

Discussion

Aquatic pollution from truck spills: Urgent action needed in Brazil and beyond



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ABSTRACT

On 29 January 2024, a truck accident spilled concentrated sulfonic acid into a river in Brazil's State of Santa Catarina. This disaster, which occurred in a protected area, killed various types of fish (e.g., crenuchids, heptapterids, and loricariids) and probably many other less observable animals, such as small invertebrates. The accident, similar to others around the world, gained national and international media attention. Because truck accidents causing aquatic pollution through chemical spills are occurring not just in Brazil but also globally, the recent event led us to consider similar cases and to recommend potential measures to help mitigate biodiversity loss in waterbodies near roads. Three factors need to be considered: (i) human (drivers); (ii) truck (mechanical condition); and (iii) road (e.g., infrastructure). In addition, improved expert assessments of the negative impact of these accidents on biodiversity are needed. A requirement to aid recovery of polluted ecosystems should be incumbent upon the companies involved in truck accidents.

1. Introduction

Roads, whether paved or unpaved, play a crucial role in connecting people, facilitating the movement of goods, and supporting other human needs (Sackey et al., 2023). However, the construction and use of roads can also have negative impacts (e.g., Carter et al., 2020; Krief et al., 2020; Pinto et al., 2020), including leaks and spills of pollutants from vehicles affecting both terrestrial and aquatic ecosystems (McCleneghan et al., 2002; Chilvers et al., 2021; Shen et al., 2014). This problem is expected to increase in many countries around the world.

Truck spills (i.e., solid or liquid pollutants) are an important threat to aquatic ecosystems in countries on all of the world's populated continents. There are cases of pollution of waterbodies by truck spills in Africa (Democratic Republic of Congo, South Africa, and Zimbabwe), Asia

(China, India, Japan, Laos, and Philippines), Central America (Costa Rica, El Salvador, Guatemala, Honduras, and Panama), Europe (Spain and United Kingdom), North America (Canada, Mexico, and United States), Oceania (Australia and New Zealand), and South America (Argentina, Bolivia, Chile, Colombia, Ecuador, and Peru) (Table S1 in Appendix A). However, the extent of pollution by trucks is poorly quantified in almost all these countries, and also reflected in the absence of scientific literature on this phenomenon—which forces one to rely substantially on media and technical reports.

In Brazil, truck spills represent a recurrent threat to the country's aquatic (marine and freshwater) biodiversity. Azevedo-Santos et al. (2022) provided an overview of cases of pollution by trucks in the country, but did not consider focal measures to avoid the problem in the future. Brazil's rich biodiversity is poorly protected, especially in aquatic

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ecosystems (Brum et al., 2021; Dias-Silva et al., 2021; Miyahira et al., 2023). The transport of dangerous cargo has likely increased in the country over the last decade given the sharp increase in documented dangerous-cargo accidents (ABTLP, 2022). Therefore, as argued by Azevedo-Santos et al. (2022), actions are urgently needed to prevent truck spills and to mitigate the associated pollution events in Brazil.

A recent case has dramatically illustrated the challenge, and motivated us to recommend ways of preventing truck spills in Brazil. On 29 January 2024, a truck crash spilled sulfonic acid, polluting the Seco River in the Cubatão do Norte River basin in Brazil's State of Santa Catarina (Munhoz, 2024). Using this recent event as a starting point, we briefly present an overview of other similar accidents that have been reported in the media, technical reports, and scientific literature. We then discuss strategies to reduce biodiversity losses from truck spills in Brazil. These measures have potential applications in other countries (e.g., Table S1) that face similar pollution challenges.

2. Tip of the iceberg: Sulfonic acid pollution

On 29 January 2024, a truck accident spilled sulfonic acid in a protected area in southern Brazil near Joinville, Santa Catarina, causing extensive contamination downstream of the spill. Sulfonic acid is a compound that poses both immediate and long-term toxicological risks to freshwater ecosystems (Garden Química, 2013). It was estimated that about 1000 L of the substance was spilled from the truck's containers (Borges, 2024a). An unknown amount of this toxic cargo reached a watercourse at the accident site.

The collision and consequent leakage occurred in the Serra Dona Francisca Environmental Protection Area (APA, in Portuguese) (approximately 26°11'39"S, 49°01'57"W) (Fig. 1). In accordance with Brazilian legislation, this type of protected area "... has as its basic objectives to protect biological diversity, discipline the occupation process, and ensure the sustainability of the use of natural resources" (Brazil, 2000; Art. 15, our translation). The event highlights the vulnerability of aquatic ecosystems in protected areas throughout Brazil (see Azevedo-Santos et al., 2019).

The sulfonic acid spill reached the Seco River, a watercourse that is approximately 10 km long and about 10 m wide at its mouth (measures inferred by us in Google Earth). The Seco River is a major tributary of the

Cubatão do Norte River, in a coastal basin in southern Brazil. Through analysis of photos taken of the affected watercourse by the local Environmental Police (e.g., Lima, 2024), we could identify some fish taxa that died from this contamination; these included Crenuchidae (*Characidium* sp.), Loricariidae (including *Pareiorhaphis* sp.), Heptapteridae (*Heptapterus* sp., and possibly species from other genera in the same family), and Acestrorhamphidae (*Oligosarcus* sp. and *Hollandichthys* sp.). However, these identifications underestimate the true negative impact on fish biodiversity. For example, the genus *Heptapterus* Bleeker 1858 is known to be more species-rich than previously thought (Azpelicueta et al., 2011; Aguilera et al., 2017; Faustino-Fuster et al., 2019; Deprá et al., 2022), and putative undescribed species occurring in the region may be affected. Other fish that occur in the Cubatão do Norte River basin, including endemic and threatened species (e.g., Table S2 in Appendix B), may occur in the negatively impacted watercourse (i.e., the Seco River).

The spillage may have also disrupted fish reproduction cycles, particularly since the period between October and March is crucial for the breeding of Neotropical freshwater fish species (Vazzoler, 1996). Whereas authorities did not report invertebrate mortality, it is probable that this occurred given that many freshwater insect larvae and other aquatic invertebrates are highly sensitive to water pollutants (Chowdhury et al., 2023). Moreover, the contaminated freshwater system ultimately flows into Babitonga Bay, which is home to marine and estuarine species threatened with extinction (Gerhardinger et al., 2020). The negative impact on this marine ecosystem was not mentioned in media reports, but may have occurred.

Two losses in environmental services are already clear. The first was through the loss or reduced abundance of fish species, which provide many services for ecosystems and people (Pelicice et al., 2023 and references therein). For example, some affected species support recreational fishing in the Cubatão do Norte River, and the same is expected for the Seco River. The second loss was water quality pollution leading to the suspension of the water supply in the city of Joinville (population approximately 600,000) (Joinville, 2024). In summary, the truck spill caused substantial negative impacts on local freshwater biodiversity and ecosystem services.

3. Pollution by truck spills

The accident described in the previous section is not an isolated event, and by no means the most serious truck spill in Brazil. For example, the Santa Clara and São João Rivers (in State of Paraná in southern Brazil) were contaminated by sulfonic acid and three other hazardous substances after a truck spill in 2001 (Folha de Londrina, 2001). A recent study has shown that, despite being underestimated, truck spills that pollute Brazilian aquatic ecosystems are more frequent than previously thought. Azevedo-Santos et al. (2022) gathered information on just over 70 truck accidents that occurred in Brazil, many of which had negative impacts on aquatic biota (Fig. 2). Among other accident cases in the country, two, that will be described below, are useful for providing greater levels of detail.

The first example is a truck spill in the State of Rio de Janeiro in southeast Brazil. In 2008, the accident, which did not involve a vehicle collision, released at least 1500 L of endosulfan into the Paraíba do Sul River via a tributary, the Pirapetinga River (DAE, 2008; IBAMA, 2009). Endosulfan is a known agrochemical that is harmful to fish (Sunderam et al., 1992; Capkin et al., 2006). At sub-lethal concentrations, it causes behavioral disorders in fish (including disorders related to swimming) and damages the gills (Jonsson and Toledo, 1993). This agrochemical is also harmful to invertebrates (e.g., Leonard et al., 1999; Jergentz et al., 2004; Muñoz-González et al., 2021). Indeed, the spill in the Paraíba do Sul River killed at least 20,000 kg of fish, as well as other aquatic and terrestrial animals (Azevedo-Santos et al., 2022). Data provided by official agencies (i.e., IBAMA, 2009) allowed us to determine that large Characiformes (especially prochilodontids fish) commonly targeted in artisanal fishing were involved. Given that the concentrations were

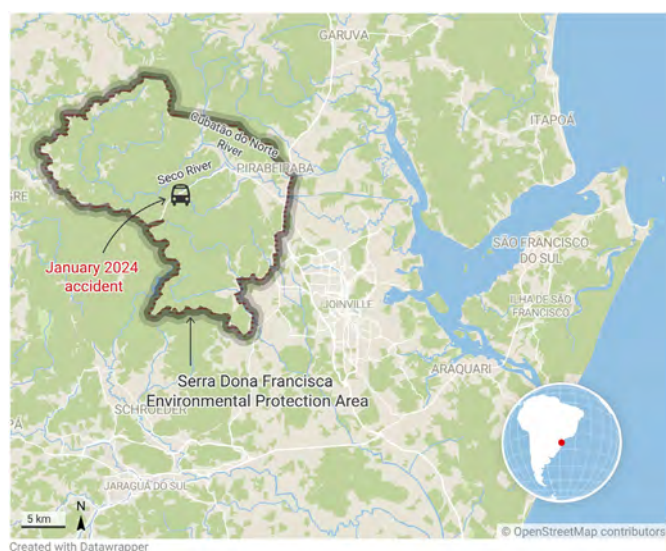


Fig. 1. Location of the January 2024 accident (truck icon), within the Serra Dona Francisca Environmental Protection Area (boundaries highlighted), and the Seco and Cubatão do Norte Rivers (both affected by sulfonic acid). Figure elaborated in the Datawrapper software using OpenStreetMap contributors.

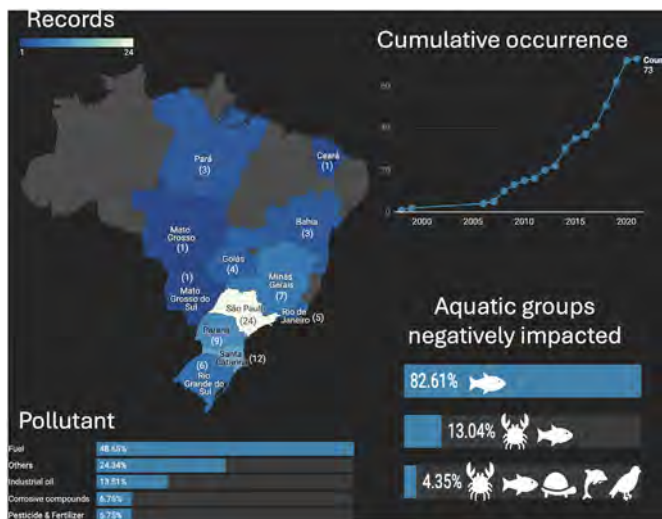


Fig. 2. Aquatic pollution from truck spills in Brazil. Figure elaborated in the Datawrapper software based on data in Azevedo-Santos et al. (2022).

sufficient to kill fish in the Paraíba do Sul River, they were surely high enough to cause sub-lethal injuries, impairing vital functions and reducing the survival rates of a wide range of other fish in the affected region. It is likely that the toxins killed macroinvertebrates and other small-bodied species, although this was ignored by authorities. Two main losses of ecosystem services were reported in the Paraíba do Sul River case: approximately 1200 people who directly depended on fishing for their livelihoods were affected, and water supplies were harmed in nearby areas (Thomé, 2009).

The second example occurred in 2022 in the São João River, in southern Brazil, when around 30,000 L of sulfuric acid spilled into the watercourse (Fernandes and Quariniri, 2022). This case is one of several known accidents in this region, following previous truck spills between 2008 and 2021, which had already polluted the same watercourse with substances such as chromated copper arsenate (CCA) (Azevedo-Santos et al., 2022). Sulfuric acid is harmful to both invertebrates and vertebrates (Trent et al., 1978). Indeed, the 2022 sulfuric-acid spill resulted in substantial fish losses. Analysis of photographs from the Civil Defense Department (in Fernandes and Quariniri, 2022) allowed us to identify dead individuals of the fish family Acestorhamphidae among rocks, in backwaters, and on the river banks. Dead individuals in the fish families Callichthyidae, Loricariidae, Synbranchidae (*Synbranchus* sp.), and Trichomycteridae (*Cambeva* sp.) were present on sand or gravel substrates along the river's banks. The pollution had a more pervasive toxic effect on the biodiversity of the São João River than initially reported. As mentioned, fishes have great value (e.g., fisheries, cultural) for society (Pelicice et al., 2023), and, therefore, there were certainly losses of ecosystem services—although these were not reported.

Truck spills affecting freshwater ecosystems are a problem for countries beyond Brazil. In the U.S., a hydrochloric acid spill from a truck killed approximately 145,000 fish in the John Day River basin (U.S. Department of the Interior, 1992). Other cases are commonplace in the U.S. (McCleneghan et al., 2002; Table S1). Acid spills have negatively affected the biodiversity of the Chamelecón River in Honduras (Central America) and the Nam Khan River in Laos (Asia) (Table S1). Creosote spill from a truck killed fish in the Murare River in Zimbabwe (Africa), and an oil spill harmed everything from insects to birds in an Australian stream (Oceania) (Table S1). Because many leaks and spills go unreported or undocumented, assessing the extent and severity of the problem is difficult.

Most known truck spills in Brazil and globally (Table S1) are those that have immediate negative effects on aquatic ecosystems—often after they gain media attention. Although leaks and spills from trucks on roads

and highways occur routinely (Verginassi et al., 2007; IBAMA, 2008; IBAMA, 2009; Shen et al., 2014), these incidents do not always immediately alter aquatic ecosystems. However, runoff in the rainy season carries pollutants from roads to rivers and wetlands (e.g., Windsor et al., 2019; Cao et al., 2022; French et al., 2022) at varying lengths of time after the spill. For instance, oil, diesel and gasoline, which are among the most commonly leaked substances on roads (IBAMA, 2008, 2009), are difficult to clean up because of their impregnating nature, but they eventually are washed into waterbodies by rainwater. Oil, gasoline and diesel contain polycyclic aromatic hydrocarbons (PAHs) (Dobbins et al., 2006), substances harmful to freshwater life (Honda and Suzuki, 2020). The situation may be even more concerning during rainy seasons because hydrophilic substances spilled on roads could be washed into watercourses, resulting in unreported negative impacts of unknown magnitude on biodiversity. In addition, truck leaks and routine spills on secondary roads, including “ghost roads” (see Engert et al., 2024), especially those used by trucks to avoid tolls, are often not reported (but they certainly occur). Lastly, not all reports of truck leaks and spills recorded by environmental authorities are available to researchers. The reality, then, is that truck leaks and spills that negatively alter aquatic ecosystems are both more pervasive and less well documented than most people appreciate.

With increasing globalization and the rapid expansion of roads in remote regions (Laurance and Arrea, 2017; Engert et al., 2024), there will be a greater flow of trucks and, as a consequence, more leaks and spills in frontier regions. In Brazil, accidents involving trucks with dangerous cargo have increased (ABTLP, 2022). In 2020, an estimated 939 accidents occurred involving the transport of chemical products in the country, increasing to 1095 the following year (ABTLP, 2022). The distances over which toxic loads are transported have continually expanded, driven by urbanization in more remote areas and the growth of agriculture throughout the country (e.g., Verginassi et al., 2007). Given Brazil's extensive network of watercourses (especially streams) crossed by roads (see Azevedo-Santos et al., 2022) and the high species richness they sustain (Agostinho et al., 2005), the transport of dangerous cargo is a potential time bomb for aquatic biodiversity. Based on the above trends, greater attention should be given to preventing and ameliorating truck leaks and spills in Brazil and other biodiverse countries. Therefore, in the next two sections, we will focus on specific measures for Brazil.

4. Actions needed before truck spills occur

A review of documents in Azevedo-Santos et al. (2022) indicated that truck spills in Brazil usually occur when the vehicle overturns or tips, but vehicle collisions or veering into waterbodies are also causes. Responses need to take into account the fact that these incidents often stem from one or more of human factors (e.g., drowsiness), mechanical problems, or road conditions.

4.1. Human factors

Accidents resulting from human shortcomings, such as inattention, speeding, and drowsiness, are well-known causes of truck accidents and resulting pollution (Ferreira, 2003; Santos and Silva, 2018). For example, Oliveira et al. (2016) showed that long time periods behind the wheel are correlated with accidents in the State of São Paulo. In fact, physical exhaustion and drowsiness of drivers were identified as contributing factors in almost two-thirds of all traffic accidents (Alves Júnior, 2010). One particular concern is the consumption of psychostimulant drugs. Easy to buy in Brazil, such drugs make drivers stay awake (e.g., Wendler et al., 2003) and may lead to increases in accidents (Takitane et al., 2013). Oliveira et al. (2016) assert that Brazilian Law 12, 619/2012—which requires a balance of rest and work for drivers—will fail if not combined with other actions. According to these authors, “... it is necessary to develop joint action between truck drivers, contracting companies, representatives of civil entities, and government authorities

with the aim of negotiating the organization of the work of this category [drivers], aiming to reduce the emission of risky behaviors ...” (Oliveira et al., 2016, p. 3765, our translation). We also believe that such collaborative efforts should be mandatory for all truck drivers transporting hazardous materials.

4.2. Truck factors

Truck condition is an important cause of accidents. For example, the Seco River accident probably resulted from a truck mechanical failure (Borges, 2024b). A study in the State of Bahia (northeastern Brazil) showed that 12% of accidents involving chemical transport also resulted from mechanical failure (Santos and Silva, 2018). A study in the State of São Paulo (southeastern Brazil) reported that mechanical problems caused 22% of accidents (Ferreira, 2003). In the same state, Pompono and Oliveira Neto (2019) evaluated accidents on roads involving toxic cargo over a period of 32 years. They found that 4.4% of the 4638 accidents resulted from mechanical problems. This shows that good mechanical condition of the truck is fundamentally important for avoiding accidents. However, adequate maintenance of trucks is far from the reality in Brazil. For example, Verginassi et al. (2007) showed that, in the State of Mato Grosso, 53% of the vehicles responsible for transporting toxic loads were in either “fair” or “poor” condition. This indicates a pressing need for increased vehicle inspection, including inspection on the roads. More importantly, there must be an effective mechanism to ensure that only trucks in “good” condition are permitted to transport hazardous materials.

4.3. Road factors

An important cause of accidents is related to problems with road maintenance and quality (Ferreira, 2003; Santos and Silva, 2018). Strategies to reduce truck spills from road factors include restrictions prohibiting vehicles with toxic loads from using certain risky roads, improving paving (which is poor on many Brazilian roads), enhancing signage, adding speed traps (including near bridges in straight roads, because these are also subject to overtaking and collisions), making structural changes in road design, and diversifying the means of transport.

Many state and federal roads cross streams and rivers both inside and



Fig. 3. Federal and state roads crossing protected areas (conservation units) in Brazil. Figure elaborated in the QGIS using ESRI Satellite (2024) and WGS 84/Pseudo-Mercator coordinate reference system and data from IBGE (2021), ANA (2024a, 2024b).

outside of protected areas (Fig. 3). These roads allow any accident to spread pollutants downstream in watercourses within protected areas. The disastrous January 2024 incident near Joinville illustrates this point. In many cases, it is necessary to close roads that pass through protected areas (Engert et al., 2024). If closure is not possible, the passage of trucks with hazardous loads should be restricted.

Currently, many roads border large Brazilian rivers. For example, the Lúcio Meira (BR-393) highway has surface runoff galleries that drain directly into the Paraíba do Sul River (Fig. 4), opening a path to the rapid input of toxic substances after truck leaks and spills. Vehicles carrying dangerous cargoes need to be prohibited from using this road and others like it.

Some watercourses have been negatively affected by multiple accidents. This is the case for the accidents that occurred in the São João River basin. The condition of these areas should be inspected, and, if possible, the road design modified to reduce future accidents.

Threatened species often occur in watercourses crossed by roads or that have roads near them (Table S3 in Appendix C). For example, threatened fish species, such as *Chasmocranus brachynema* Gomes & Schubart 1958, *Brycon orbignyus* (Valenciennes 1850), *Prochilodus vimboides* Kner 1859, and *Sternarchella curviperkulata* Godoy 1968, occur in the Mogi-Guaçu River (Table S3). The Mogi-Guaçu River is crossed by several roads with high truck traffic (see Fig. 5 for an example), necessitating enforcement actions such as inspections, speed bumps, and speed traps in these areas.

Many watercourses affected by truck leaks and spills have little information available about their biodiversity. This was the case for the Seco River, affected by the January 2024 accident. Because many Brazilian roads were planned and built when there was little concern about environmental issues, waterbodies crossed by old roads should be reevaluated to assess the biodiversity present. Understanding which species could be negatively affected by future spills is necessary, especially using new taxonomic tools and recent protocols.

The construction of potentially harmful new roads, such as those planned for Amazonia, should be reevaluated based on their need versus negative impacts (Fearnside, 2015; Laurance and Arrea, 2017). This proliferation must also be carefully studied from the point of view of pollution. Some strategies have been discussed to build roads that are more “ecological.” For example, Vasiliev et al. (2024) explain the advantages of what they refer to as “underground tunnels,” “covered ways,” and “covered elevated roads.” However, none of these solutions clearly addresses how truck leaks and spills could be contained and removed from the roads.

Brazilian highways are increasingly overloaded with car and truck traffic, which has led to discussions about duplication or construction of new roads (DNIT, 2024). A promising alternative is the reactivation of



Fig. 4. Section of the Lúcio Meira highway (BR-393) with a surface drain (red arrow) into the Paraíba do Sul River, in southeastern Brazil.



Fig. 5. One of the bridges on the Mogi-Guaçu River (road SP-225). There are no speed bumps near or on the bridge in this area (photographed 15 July 2024).

Brazilian railways (Daga et al., 2020) to transport dangerous cargo. This would ease highway traffic and reduce truck accidents, because traffic would be divided between roads and railways. Although this initiative would increase train accidents, it would also reduce car-truck accidents.

5. Actions needed after truck spills occur

5.1. Rigorous evaluations

Post-accident assessments usually fail to collect comprehensive information on biodiversity loss. In general, these assessments focus on water quality and fish mortality, neglecting other important biological groups (e.g., CETESB, 2020). This is a common pattern for numerous disasters with pollutants in Brazil (Azevedo-Santos et al., 2022, 2024). One potential path forward is specific legislation aimed at long-term monitoring of high-value waterbodies commonly altered by truck spills. These evaluations should involve multidisciplinary teams, including, for example, entomologists and ichthyologists, to ensure a thorough assessment of ecological impacts.

5.2. Recovery of affected waterbodies

It is essential to establish clear plans for the rehabilitation of environments affected by truck spills. These plans are urgently required in the country to deal with pollution by chemical substances (Azevedo-Santos et al., 2024). Brazilian law (No. 9605/98, Article 54) considers pollution after an accident to be a crime (Brazil, 1998). However, even when fines are imposed, little to no action is typically taken to rehabilitate the ecosystems affected by truck spills. For example, the Brazilian Public Ministry posed an initial fine of approximately R\$4,000,000 (around US\$696,000) for those involved in the Seco River accident (MPSC, 2024). However, it is not clear how those involved in the accident (or public authorities) will work to rehabilitate the watercourse. The difficulty of rehabilitating freshwater ecosystems after pollution events underscores the need to take actions (Azevedo-Santos et al., 2024) before new truck spills occur.

6. Conclusions

The sulfonic acid spill in Santa Catarina highlights the urgent need for actions to prevent and mitigate the impact of these incidents on aquatic ecosystems. The impact on biodiversity, mainly the immediate death of fish, the potential harm to invertebrates, and the chronic effects of toxic chemicals highlight the severity of the problem. The disruption of environmental services, such as safe drinking water and recreational and

artisanal fisheries, raises concerns about the far-reaching consequences of such accidents.

The documented history of over 70 similar accidents in Brazil (certainly a gross underestimate) indicates the magnitude of the problem. However, the same problem affects other countries. The number of accidents, reflecting the increase in cargo transportation to remote regions, highlights an urgent need for actions (on different fronts) against pollution caused by truck spills worldwide.

We indicate possible initiatives to reduce future truck spills, not just in Brazil, but in other countries as well. Assessment of the negative impact of potential pollution events should focus on three well-known groups of factors: (i) human (the drivers), (ii) truck (mechanical condition), and (iii) road (e.g., infrastructure). Following accidents, better assessments involving biodiversity specialists are needed. Finally, the recovery of polluted ecosystems should be an obligation of the companies involved in truck accidents.

CRedit authorship contribution statement

Valter M. Azevedo-Santos: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Tai-laine R. Pereira:** Writing – review & editing, Investigation, Formal analysis. **Anne E. Magurran:** Writing – review & editing, Formal analysis. **Wagner M.S. Sampaio:** Writing – review & editing, Formal analysis. **Philip M. Fearnside:** Writing – review & editing, Formal analysis. **William F. Laurance:** Writing – review & editing, Formal analysis. **Tommaso Giarrizzo:** Writing – review & editing, Formal analysis.

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Declaration of competing interest

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Appendix. A to C - Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.watbs.2025.100372>.

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