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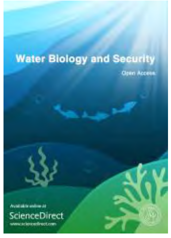

Discussion

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 accident 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 (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.

Keywords: Acid; Cargo; Conservation Unit; Fish kill; Fuel; Highway; Protected areas; Roads; Spill; Threatened species.

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 ecosystems (Brum et al., 2021; Dias-Silva et al., 2021; Miyahira et al., 2022). The transport of dangerous cargo has likely increased in Brazil 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 the country.

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 liters 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) (Figure 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), Acestrorhamphidae (*Oligosarcus* sp. and *Hollandichthys* sp.). However, these identifications underestimate the true negative impact on fish biodiversity. For example, the genus *Heptapterus* 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 affected 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.

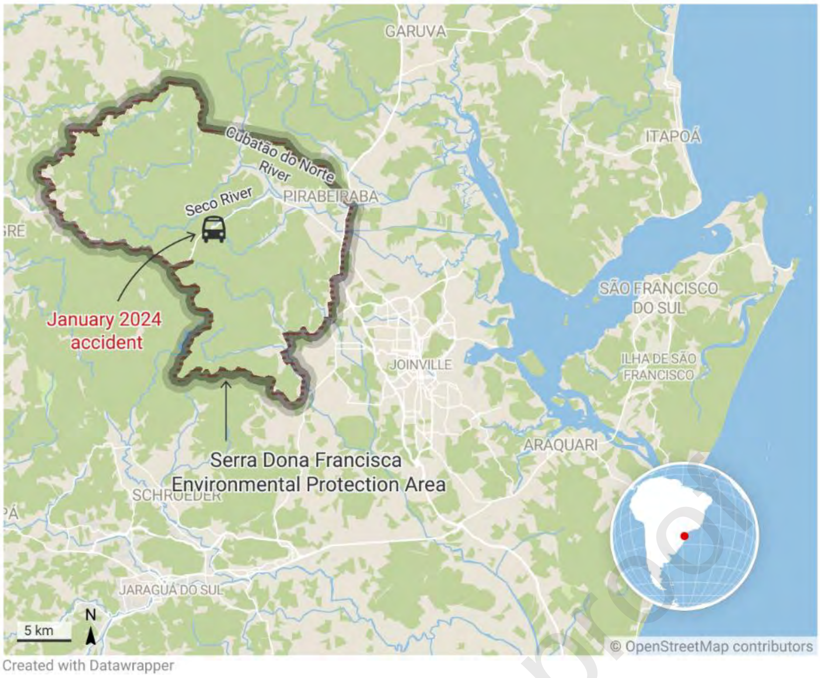

Fig. 1. Location of the January 2024 accident (truck icon), within the Serra Dona Francisca Environmental Protection Area (boundares highlighted), and the Seco and Cubatão do Norte Rivers (both affected by sulfonic acid). Figure elaborated in the Datawrapper software using OpenStreetMap contributors.

3. Pollution by truck spills

The accident described in the previous section is by no means the most serious truck spill in Brazil, and it is not an isolated event. 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 (Figure 2). Among the those other accident cases in Brazil, two 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 liters 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; Muñiz-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 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 liters 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 Acestrorhamphidae 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., 2024), and, therefore, there were certainly losses of ecosystem services, although these were not reported.

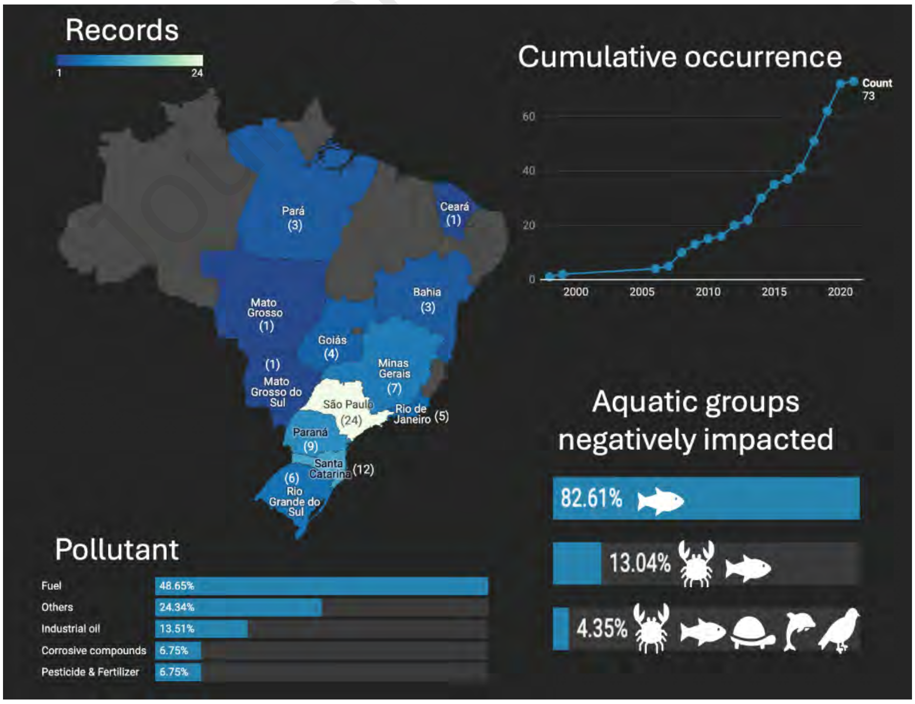

Fig. 2. Aquatic pollution from truck spills in Brazil. Figure elaborated in the Datawrapper software based on data in Azevedo-Santos et al. (2022).

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. (McClenegha et al., 2002; Table S1 in Appendix A). 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 in Appendix A). 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 in Appendix A). 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 in Appendix A) 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" (Engert et al., 2024), especially those used by trucks to avoid tolls, are often not reported (but they certainly occur). In addition, 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 truck drivers were identified as contributing factors in almost two-thirds of all traffic accidents (Brazil, 1998 *apud* Alves-Junior, 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, Pompone 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 outside of protected areas (Figure 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.

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

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 (Figure 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, threatebed fish species, such as *Chasmocranus brachynema* Gomes & Schubart 1958, *Brycon orbignyanus* (Valenciennes 1850), *Prochilodus vimboides* Kner 1859, and *Sternarchella curvioperculata* Godoy 1968, occur in the Mogi-Guaçu River (Table S3). The Mogi-Guaçu River is crossed by several roads with high truck traffic (see Figure 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.

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).

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 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 river. 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 (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.

Declaration of Competing Interest

None. One of us, Valter M. Azevedo-Santos, is a member of the editorial board of *Water Biology and Security*. However, he was not involved in any editorial decisions related to this article.

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Author Contributions

Valter M. Azevedo-Santos: Conceptualization, Formal analysis, Investigation, Roles/Writing - original draft, Writing - review & editing. **Tailaine Rocha Pereira:** Formal analysis, Investigation, Writing - review & editing. **Anne E. Magurran:** Formal analysis, Writing - review & editing. **Wagner Martins Santana Sampaio:** Formal analysis, Writing - review & editing. **Philip M. Fearnside:** Formal analysis, Writing - review & editing. **William F. Laurance:** Formal analysis, Writing - review & editing. **Tommaso Giarrizzo:** Formal analysis, Writing - review & editing.

Appendix A

Table S1; Key references.

Appendix B

Table S2; References

Appendix C

Table S3; References

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Highlights

- Truck spills are polluting aquatic ecosystems in Brazil and beyond.
- We propose measures against pollution by truck spills.
- We need post-accident evaluations.

Appendix A

Table S1. Examples of truck leaks and pollution of aquatic ecosystems around the world.

Continent	Country	Pollutant	Amount spilled (Liters or Tonnes)	Waterbody	Year	Affected biological group (s)	Key references
Africa	Democratic Republic of Congo	Sulfuric acid	Unknown	Dikulwe River	2023	Fish	A
Africa	South Africa	Sulfuric acid	28,000 L	Nyl River	2015	Fish and other groups	B
Africa	Zimbabwe	Creosote oil	30,000 L	Murare River	2023	Fish and other groups	C
Asia	China	Sulfuric acid	30 T	River (Unknown name)	2008	Fish	D
Asia	India	Latex fluid	Unknown	Meenachil River	2023	Fish	E
Asia	Japan	Body soap	~1 T	Chihaya River	2022	Unknown	F
Asia	Laos	Sulfuric acid	>30 T	Stream to the Nam Khan River	2024	Fish	G
Asia	Philippines	Caustic soda	Unknown	Suawan River	2022	Fish	H

Central America	Costa Rica	Vegetable oil	~19,000 L	Ciruelas River	2006	Unknown	I
Central America	El Salvador	Fuel	Unknown	Grande River	2019	Unknown	J
Central America	Guatemala	Vegetable oil	Unknown	Gracias a Dios River	2021	Unknown	K
Central America	Honduras	Sulfonic acid	~80,000 L	Chamelecón River	2019	Fish	L
Central America	Panama	Fuel	~16,600 L	Cascajal River	2016	Unknown	M
Europa	Spain	Fuel	~5,000 L	Ronfrío River	2011	Unknown	N
Europa	United Kingdom	Fuel	Unknown	Thames River	2024	Unknown	O
North America	Canada	Fuel	~50,000 L	Salmo River	2019	Fish	P
North America	Mexico	Sodium cyanide	3,000 L	Yaqui River	2013	Fish, reptiles, and birds	Q
North America	United States	Asphalt emulsion	~19,000 L	Mohawk River	2023	Fish	R
Oceania	Australia	Oil	28,000 L	Kirkalocka stream	2021	Insects, crustaceans, reptiles, and birds	S
Oceania	New Zealand	Oil	~20,000 L	Awakino River	2011	Birds	T

South America	Argentina	Fuel	~50 L	Blanco River	2022	Unknown	U
South America	Bolivia	Vegetable oil	55,000 L	Lake Titicaca	2023	Fish and birds	V
South America	Chile	Fuel	Unknown	San Francisco River	2017	Unknown	W
South America	Colombia	Oil	Unknown	Oibita River	2021	Unknown	X
South America	Ecuador	Acid	Unknown	Toachi River	2006	Insects and fish	Y
South America	Peru	Zinc	~30 T	Chillón River	2022	Fish	Z

Note: "Unknown" refers to information we were unable to find in the sources consulted.

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Capital letters before reference (s) refer to sources in the last column in Table S1.

Appendix B

Table S2. Some of the fish species known to occur in the Cubatão do Norte River basin (Babitonga Bay system) that may occur in the tributary Seco River, which was polluted in early 2024 by a major sulfonic acid spill. Occurrence records are based on scientific literature (Katz and Barbosa, 2014; Abrahão et al., 2015; Costa et al., 2023) and material deposited in the Museu de Ciências e Tecnologia (voucher MCP-Peixes 000031575) at the Pontifícia Universidade Católica do Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brazil. Classifications of the species are as provided in "Eschmeyer's Catalog of Fishes" (Fricke et al., 2024). Conservation status according to Brazil's Ministry of Environment and Climate Change (MMA, 2022).

ORDER/Family/Species	**Conservation status**	**Name of the waterbody**
CHARACIFORMES		
Acestrorhamphidae		
Astyanax sp.	Not listed	Pirabeiraba River
Deuterodon stigmaturus (Gomes 1947)	Not listed	Pirabeiraba River
Hollandichthys multifasciatus (Eigenmann & Norris 1900)	Not listed	Pirabeiraba River
Psalidodon laticeps (Cope 1894)	Not listed	Pirabeiraba River
Stevardiidae		
Mimagoniates lateralis (Nichols 1913)	Vulnerable	Prata River

Crenuchidae		
Characidium occidentale Buckup & Reis 1997	Not listed	Pirabeiraba River
Characidium pterostictum Gomes 1947	Not listed	Pirabeiraba River
CICHLIFORMES		
Cichlidae		
Geophagus brasiliensis (Quoy & Gaimard 1824)	Not listed	Pirabeiraba River
CYPRINODONTIFORMES		
Poeciliidae		
Phalloceros sp.	Not listed	Pirabeiraba River
GYMNOTIFORMES		
Gymnotidae		
Gymnotus sylvius Albert & Fernandes-Matioli 1999	Not listed	Pirabeiraba River
SILURIFORMES		
Heptapteridae		

Rhamdia aff. *quelen* (Quoy & Gaimard 1824)	Not listed	Pirabeiraba River
Loricariidae		
Epactionotus itaimbezinho Reis & Schaefer 1998	Not listed	Pirabeiraba River
Pareiorhaphis splendens (Bizerril 1995)	Not listed	Pirabeiraba River
Pareiorhaphis sp.	Not listed	Pirabeiraba River
Rineloricaria aequalicuspis Reis & Cardoso 2001	Not listed	Pirabeiraba River
Trichomycteridae		
Cambeva cf. *botuvera* Costa, Feltrin & Katz 2021	Not listed	Alandaf River; Cubatão do Norte River; Lindo River
Cambeva cubataonis (Bizerril 1994)	Not listed	Cubatão do Norte River

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Appendix C

Table S3. Examples of listed fish species in waterbodies near roads or crossed by roads. Occurrence records are based on scientific literature (i.e., Godoy, 1968; Weitzman and Cruz, 1981; Jégu and dos Santos, 1988; Kullander, 1988; Jégu, 1992; Weitzman and Malabarba, 1999; Malabara and Kindel, 1995; Carvalho and Bertaco, 2006; Costa, 2007; Meschiatti and Arcifa, 2009; Calegari and Reis, 2010; Ferreira et al., 2011; Menezes and Weitzman, 2011; Reis et al., 2012; Bertaco and Malabarba, 2013; Costa et al., 2014; Lima, 2017; Deprá and Slobodian, 2024). Classifications of the species are as provided in "Eschmeyer's Catalog of Fishes" (Fricke et al., 2024). Conservation status according to Brazil's Ministry of Environment and Climate Change (MMA, 2022). Roads near to or crossing waterbodies were found based on information provided in scientific literature (cited above) and using Google Earth software.

ORDER/Family/Species	**Name of the waterbody**	**Conservation status**	**Road**
CHARACIFORMES			
Acestrorhamphidae			
Hollandichthys taramandahy Bertaco & Malabarba 2013	Unknown name stream	Endangered	RS-239
Hyphessobrycon notidanos Carvalho & Bertaco 2006	Doze de Outubro River	Not listed	BR-364
Rachoviscus graciliceps Weitzman & Cruz 1981	Unknown name stream	Endangered	BA-001
Bryconidae			
Brycon insignis Steindachner 1877	Paraíba do Sul River	Endangered	BR-393
Brycon opalinus (Cuvier 1819)	Turvo River	Vulnerable	SP-125

Brycon orbignyanus (Valenciennes 1850)	Mogi-Guaçu River	Critically Endangered	BR-369
Brycon vermelha Lima & Castro 2000	Mucuri River	Endangered	BR-418
Prochilodontidae			
Prochilodus vimboides Kner 1859	Mogi-Guaçu River	Vulnerable	BR-369
Serrasalmidae			
Mylesinus paucisquamatus Jégu & dos Santos 1988	Tocantins River	Endangered	PA-263
Ossubtus xinguense Jégu 1992	Xingu River	Vulnerable	BR-230
Spintherobolidae			
Spintherobolus broccae Myers 1925	Unknown name stream	Endangered	SP-98
Stevardiidae			
Bryconamericus lambari Malabara & Kindel 1995	Unknown name stream	Endangered	BR-116
Diapoma pyrrhopteryx Menezes & Weitzman 2011	Peixe River	Endangered	SC-390
Diapoma thauma Menezes & Weitzman 2011	Antas River	Not listed	RS-448
Lepidocharax diamantina Ferreira, Menezes & Quagio-Grassiotto 2011	Santo Antônio River	Endangered	BR-242

CICHLIFORMES			
Cichlidae			
Teleocichla cinderella Kullander 1988	Tocantins River	Endangered	PA-263
CYPRINODONTIFORMES			
Rivulidae			
Nematolebias catimbau Costa, Amorim & Aranha 2014	Unknown name pool	Critically Endangered	RJ-106
Pituna brevirostrata Costa 2007	Meia Ponte River (lateral)	Critically Endangered	BR-153
GYMNOTIFORMES			
Apteronotidae			
Sternarchella curvioperculata Godoy 1968	Mogi-Guaçu River	Endangered	BR-369
SILURIFORMES			
Heptapteridae			
Chasmocranus brachynema Gomes & Schubart 1958	Mogi-Guaçu River	Endangered	BR-369
Loricariidae			

Microlepidogaster longicolla Calegari & Reis 2010	Santana stream	Not listed	DF-140
Microlepidogaster perforata Eigenmann & Eigenmann 1889	Carandaí River	Critically Endangered	MG-275
Plesioptopoma curvidens Reis, Pereira & Lehmann A. 2012	Paraopeba River	Critically Endangered	BR-040

Note: In some cases (e.g., Mogi-Guaçu River), the road is an example (i.e., not all were included). In addition, several species listed have occurrences recorded in other waterbodies beyond those given in the "Name of the waterbody" column.

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