Drivers of human-wildlife impact events involving mammals in Southeastern Brazil

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Abstract

Annually millions of animals are killed as a result of human-wildlife impacts. Each year the NGO Associação Mata Ciliar (NGOMC), in Southeastern Brazil, receives and rehabilitates thousands of animals. We evaluated how natural and anthropogenic characteristics affect the risk of different types of human-wildlife impacts for mammals that arrive at the NGOMC; and explore the relationship between both the animal's size and the type of human-wildlife impact event, survival rates and the likelihood that these animals can be fully rehabilitated. To test our hypotheses regarding the drivers and consequences of the total number of human-wildlife impact events, traffic collisions, electrocutions, and requested removals, we used records of the mammals that arrived at the NGOMC between 2012 and 2018, and obtained data on environmental attributes and anthropogenic factors at the municipality level, as well as species weights. The total number of human-wildlife impact events and of requested removals were both positively correlated with deforestation rate and urban area. The number of traffic collisions was positively related to the number of fires. Municipalities with larger urban areas were more likely to have at least one electrocuted mammal. Temporally, the number of fires two months before was positively correlated with the number of human-wildlife impact events. Traffic collisions and electrocutions more frequently resulted in the death of the animal, than did other events. Animals that died were heavier on average than those that remained in captivity or were successfully released back into the wild. We conclude

that human-wildlife impact event rates should decline with lower rates of deforestation, less anthropogenic fires and the adoption of other specific measures to avoid both traffic collisions with fauna and electrocutions.

Keywords: Biodiversity conservation, Human-wildlife conflict, Wild-Fauna, Powerline, Road

1. Introduction

Anthropogenic activities have contributed to the decline and loss of animal and plant species in almost all the terrestrial ecosystems of the Earth (Barnosky et al., 2011), and consequently contributed to a decrease in ecosystem resilience, functional integrity (Larsen et al., 2005) and the loss of associated ecosystem services (Valiente-Banuet et al., 2015). Habitat loss and degradation, overexploitation, pollution, invasive alien species and disease are the main drivers of defaunation (Dirzo et al., 2014; Pereira et al., 2012). However, other direct factors such as large, uncontrolled fires (Lewis, 2020), traffic collisions (Abra et al., 2019; Abra et al., 2021), and indirect factors, such as the expansion of urban centres without proper planning (McKinney, 2002) can add to these key drivers and amplify their effects, increasing the challenges associated with the mitigation of threats to biodiversity conservation (e.g. Grilo et al., 2010). Beyond this, each year millions of animals are killed globally as a result of accidents caused by human activities, such as road traffic collisions (Abra et al., 2019; Adania et al., 2017; Lester, 2015; Malo et al., 2004), electrocution on power lines (Hernández-Matías et al., 2015; Katsis et al., 2018; Lokschin et al., 2007) and burn injuries sustained in uncontrolled fires (Mendonça et al., 2015; Sgardelis and Margaris, 1992).

There are both conservation, practical, and ethical motivations to prioritize the prevention of such accidents. Firstly, many of these species are threatened with extinction (Hernández-Matías et al., 2015; Medici and Desbiez, 2012; Mumme et al., 2000; Pinto et al., 2020), such that the loss of these individuals represents a serious threat to already endangered populations (Diniz and Brito, 2013; Hernández-Matías et al., 2015; Medici and Desbiez, 2012). Secondly, there are human costs associated with these accidents including risks of injury or death in traffic collisions with wild fauna (Abra et al., 2019; Lester, 2015), potential damage to property and inconvenience as a result of power outages caused by electrocution events (FTI Consulting, 2016), and risk of disease transmission due to contact of wild animals with humans and domestic animals (Chapman et al., 2015; Curi et al., 2012; Thompson, 2013). Given this two-way nature, these types of accidents, together with other events such as the taking of livestock by large predators and retaliatory attacks on predators, are collectively referred to as human-wildlife impacts (Redpath et al., 2013). Finally, from an ethical viewpoint, each of these individual animals is a sentient being, and we should value its life, avoiding suffering when possible (Singer, 1990). Given this range of possible motivations, there is a need for effective strategies to minimize the likelihood of human-wildlife impact events occurring. In the case of road-traffic collisions and electrocutions, strategies commonly used include the suppression of vegetation along roadsides, use of speed bumps and speed management (Collinson et al., 2019; Lester, 2015), implementation of fences and wildlife crossing structures as underpasses, overpasses, and adaptation of drainage culverts and bridges (Malo et al., 2004, Polak et al., 2019, Abra et al., 2020), increased spacing and better insulation of power lines (Tintó et al., 2010), or alternatively installation of subterranean power lines (Richardson et al., 2017).

To ensure that mitigation measures are effective, their design requires a better understanding of the ultimate causes of the human-wildlife impact events (hereafter referred to as events). However, most studies have focussed on the proximate causes, such as travel velocity and visibility on roads (Collinson et al., 2019; Hobday and Minstrell, 2008; Lester, 2015), or the structure of power transmission lines (Dwyer et al., 2013; Tintó et al., 2010). Relatively few studies have attempted to evaluate the ultimate causes, including the ways in which natural and anthropogenic characteristics of the environment lead to increased or decreased probabilities of events occurring. Those that have examined such effects suggest that, for example, the probability of roadkill events is higher where roads pass through areas with more native vegetation (Freitas et al., 2015; Malo et al., 2004), lower in areas with intense road traffic (Grilo et al., 2015; Kreling et al., 2019), and that habitat structure has an effect, with a lower probability of roadkills in more open habitats (Kioko et al., 2015). Perhaps unsurprisingly, the density of both animals and electricity networks have been shown to be important predictors of the number of electrocution events (Katsis et al., 2018). A better understanding of how the probability of human-wildlife impact events caused by human activities varies over space and time is essential in order to design effective mitigation actions and plan for their implementation. Minimising the probability of such events not only has positive conservation impact, but also direct economic benefits, as treatments required to rehabilitate injured animals are expensive, and for those animals that cannot be fully rehabilitated, there will be permanent costs of their upkeep in captivity.

In this study, we use data on human-wildlife impact events held by the NGO *Associação Mata Ciliar* (hereafter, NGOMC), which receives and, when possible, rehabilitates thousands of animals each year in the state of São Paulo, in the southeast of Brazil (Fig. 1). We aim to: 1) relate spatial patterns of events of different types to natural and anthropogenic landscape characteristics, to evaluate how such characteristics may affect the risk of human-wildlife impact events occurring; and 2) determine survival rates after different types of events, as well as the likelihood that animals can be fully rehabilitated and released, as opposed to being kept in captivity, or not surviving their injuries and relate this to animal's size and to the event type. We also discuss the implications of our results in the context of actions that could help to prevent these types of human-wildlife impact events , as well as the effectiveness of rehabilitation of injured animals.

2. Material and Methods

2.1. Study system

The NGOMC is located in the municipality of Jundiaí, in the state of São Paulo, in the southeast of Brazil (Fig. 1). The NGOMC was founded in 1987, with the aim of promoting the conservation of water resources in the state of São Paulo (Mata Ciliar, 2020). Later, biodiversity conservation and wildlife rehabilitation were incorporated as further aims (Mata Ciliar, 2020). As such, each year thousands of injured animals arrive at the NGOMC due to various causes, including human-wildlife impact events such as traffic collisions, electrocutions and burns, or after having been seized from animal traffickers or removed after turning up in residences or business premises. The latter, hereafter referred to as requested removals, often occur when young animals disperse in search of their own territories, causing them to approach human habitations. Such incidents may also occur when animals lose their territories, both for natural (e.g. displacement by another animal) or anthropogenic (e.g. fire, clearing) causes, or when resources in their natural habitats become scarce. These requested removals mostly include animals entering houses or backyards, or potentially dangerous animals, such as pumas, ranging near to residences. Thus, most of the cases involve fear or inconvenience caused by the presence of animals near people. Indeed, most of the requested removals do not result in any harm to either the animal or to people, but are still undesirable events involving fauna. Thus, for simplicity, throughout this paper we use the term event to refer to all types of records, including traffic collisions, electrocutions, requested removals, and others.

Whilst the animals can arrive from anywhere in Brazil, municipalities that are geographically closer to the NGOMC tend to send more animals. Furthermore, the NGOMC has specific agreements in place with eleven municipalities, including Jundiaí and neighbouring areas (see Fig. 1), to receive injured animals in return for regular funding.

When the animals arrive at NGOMC, data recorded include species identification, the municipality from which the animal came, the arrival date, and the type of event that occurred (Table 1; Supplemental Fig. 1). The animals then receive veterinary care, and where possible, are then re-released close to where they were found. When the animals survive, but re-release is not possible, the animals are cared for in captivity at the NGOMC.

2.2. Data collection and processing

In this study, we used the data on wild mammals that arrived at the NGOMC between 2012 and 2018. We considered each event to be a data point. If ≥1 individual of the same species was injured in the same event, only one event was recorded (i.e. each event was regarded as a single independent record regardless of the number of individuals involved in the event). As most records only included the municipality in which the event occurred, we could not carry out analyses at a finer spatial scale and data were treated at the municipal level. Therefore, from the event data, we then calculated municipality-level data on the total number of events, and the total number of traffic collisions, electrocutions, and requested removals across the full seven-year period (Supplemental Fig. 1). There were a few rare (n=9) cases where animals arrived at the NGOMC from places very far from Jundiaí (i.e. >600 km away, not shown in Fig. 1 and Supplemental Fig. 1), resulting in just one record per municipality located in other regions of the country, with very different environmental characteristics. These records were removed from the data as they would not be informative in the context of these analyses. Records from the municipality of Jundiaí itself represented 35.3% of the total number of events, largely because the NGOMC is located in Jundiaí, and, as such, these records were also excluded from the municipality-level analyses to avoid a disproportionate influence of these data in the results. However, events from Jundiaí were considered in the other analyses (i.e. the effect of event type and animal weight on the fate of the animal - death, captivity or release - and the effect of fire on the monthly number of events), which were not carried out at the municipal level.

We then constructed a number of hypotheses to explain the number of events of different types, based on environmental attributes, anthropogenic factors, and species size (see variable description and hypotheses in Fig. 2). The latter was expected to influence the outcomes of treatment (rehabilitated and released, rehabilitated and cared for in captivity, or fatality), assuming that larger animals will be more likely than smaller animals to survive after suffering any accident as they should be more resilient.

According to our hypotheses, we first built full models for each response variable (see data analysis and Supplemental Table 1). In addition to the explanatory variables, we also controlled for the effect of a further two variables in all models: distance from the municipality to the NGOMC and presence or absence of a specific agreement between the municipality and the NGOMC (see description of study system). These variables were not expected to influence the number of events, but rather the probability that the injured animals would be taken to the NGOMC. Specifically, we expected a higher probability for municipalities closer to Jundiaí and those which have specific agreements with the NGOMC. In addition, we tested if the increase in the total number of events could occur as an immediate reaction to fire events, and therefore in the same month as the fire started, or if the effect could be lagged by one to two months as a result of reduced resource availability. We also explored the effect of species size on the outcomes of treatment (rehabilitated and released, rehabilitated and cared for in captivity, or fatality), considering each event as a sampling unit.

2.3. Data analysis

2.3.1. Risk factors for different types of human-wildlife impact events

To respond to our first aim, the total number of events, number of traffic collisions and the number of requested removals were modelled against the municipality-level explanatory variables using negative binomial generalised linear models (GLMs). Events that were not assigned as traffic collisions, electrocution or requested removals were regarded as "others" and were considered only for the analysis of the total number of events. The "others" category was composed mostly by animals that arrived at the

NGOMC having been injured by unknown causes, or infant animals that were found without their mothers. The nature of the events included in the “others” category is different from that linked to requested removals, as most of the animals (or their mothers) associated with the former category may have been involved in previous accidents. For the analysis of the total number of events (TOT) we considered only the municipalities in which at least one event occurred (Fig. 1), and to deal with the absence of zeros in the model, we used TOT-1 as response variable. A Zero-Altered Negative Binomial (ZANB) model (Zuur et al., 2009) was used to model the data on the number of electrocutions, as a large number of municipalities had zero records for this type of event. The ZANB model is made up of two parts, the Zero Hurdle Model, which explains the presence or absence of electrocution events in each municipality, and the Count Model, which explains the number of electrocutions in municipalities where at least one event of this type occurred.

All models included terms for the distance to the NGOMC and the existence or not of a specific agreement for the destination of animals between the NGOMC and the municipality, as both these aspects are expected to influence the number of animals arriving at the NGOMC without contributing to the number of animals involved in human-wildlife impact events in the municipality. For each response variable, the full model (Supplemental Table 1) was implemented, and variables with little explanatory power (based on their p value) were then removed in sequence until the most parsimonious model with the best explanatory power had been found (i.e. lowest Akaike Information Criterion – AIC) (Zuur et al., 2009). All models were checked for multicollinearity (using the Variance Inflation Factor - Zuur et al., 2009), and spatial autocorrelation (using correlograms of the model residuals - Fortin and Dale, 2005).

We tested the hypothesis that the number of animals arriving at the NGOMC is related to the number of fires in the month when the animal arrived (T0) or with a time lag of one (T1) or two months (T2). The number of fires was assessed from records of 16 satellites provided by INPE (2020). We downloaded the data of hot pixels (i.e. indicators of fire occurrence) within each municipality from 2012 to 2018. To assure independence of the data, we assessed the location of the hot pixels and excluded those records that were less than 1 km from each other, on the same day. Subsequently, we counted the number of independent hot pixels within the whole study area (i.e. in all municipalities in which at least one event occurred) in each month, and used this as a surrogate of the number of fires. We used a generalised additive model (GAM) relating the total number of human-wildlife impact events (response variable) and the number of fires (T0, T1 or T2), and including month as a covariable. Here, the sampling unit was each month of the study period. We selected the variable (T0, T1 or T2) that best explained the number of records based on the model's R^2. This was the only model carried out using months as the sampling unit. In the other models municipality was the sampling unit, as we intended to explore the spatial distribution of the events, and given that the explanatory variables were not available on a monthly basis.

2.3.2. Factors related with survival rates and likelihood of successful rehabilitation

To respond to our second aim, a chi-squared test was used to test whether event type influences the outcome of the animals receiving treatment at the NGOMC (fatality, captivity, re-release), considering each arrival of an animal at the NGOMC as a sampling unit. An ANOVA was used to test for an effect of the animal's weight, in kilogrammes, on the outcome of treatment, also considering each arrival as the sampling unit.

All analyses were carried out using packages 'car' (Fox and Weisberg, 2019), 'MASS' (Venables and Ripley, 2002), 'ncf' (Bjornstad, 2019), and 'mgcv' (Wood, 2003) of the programming language R, version 3.6.3 (R Core Team, 2020).

3. Results

A total of 4,552 individuals of 56 mammal species and 44 mammal genera (Supplemental Table 2) arrived at NGOMC between 2012 and 2018, as a result of 2,882 independent events. Five of these species are classified as threatened with extinction by the IUCN red list (IUCN, 2021) and 12 by the Brazilian red list (ICMBio, 2018) (Supplemental Table 2). These animals came from 126 municipalities across nine Brazilian states, though the vast majority (98%) came from the state of São Paulo where the NGOMC is located. Of the 126 municipalities, eleven have a specific agreement with the NGOMC (see Supplemental Tables 3 and 4).

Requested removals were the most common event (29.1%), followed by traffic collisions (15.2%) and electrocutions (5.9%). Animals arriving at the NGOMC due to burn injuries were relatively uncommon (0.7%). For almost half (49.1%) of the events, animals were taken to the NGOMC for other varied causes, including mostly infants without their mothers or animals that were injured as a result of unknown causes.

3.1. Risk factors for different types of human-wildlife impact events

The total number of events, the number of requested removals, and the number of animals arriving following traffic collisions were all positively correlated with both the proximity of the municipality to the NGOMC, and with the existence of a specific agreement between the municipality and the NGOMC (Table 2). The total number of events and the number of requested removals were also both positively correlated with the rate of deforestation and urban area (Table 2). The number of animals arriving following traffic collisions was also positively related to the number of fires (*hot pixels*) (Table 2).

Municipalities closer to the NGOMC and those with a specific agreement with this institution were more likely to both send at least one animal that had been electrocuted to the NGOMC (Zero Hurdle Model - Table 3), and to send more animals that had been electrocuted, than those further away and with no specific agreement (Count Model - Table 3). Municipalities with greater urban areas were more likely to be the origin of at least one electrocuted mammal arriving at the NGOMC (Table 3). The occurrence, but not the number, of electrocutions was also higher where deforestation rates were higher (Table 3). However, the leverage of two municipalities (Piracaia and Atibaia) was particularly high in the model, and when they were removed from the analysis, the relationship between the occurrence of electrocutions and both distance to the NGOMC and deforestation rate became non-significant (Count model), suggesting a lack of robust support for these relationships. The removal of these two municipalities had no effect on the Zero Hurdle Model, or on the relationship with the specific agreement between municipalities and the NGOMC.

Over time, the total number of animals arriving at the NGOMC was related to the number of fires (*hot pixels*) in the two months prior to the arrival month ($p<0.001$). There was a sharp increase in the number of events according to the number of fires, stabilizing above 2000 fires/month (Fig. 3).

3.2. Drivers of survival rates and likelihood of successful rehabilitation

Traffic collisions and electrocutions more frequently resulted in the death of the animal, than did other events. Inversely, animals arriving at the NGOMC as a result of a requested removal were more likely to survive than those involved in the other types of event ($\chi^2 = 97.773$, df = 4, $p < 0.001$ - Fig. 4a). Finally, animals that did not survive were heavier on average than those that remained in captivity or were successfully released back into the wild ($F_{2,2534}= 5.093$, $p = 0.006$ - Fig. 4b).

4. Discussion

4.1. Risk factors for different types of animals and human-wildlife impact events

We found that anthropogenic changes in the environment, namely the occurrence of deforestation and fires, as well as the existence of larger urban areas, influence the occurrence of human-wildlife impact events with fauna. We also found that species body size and the type of event influence the likelihood that the animal survives and fully recovers from the events.

The extent of the urban area of the municipalities was positively related to the total number of events and to the occurrence of electrocution and requested removals in the municipalities. This indicates an essentially urban character of the places where most events occur, showing that cities pose additional risks to animals. Furthermore, it also reflects how wildlife is increasingly present in urban environments (Mazzolli, 2012). In cities there are a large number of potential sources of accidents, such as a higher density of paved roads and power lines, in addition to a greater density of people in cities that might increase the chance of animals being found and sent to the NGOMC, relative to animals in rural areas.

Relatively high levels of deforestation and frequency of fire outbreaks were related to an increase in the number of requested removals and traffic collisions, respectively. Deforestation also has a potential effect on the number of animals electrocuted. These two factors (deforestation and fires) promote a reduction in the resources available to wild animals in their natural environments (Borkowski, 2004; Carrara et al., 2015), creating a need to move more in search of resources. The loss of habitat caused by these activities, however, apparently has an effect with a limited duration, given that the amount of native environment in the municipalities did not affect the occurrence of the various events assessed. If there were a persistent effect of habitat loss on the number of events, we would expect that in municipalities with less native environments there would be a greater number of events. This relationship does not occur because the animals displaced by habitat loss eventually die (from accidents or other causes) or scatter, and their abundance becomes adjusted to the amount of resources in the remaining native environment. A similar fact occurs during the fragmentation process, where species increase their local abundance in the remaining habitat fragments at first, but with a gradual reduction in abundance and stabilization afterwards (Bierregaard Jr. et al., 1992).

In addition to being of limited duration, the effect of fires on the number of events is also not immediate, and peaks two months after the occurrence of fires. There are at least two, non-exclusive, possible explanations for this. Firstly, animals may be reluctant to seek resources in hostile environments (cities), resorting to this alternative only after a certain time spent seeking other possibilities without success. Secondly, the animals may be weakened by lack of resources (e.g. food, water) or by burn injuries sustained in the areas, and this state of weakness, which increases during these initial months, leaves them more vulnerable to human-wildlife impact events. In these cases, a temporary supplementation of resources (e.g. water sources, food of various types) in the burned areas would potentially reduce the risk of human-wildlife impact events (Birdlife Australia, 2020; Wildlife Health Australia, 2020), although it is still necessary to test this hypothesis for the Neotropical region.

The positive effect of the occurrence of deforestation and fires on the occurrence of events shows that these actions generate fauna mortality not only *in loco* (e.g. fauna suffering burn injuries), but also increase events with fauna in other places (e.g. traffic collisions and requested removals). The increase in these events puts, in some cases, the human population itself at risk as the traffic collisions can also cause damage to the vehicle and injure occupants (Abra et al., 2019, Huijser et al., 2009; Lester, 2015), and proximity to wildlife increases the likelihood of interactions with potentially aggressive animals and / or the potential transmission of zoonoses (Neto et al., 2011; Thompson, 2013). In the latter case, there may also be damage to domestic animals (Mazzoli, 2009; Thompson, 2013). Therefore, it is essential to highlight the reduction of deforestation and fires caused by anthropogenic causes as a protection measure not only for wild animals, but also for people and domestic animals.

Roadkill studies are often concentrated on busy highways (e.g. Abra et al., 2019; Ascensão et al., 2017; Grilo et al., 2009; Lester, 2015; Mumme et al., 2000), as speed is one of the factors that leads to the occurrence of fauna traffic collisions (Hobday and Minstrell, 2008), and highways are where the flow and the speed of the vehicles is greater. The lack of relationship that we detected between the length of roads (including highways) and traffic collisions with wildlife may indicate that a significant part of the deaths occur on other roads, such as avenues and streets, i.e., on the roads located within the urban network. Fences and fauna passageways are among the most common approaches to mitigate fauna traffic collisions (Polak et al., 2019; Abra et al.,

2020) in non-urban areas. However, these measures are not compatible with the characteristics of urban environments and are practically impossible to implement in many cities and towns. In this case, speed reducers and signage can be more efficient alternative measures in cities (Lester, 2015). On the other hand, mortality is not homogeneous along roads (Hobday and Minstrell, 2008), with specific factors that promote accidents (e.g. the presence of curves in the road, tree cover on road verges, distance to urban areas, etc. - Ascensão et al., 2017, Grilo et al., 2009). These factors may have prevented us from detecting a relationship between the length of roads (including highways) and the number of animals being run over.

We did not have access to the exact location of each event, and thus, our analysis is at a coarse scale (municipality level). An analysis at a finer scale would allow us to explore the effects of other variables (e.g. local characteristics of roads, land use variables) or even find significant effects of other variables included in our analysis. However, this does not invalidate the relationships reported here. Additionally, the dataset we evaluated in this study does not directly measure the number of each type of event that occured in each municipality. Instead, we rely on data of animals that were taken to the NGOMC after being involved in these events. Although the probability of taking these animals to the NGOMC may be related to animal traits, such as size, charisma, or if the animal represents a danger to people, there are no reasons to believe this would vary across the municipalities. Thus, we can assume that our identification of the drivers of human-wildlife impacts involving mammals in Southeastern Brazil is sufficiently robust.

4.2. Survival rates after different human-wildlife impact events and likelihood of successful rehabilitation

Not all types of events result in the same level of risk. Traffic collisions and electrocution represented a higher risk of death for the animals. In addition, these events are likely to cause greater problems for humans (e.g. risk to vehicle occupants, damage to the vehicle, power outages). Thus, these can be identified as the most important events to be avoided. In addition, animal mortality, in general, was higher for larger animals. This may be partially explained by external factors, such as capture myopathy, which is likely to occur in some of the larger animals of the region, such as capybaras and deer (Caulkett and Arnemo, 2014). Nevertheless, this result has important conservation implications. Larger animals tend to reproduce slower, have lower population densities, and tend to be the target of other risks, such as hunting (Cardillo et al., 2005; Carvalho et al., 2019). As a result, larger animals tend to be more threatened with extinction (Cardillo et al., 2005), and therefore, reducing the number of human-wildlife impact events should be considered to be one of the important conservation measures for such species.

Only approximately 20% of mammals that arrive at the NGOMC are returned to the wild and the treatment of these animals is very costly. However, the fact that the animals are returned to the wild does not assure their survival, which often depends on the severity of the injuries suffered, habitat quality of the release area, the handling protocol when in captivity and the time spent in captivity (Jule et al., 2008), due to what is commonly named the “burden of captivity”, where physiological and behavioural changes are linked to being in captivity (Champagnon et al., 2012). Furthermore, animals that are unable to be released into the wild, as a result of long-term effects of the events are maintained in captivity, generating permanent costs of food and care. Thus, whatever the option taken after recovery, accident prevention has associated conservation and economic benefits, and should therefore always be considered to be the best option.

Considering our results, we can recommend that the licensing process for construction of roads, powerlines, and new urban areas should be based on best practices to avoid human-wildlife impact events involving fauna. It is necessary to create safe suspended structures for the movement of arboreal/scansorial animals through the city (Lokschin et al., 2007; Teixiera et al., 2013). Insulating wires or even burying the power grid are also ways to reduce the electrocution risk, not only for arboreal animals but also for humans themselves (Lokschin et al., 2007; Richardson et al., 2017; Tintó et al., 2010). Fences and fauna passageways should be built to avoid roadkills (Polak et al., 2019; Abra et al., 2020), and speed reducers and signage should be implemented within the cities (Lester, 2015). Also, deforestation levels should be kept to a minimum during the construction of such infrastructures.

5. Conclusions

Here we identified the causes of human-wildlife impact events involving fauna, which is an important step in designing appropriate actions for the prevention and mitigation of these events. Threats arising from anthropogenic activities, such as deforestation and fires, increase the frequency of these events. We also showed the low success rate of wildlife recovery and release after incidents. This context highlights the importance of implementing mitigation measures that ensure a reduction in the frequency of human-wildlife impact events, the survival of individuals and the conservation of biodiversity. Combating deforestation and reducing anthropogenic fires reduces the number of animals that seek refuge in cities and towns, and that are consequently involved in human-wildlife impact events. The supplementation of resources in burnt areas has the potential to reduce human-wildlife impact events; however, this hypothesis still needs to be tested. The adoption of established measures to avoid traffic collisions with fauna (i.e. fences, passages for animals, speed reducers and specific signs, such as speed signs and wildlife crossing signs) and electrocution (i.e. separation and isolation of electric wires, or burial of the electrical network) should lead to a reduction in human-wildlife impact event rates and in the severity of these events, when they occur. The implementation of these measures would also reduce the risk of impacts associated not only with wild fauna, but also with people and their domestic animals, leading to socio-economic benefits over and above the positive impacts for biodiversity conservation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Figure captions

Fig. 1. Location of the municipality of Jundiaí (São Paulo State, Brazil, shown in yellow), where the *Mata Ciliar* NGO is located, relative to the municipalities (shown in green and red) from which animals arrived at the NGO during the study period. The municipalities shown in red are those that have specific agreements in place with the *Mata Ciliar* NGO to receive animals involved in accidents or otherwise rescued / removed.

Fig. 2. Hypotheses regarding each variable that was used to predict the number of animals that arrived at the NGO *Mata Ciliar* during the study period and their definitions. For variable sources, see Supplemental Table 5.

Fig. 3. Relationship between the number of fires and the number of animals arriving at the *Mata Ciliar* NGO two months later. The relationship (blue line) was obtained using a Generalised Additive Model (GAM), and the shaded area represents the 95% confidence interval. The points represent the observed data.

Fig. 4. a) Comparison of the proportion of surviving animals according to the type of event; and b) comparison of the weight of animals with different outcomes after arriving at the NGOMC.

Supplemental Fig. 1. Spatial distribution of the different human-wildlife impact event types. A: All records; B: Traffic collisions; C: Electrocuted animals; D: Requested removals.

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Table 1. Description of the types of human-wildlife impact events evaluated in this study

Event	Description
Traffic collision (TRCOL)	Animals injured as a result of collision with motor vehicles
Electrocution (ELEC)	Animals injured as a result of direct contact with the electricity network
Requested removal (RR)	Animals that are brought to the NGOMC after getting close to or entering human habitations, leading to a request made by local residents for their removal (via direct contact with NGOMC, rangers, firemen or policemen via telephone).
Total (TOT)	Total number of events including traffic collisions, electrocutions and requested removals, as well as burns and events of undefined causes (e.g. injured animals, motherless infants)

Table 2. Results of the best negative binomial Generalized Linear Models, relating the total number of records of mammals that arrived at the NGO Mata Ciliar between 2012 and 2018, as well as the number arriving as a result of traffic collisions and requested removals with the predictor variables.

	Total records			Traffic collisions			Requested removals		
	Coef	Std. Error	P	Coef	Std. Error	P	Coef	Std. Error	P
Intercept	6.06	0.99	<0.001	2.93	1.06	<0.001	4.19	0.92	<0.001
Distance to NGO	-1.51	0.20	<0.001	-1.33	0,20	<0.001	-1.08	0.19	<0.001
Agreement	2.69	0.45	<0.001	1.92	0.37	<0.001	2.06	0.41	<0.001
Deforestation rate	1.15	0.30	<0.001	-	-	-	0.81	0.25	0.001
Urban area	0.46	0.12	<0.001	-	-	-	0.45	0.11	<0.001
Fire	-	-	-	0.51	0.16	0.001	-	-	-

Table 3. Results of the best Zero Altered Negative Binomial model that explains the total number of electrocuted mammals that arrived at the NGO Mata Ciliar.

	Count model			Zero hurdle model		
	Coef	Std. Error	P	Coef	Std. Error	P
Intercept	5.00	1.97	0.011	4.54	2.70	0.093
Distance to NGO	-1.64	0.67	0.014	-2.16	0.62	<0.001
Agreement	2.90	0.90	0.001	3.18	1.24	0.010
Clearing rate	3.83	1.87	0.041	-	-	-
Urban area	-	-	-	0.79	0.37	0.034

Figure 1

Click here to access/download;Figure;Figure 1.tiff

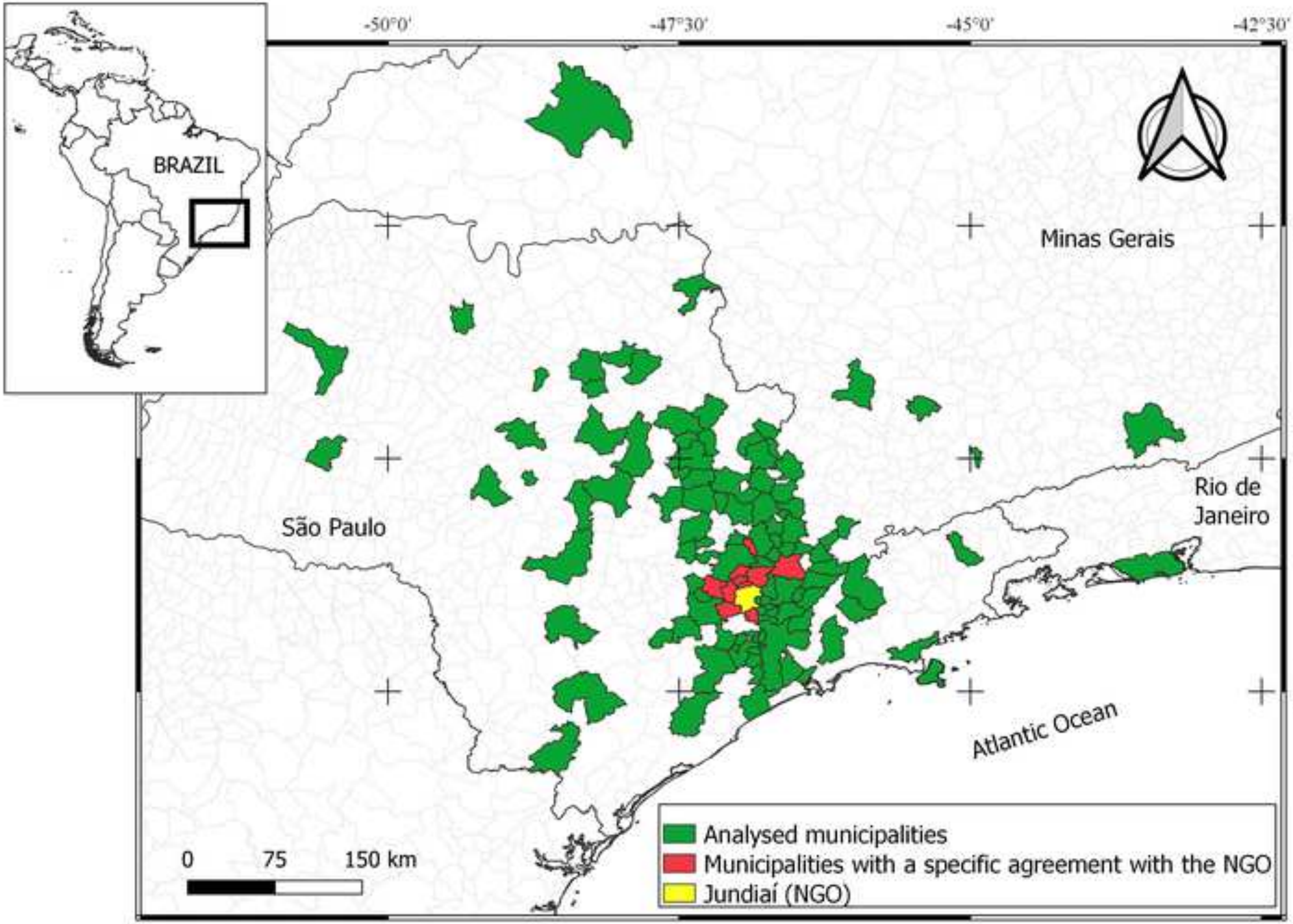
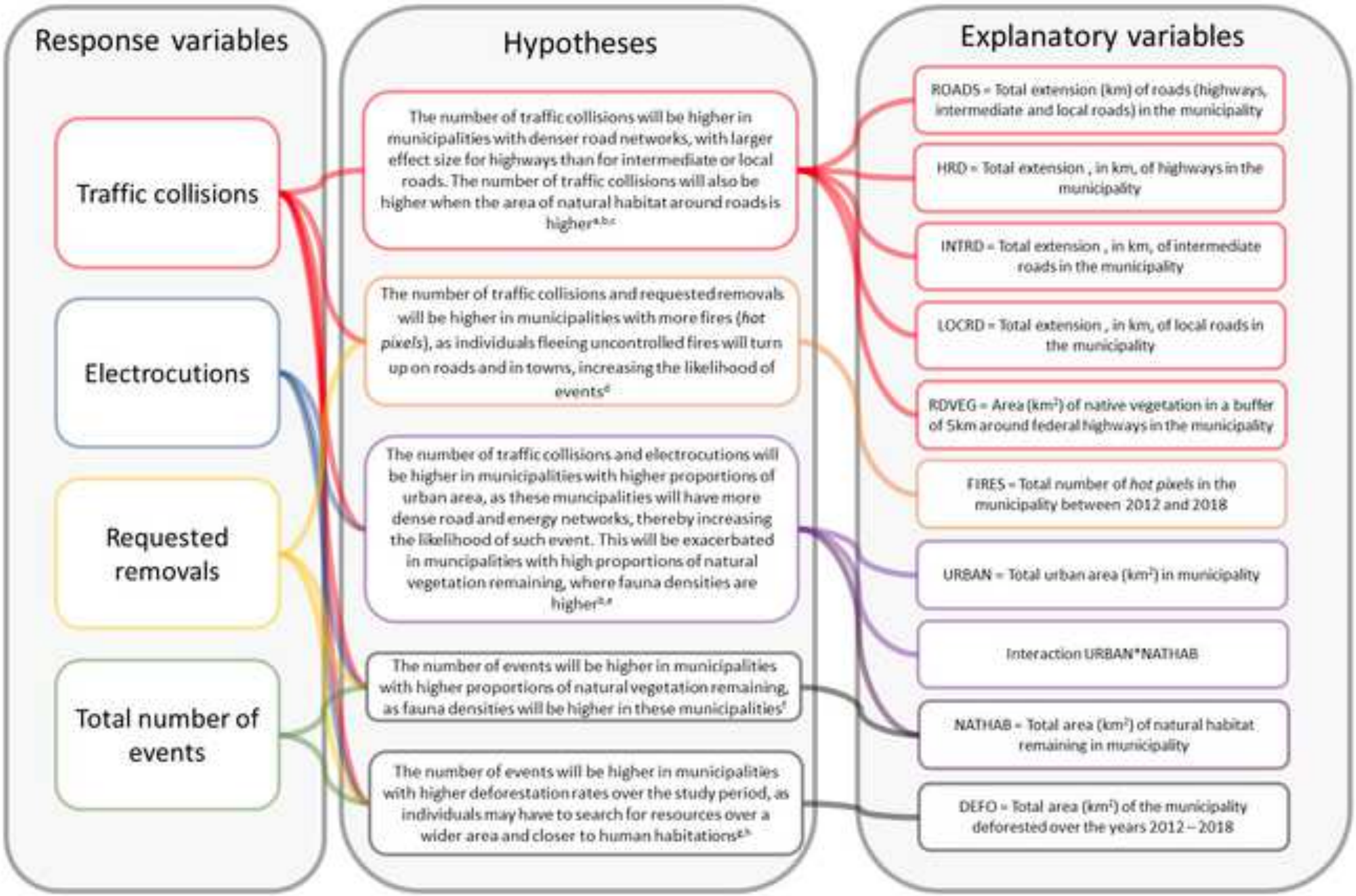
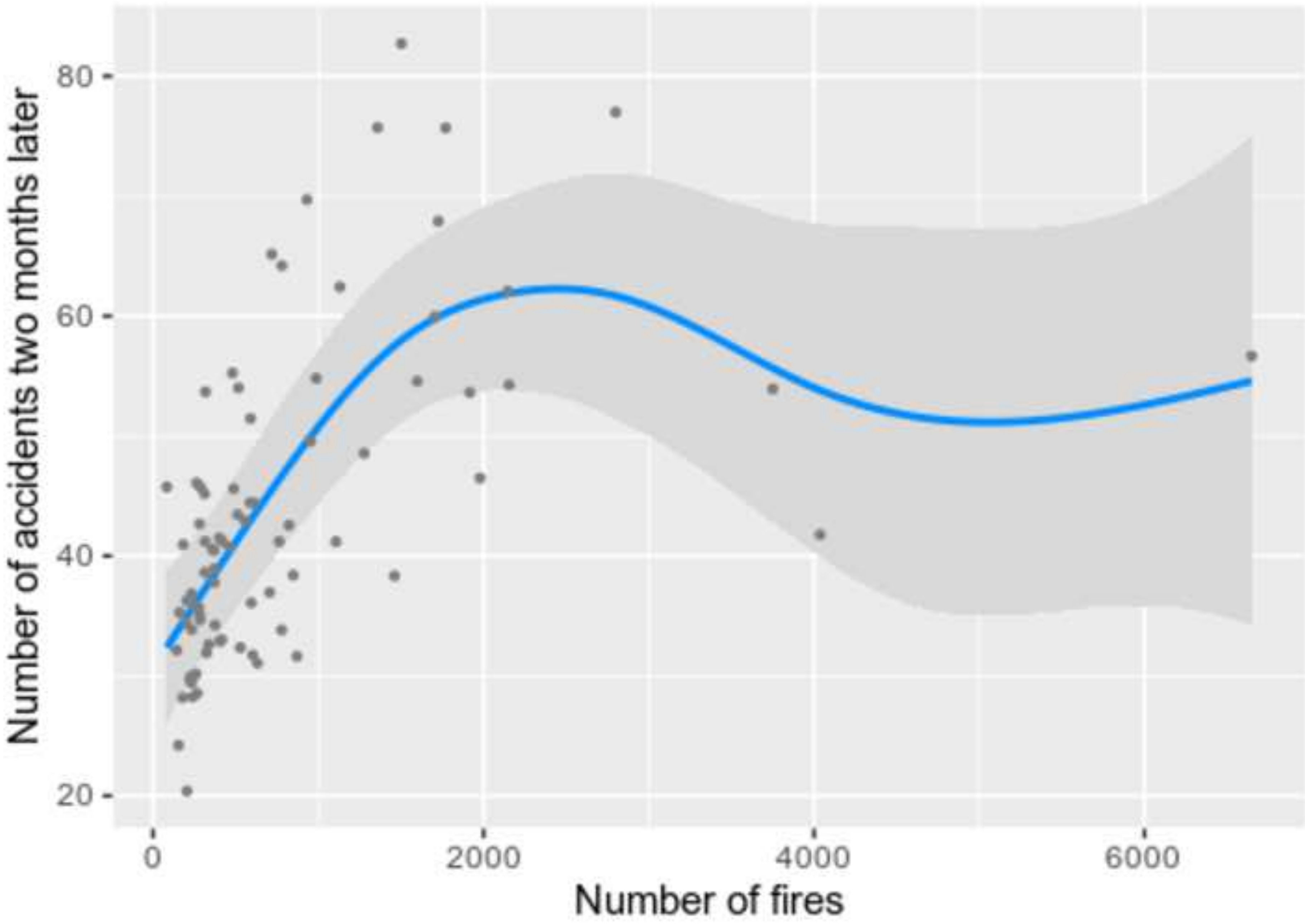


Figure 2



a – Beazley et al. (2004); b – Malo et al. (2004); c – Guson et al. (2011); d – Lewis (2020); e – Katsis et al. (2018); f – Roshnath & Jayaprasad (2017); g – Taylor et al. (1993); h – Borkowski (2004)

Figure 3



Number of accidents two months later
80
60
40
20
0
2000
4000
6000
Number of fires

Figure 4

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