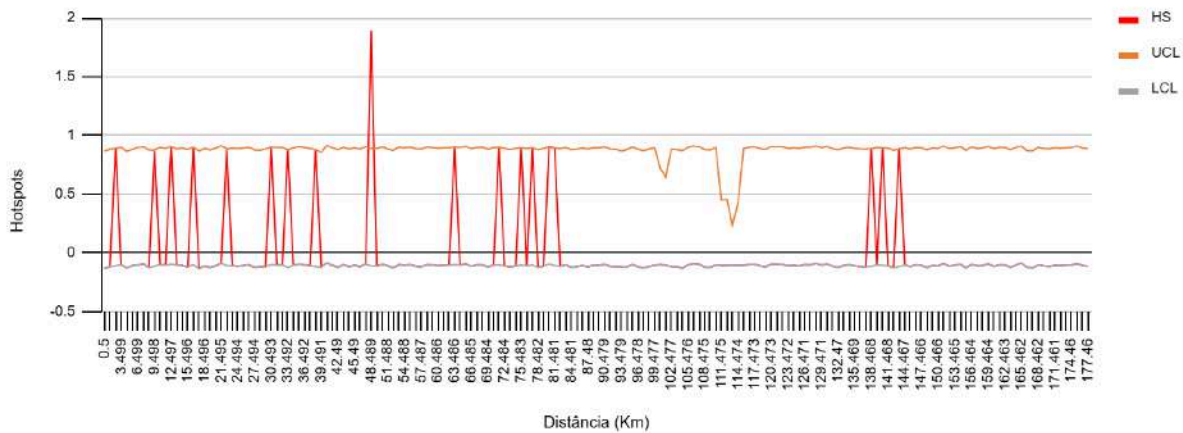


Figure S30. Hotspot distribution of all roadkill events included in our study for birds for the fourth year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

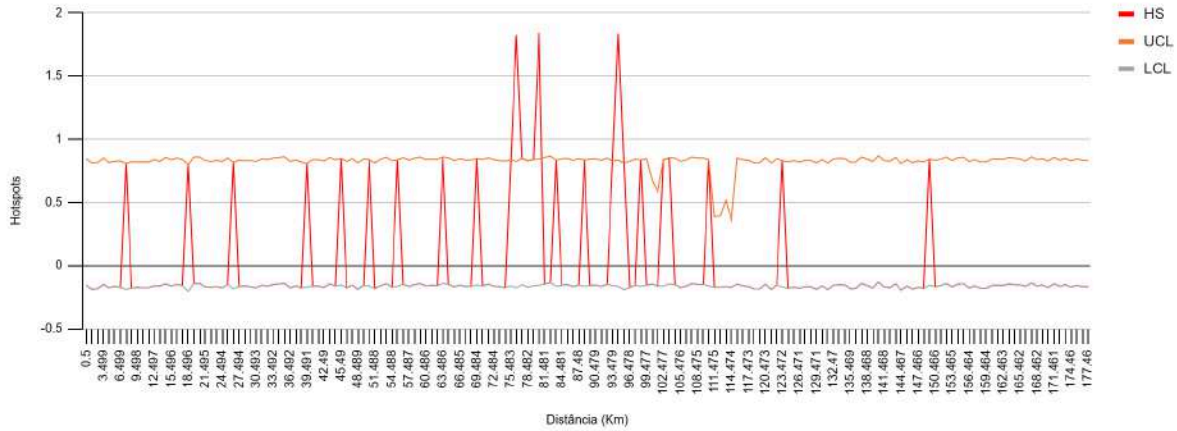


Figure S31. Hotspot distribution of all roadkill events included in our study for mammals for the first year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.



Figure S32. Hotspot distribution of all roadkill events included in our study for mammals for the second year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.



Figure S33. Hotspot distribution of all roadkill events included in our study for mammals for the third year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

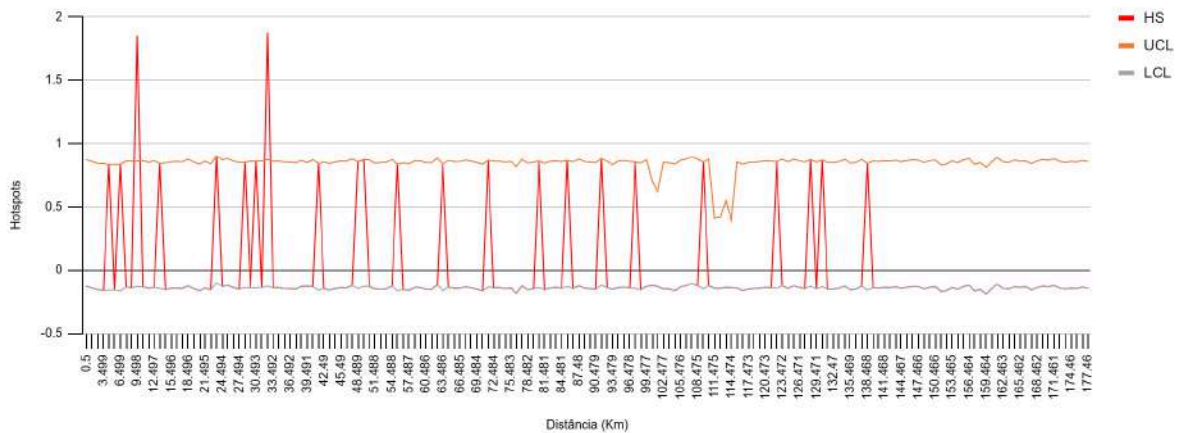


Figure S34. Hotspot distribution of all roadkill events included in our study for mammals for the fourth year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

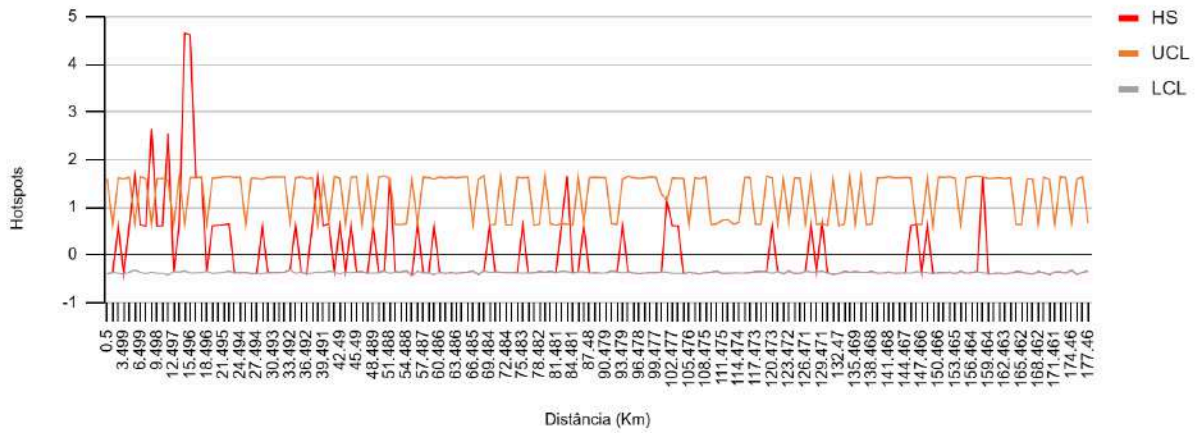


Figure S35. Hotspot distribution of all roadkill events included in our study for reptiles for the first year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

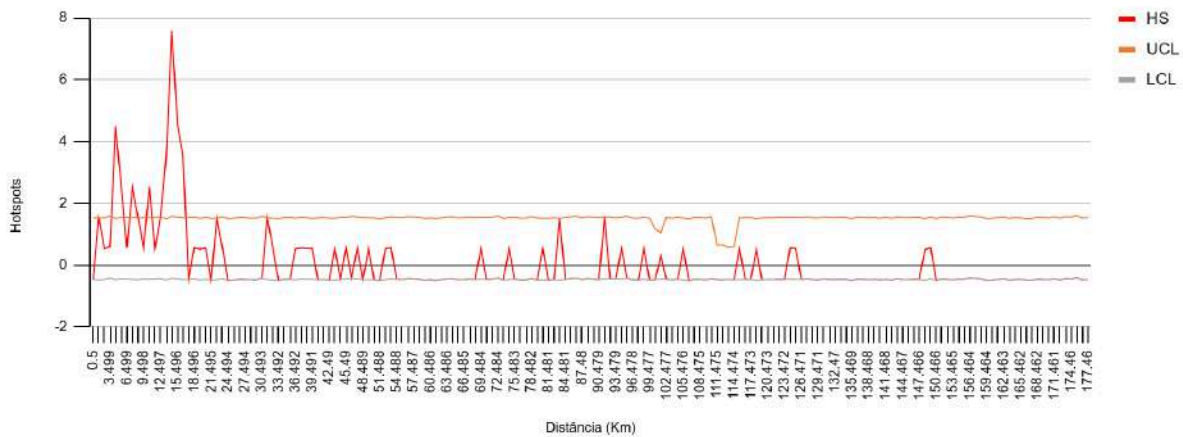


Figure S36. Hotspot distribution of all roadkill events included in our study for reptiles for the second year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

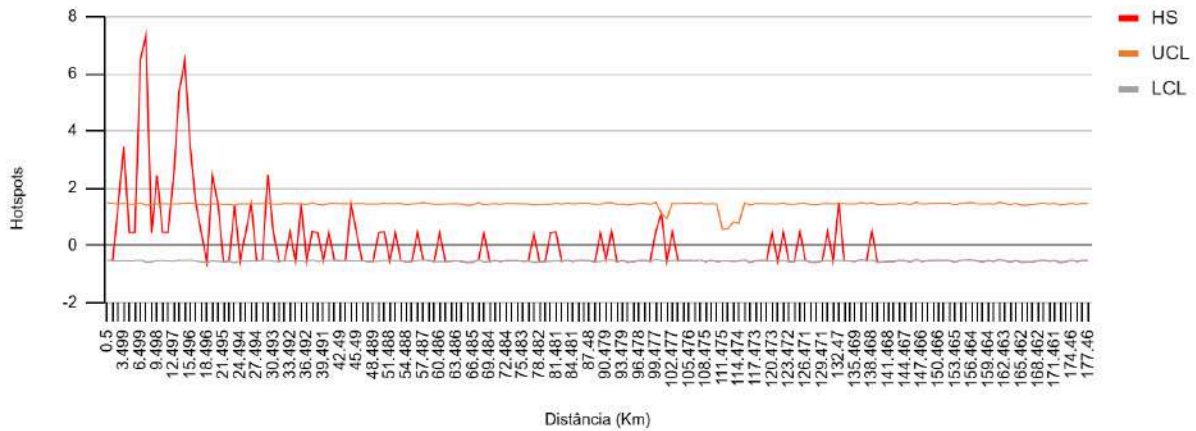


Figure S37. Hotspot distribution of all roadkill events included in our study for reptiles for the third year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

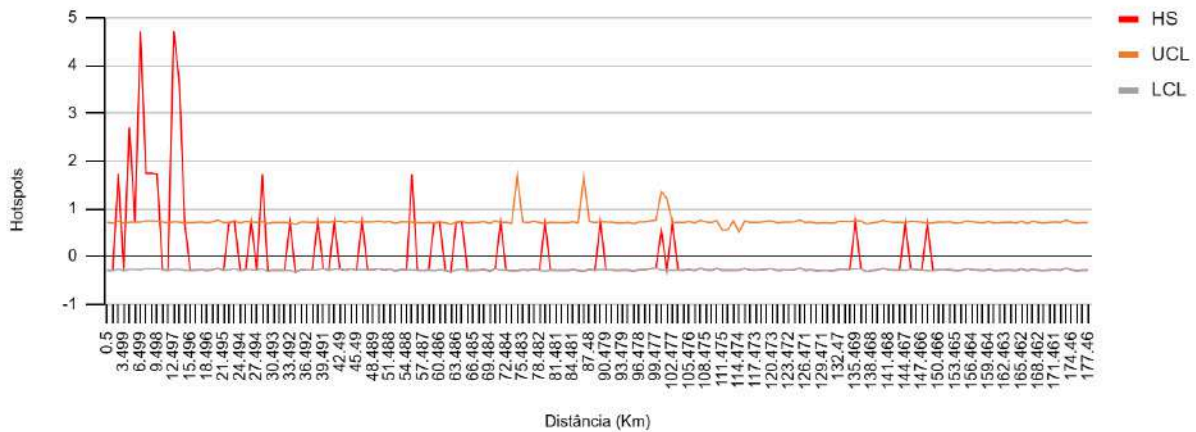


Figure S38. Hotspot distribution of all roadkill events included in our study for reptiles for the fourth year of study. Hotspot Score values are indicated by the red line, while upper limits (UCL) and lower limits (LCL) are represented by the orange and grey lines respectively.

CONSIDERAÇÕES FINAIS

Os resultados deste estudo revelam que os atropelamentos ao longo da BR-319 apresentam uma variação temporal e espacial complexa, com *hotspots* recorrentes e dinâmicos ao longo do tempo. Fatores climáticos e de paisagem, como cobertura florestal, áreas agrícolas e zonas alagadas, influenciam diretamente a mortalidade da fauna. As taxas de atropelamento mostraram-se particularmente concentradas em áreas específicas ao longo da rodovia, especialmente em regiões fragmentadas e com alto tráfego. A variação temporal dos *hotspots* destaca a natureza dinâmica da mortalidade da fauna, sugerindo que o risco de atropelamento não segue um padrão fixo, mas sim um comportamento mutável, o que exige estratégias de mitigação adaptáveis.

No que diz respeito aos fatores climáticos, a pluviosidade demonstrou uma correlação negativa com o atropelamento de anfíbios e répteis, possivelmente devido à redução do fluxo de tráfego durante chuvas intensas e à remoção das carcaças pelas enxurradas. Por outro lado, a temperatura apresentou uma correlação positiva com o atropelamento desses grupos, indicando que o aquecimento pode aumentar o risco de mortalidade. Para mamíferos e aves, as respostas climáticas foram mais variáveis, refletindo as diferentes estratégias de movimentação e comportamento das espécies envolvidas.

Do ponto de vista da paisagem, a cobertura florestal se mostrou um fator protetor, reduzindo as taxas de atropelamento em todas as espécies e escalas espaciais, o que evidencia o papel crucial das florestas preservadas como barreiras naturais que limitam o movimento da fauna ao longo das rodovias. As áreas de transição entre cobertura florestal e agrícola, por sua vez, apresentaram menores taxas de atropelamento, sugerindo que funcionam como “zonas de segurança”. No entanto, a maior vulnerabilidade de anfíbios e répteis nas interseções entre zonas alagadas e áreas agrícolas, especialmente nas regiões urbanizadas, ressalta a importância de considerar a mobilidade e as condições microclimáticas desses grupos ao planejar medidas de mitigação.

Esses achados destacam a importância da preservação florestal na mitigação dos impactos das rodovias, especialmente em áreas de grande valor conservacionista, como a Amazônia. A expansão rodoviária, um dos principais fatores de fragmentação do habitat, representa um desafio significativo para a conservação, especialmente no contexto da pavimentação da BR-319. Para reduzir a mortalidade da fauna, são essenciais medidas de mitigação, como corredores e barreiras ecológicas, especialmente nas áreas em que a atividade humana se sobrepõe a habitats fragmentados. Além disso, a integração de fatores climáticos e paisagísticos no planejamento de conservação pode ajudar a proteger a biodiversidade da Amazônia e minimizar os impactos negativos da infraestrutura sobre a fauna local.