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ROADS TO POLLUTION: BRAZIL´S AQUATIC BIODIVERSITY AFFECTED BY TRUCK LEAKS

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Abstract: Roads are responsible for various negative impacts on terrestrial and aquatic biodiversity. However, the negative effects of roads used by vehicles on aquatic biodiversity have been little explored. In this study, based on reports obtained from digital media and technical reports, we provide an overview of the pollution in Brazilian aquatic ecosystems caused by leakage from trucks. We found 73 truck leaks that reached Brazilian waterbodies, polluting them with fuel, pesticides and other substances. Pollution events caused the deaths of crustaceans, fish, and other vertebrates. According to the data obtained in our search, fish were the most impacted group, with records of at least 20 tons killed from a single spill. Measures must be adopted to prevent the entry of pollutants into waterbodies through truck leaks.

Keywords: Chemical products; fish deaths; fuel; oil spills; pesticide

INTRODUCTION

Roads are highly impactful for biodiversity in all parts of the planet. Some notable consequences are deforestation (Fearnside 1987, Laurance & Arrea 2017), deaths of animals run over by vehicles (Coelho *et al.* 2008, Kociolek *et al.* 2011, Grilo *et al.* 2018, Carvalho-Roel *et al.* 2021) and habitat fragmentation (Brejão *et al.* 2020). Roads can impact aquatic ecosystems in various ways (*e.g.*, Brejão *et al.* 2020), although these impacts are less documented than those in terrestrial ecosystems. For example, roads can block fish movements within and between waterbodies (Makrakis *et al.* 2012, Stegmann *et al.* 2019). Roads open the opportunity for numerous activities — both legal and illegal — with negative impacts on ecosystems, especially aquatic ones (Laurance *et al.* 2009, Azevedo-Santos *et al.* 2021). This situation is likely to worsen in the coming decades, since there is a trend towards the construction of new roads (or reactivation of abandoned ones) in some of the world's most biodiverse areas (*e.g.*, the Brazilian Amazon; see Ferrante *et al.* 2020).

Leakage of pollutants from trucks into aquatic environments occurs for reasons such

as collisions, mechanical problems, and lack of vehicle maintenance. In Brazil, and in the world in general, little is known about how leaks from trucks affect aquatic biodiversity (*e.g.*, Masnik *et al.* 1976, McCleneghan *et al.* 2002, Etkin 2011). For Brazil, we only know of one scientific article that reports on leakage and the pollution of waterbodies, documenting a massive die-off of freshwater organisms (Azevedo-Santos *et al.* 2018). Because cargo in Brazil is mainly transported by trucks (de Paula Junior & Lopes 2020), which frequently carry large quantities of toxic substances (*e.g.*, fuels) and travel along roads that cross on or are near to watercourses (see Figure 1), we expect that leaks from these vehicles in the country will be greater than currently documented in scientific literature.

When there is an assessment of a truck leak in a waterbody, the data are usually not made available — with the exception of a very few technical reports (CETESB 2020). This makes information from the internet an important source of data. Digital media and technical reports can help us understand a variety of problems in biodiversity conservation (El Bizri *et al.* 2015, Ryan 2018, Ferraz *et al.* 2019, Azevedo-Santos *et al.* 2021, Magalhães *et al.* 2021). Based on information from these sources, we provide a comprehensive overview

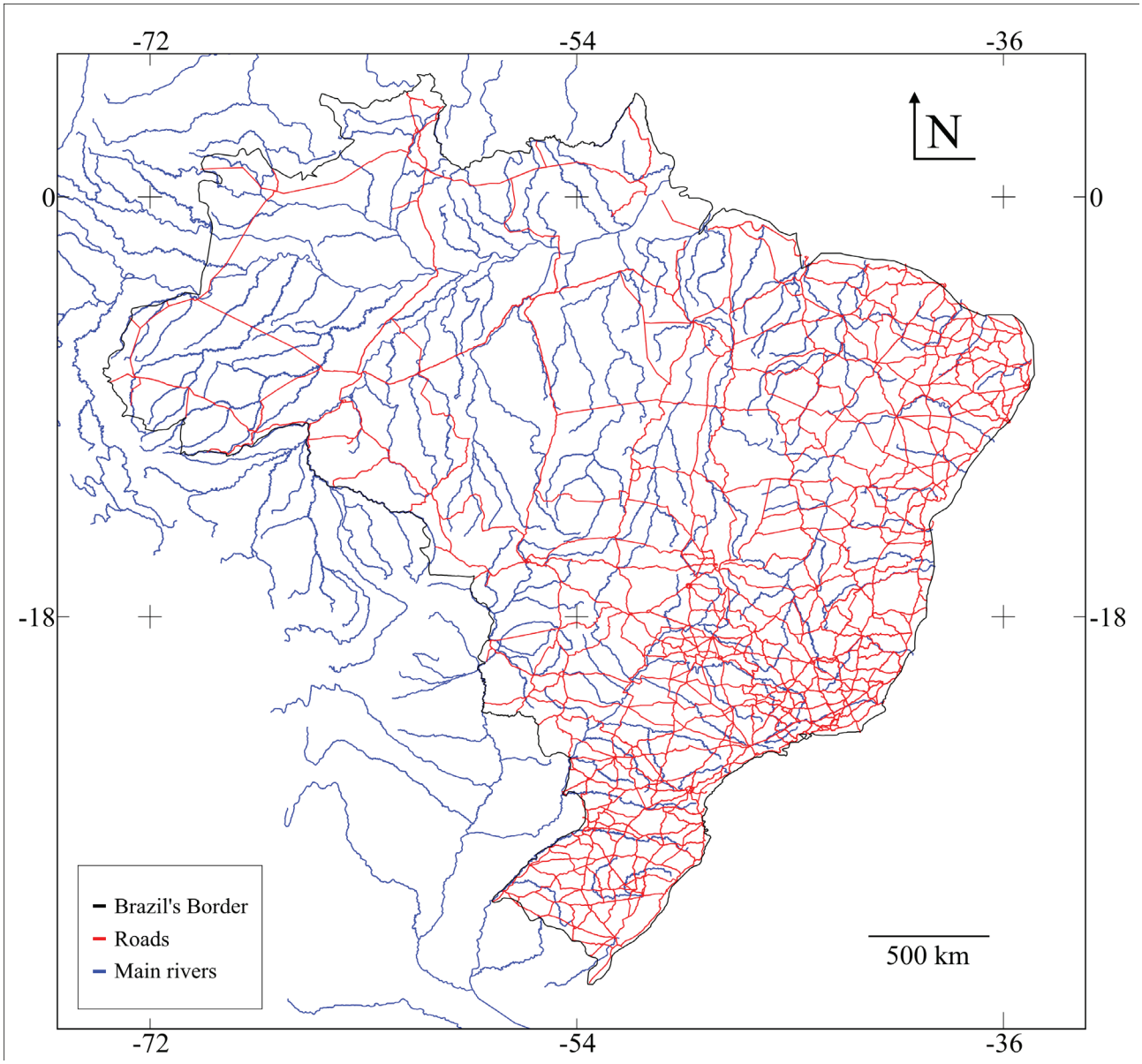

Figure 1. Federal roads (in red) crossing major rivers (in blue) in Brazil. We prepared the image in Quantum GIS software (QGIS Development Team 2018) using shapefiles of federal roads (from ONTL 2020) and main rivers (*sensu* ANA 2018).

of how truck leaks impact Brazilian aquatic environments with an emphasis on biodiversity.

MATERIAL AND METHODS

The search for digital media and technical reports was carried out between September 2020 and February 2021 using Google[BR] (https://www.google.com.br/) and considered events in any year. For this search we used the combination of the term "*vazamento de caminhão*" (truck leak) with the following words: "*rio*" (river), "*córrego/ribeirão/riacho*" (stream), "*praia*" (beach), "*lago*" (lake), "*mangue*" (mangrove), "*estuário*" (estuary), "*poluição*" (pollution), "óleo" (oil), "*rio Amazonas*" (Amazon River), "*mar*" (sea), "*morte de peixes*" (fish death), "*morte de camarão*" (shrimp death), "*oceano Atlântico*" (Atlantic Ocean), "*morte de animal*" (animal death) and "IAP" (the Brazilian acronym for Paraná Environmental Institute). We also searched documents in the Environmental Company of São Paulo State (CETESB), looking for data on fish mortality in the Inland Waters section (CETESB 2020). The keyword "IAP" and the company CETESB were included in our search because we only recorded reports mentioning these entities and decided to do a detailed search on these institutions. We made sure that the information provided in CETESB (2020) was not the same as that already registered in the search using digital media.

From each record we extracted (when available) information regarding the aquatic environment affected (*e.g.*, lake, river, stream) and the name of the pollutant (the chemical agent, *e.g.*, hydrochloric acid). For the compounds retrieved in the search, we extracted (when available) the quantity leaked (liters or kg) from a truck. We also compiled information regarding the municipality (county) where the truck leak occurred, the state, and the hydrographic region (this last being based on ANA 2020). Lastly, we extracted from the records information regarding the impacts on biodiversity and the quantity of dead organisms (when available), as well as the year of the truck leak.

RESULTS

We found 73 events of truck leaks across Brazilian regions, based on 65 incidents reported in digital news media and eight in technical reports. Fuel is among the most-frequently reported leaked substances, but other pollutants, such as pesticides, acids, and organic substances, were also reported (Table 1). Pollutants recorded here leaked in quantities that ranged from 9 to >35,000 liters, and from 13,000 to 37,000 kg (Table 1). Truck leaks resulted in the pollution of such aquatic environments as reservoirs, groundwater, lakes, streams, and rivers, as well as marine ecosystems, including pollution carried to the ocean by streams and rivers. Watercourses in several Brazilian states received pollutants from truck leaks (Table 1).

Of the 73 truck leak events, only 23 reported animal deaths, including crustaceans, fish and other vertebrates (Table 1). Of the taxonomic groups reported, fish death was the most notable, mentioned in all 23 truck-leak events (Table 1). Only four of these reports indicated the magnitude of the impact on biodiversity and ecosystem services.

DISCUSSION

Our study is the broadest ever carried out on truck leaks and their impacts on aquatic biodiversity in Brazil. We found 73 truck-leak events causing negative impacts on marine and freshwater environments, with several cases of animal kill. However, our results are almost certainly underestimated because some vehicle accidents have undoubtedly not been covered by digital media, and the technical reports were limited to São Paulo State.

Fuel was the most frequent pollutant leaked from trucks, and the release of this substance caused the death of animals in aquatic ecosystems (Table 1). Therefore, although many of the reports we consulted did not provide information concerning the negative impacts of fuel leaked from trucks on aquatic biodiversity, it is likely that these impacts occurred.

Brazilian streams generally hold high biodiversity (Castro & Polaz 2020, Castro *et al.* 2020, Firmiano *et al.* 2021, Manoel & Uieda 2021), and in numerous cases the streams harbor threatened species (*e.g.*, Bueno & Shimizu 2008; Trevisan & Santos 2014). Truck leaks in these small watercourses, therefore, may disrupt biodiversity beyond fishes.

Table 1. Leaked pollutants from trucks that were reported in Brazil. Key references in Supplementary Material. NF: information not found.

Pollutant	Quantity of pollutant leaked -Liters (L) or kilograms (kg)	Affected environment	Hydrographic region	Municipality (County)	State	Impacts on biodiversity	Quantity of dead fish (kg)	Year	Key references
Ferric chloride	ca. 200 L	Stream	Paraná	Campinas	São Paulo	NF	NF	1998	1
Sulfuric acid	17,000 L	Stream	Paraná	Rio Claro	São Paulo	NF	NF	1999	2
Fuel	34,000 L	Reservoir	Paraná	São José do Rio Preto	São Paulo	Fish	NF	2006	3
Alkyd resin	ca. 13,000 kg	Stream	South Atlantic	NF	Paraná	NF	NF	2006	4
Acid	4,000 L	River	Southeast Atlantic	NF	São Paulo	Fish	NF	2007	5
Fuel	25,000 L	River	South Atlantic	Tubarão	Santa Catarina	NF	NF	2008	6
Oil	10,000 L	River	Southeast Atlantic	João Monlevade/ Itabira	Minas Gerais	NF	NF	2008	7
Pesticide	1,500 L	River	Southeast Atlantic	Resende	Rio de Janeiro	Fish, crustaceans, reptiles, mammals, and birds	>20,000	2008	8, 9, 10 and 11
Hydrochloric acid	ca. 15,000 L	Stream	Paraná	Planura	Minas Gerais	NF	NF	2008	12
Aluminum sulfate	ca. 8,000 L	Stream	South Atlantic	Guaratuba	Paraná	Fish	NF	2008	13
Fuel	ca. 6,000 L	Stream	Uruguay	São Pedro do Sul	Rio Grande do Sul	NF	NF	2009	14
Lubricant oil	NF	River	Southeast Atlantic	Areal	Rio de Janeiro	NF	NF	2009	15
Fuel	ca. 10,000 L	Stream	Southeast Atlantic	Sapucaia	Rio de Janeiro	NF	NF	2009	16

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Pollutant	Quantity of pollutant leaked -Liters (L) or kilograms (kg)	Affected environment	Hydrographic region	Municipality (County)	State	Impacts on biodiversity	Quantity of dead fish (kg)	Year	Key references
Phosphoric acid	ca. 2,000 L	NF	NF	Guaratuba/ Garuva	Paraná/ Santa Catarina	NF	NF	2010	17
Oil	>13,000 L	Stream	East Atlantic	Riachão do Jacuípe	Bahia	Fish	>10,000	2010	18
Lubricant oil	5,000 L	Stream	Paraná	Cascavel	Paraná	NF	NF	2011	19
Fuel	ca. 15,000 L	Stream-Ocean	Southeast Atlantic	Maresias	São Paulo	Fish and crustaceans	NF	2012	20
Fuel	NF	Stream	Uruguay	Maraú/Passo Fundo	Rio Grande do Sul	NF	NF	2012	21
Oil	ca. 37,000 kg	Stream	Tocantins-Araguaia	Vila Propício	Goiás	NF	NF	2012	22
Fuel	NF	Stream	Southeast Atlantic	São Sebastião	São Paulo	Fish	NF	2012	23
Fuel	25,000 L	Stream	Paraná	Ourinhos	São Paulo	NF	NF	2013	24
Aluminum sulfate	NF	Stream	South Atlantic	Jaraguá do Sul	Santa Catarina	NF	NF	2013	25
Fuel	NF	Stream	East Atlantic	Jequié	Bahia	NF	NF	2014	26
Fuel	NF	Stream	Paraná	Goiânia	Goiás	NF	NF	2014	27
Hydrochloric acid	29,000 L	Stream	Paraná	Itapevi	São Paulo	NF	NF	2014	28
Fuel	~20,000 L	Ocean	South Atlantic	Florianópolis	Santa Catarina	NF	NF	2014	29
Industrial effluent	NF	Stream	South Atlantic	Florianópolis	Santa Catarina	NF	NF	2014	30
Bitumen (oil)	~30,000 L	River	Amazon	Santarém	Pará	Fish	NF	2014	31 and 32

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Table 1. ...continued

Pollutant	Quantity of pollutant leaked -Liters (L) or kilograms (kg)	Affected environment	Hydrographic region	Municipality (County)	State	Impacts on biodiversity	Quantity of dead fish (kg)	Year	Key references
Fuel	ca. 3,000 L	Stream	South Atlantic	Porto Alegre	Rio Grande do Sul	NF	NF	2014	33
Unspecified	NF	River	Southeast Atlantic	Cruzeiro	São Paulo	Fish	NF	2014	34
Black liquor	NF	Stream	Paraná	Itaporanga	São Paulo	NF	NF	2015	35
Fuel	NF	Stream	Eastern Northeast Atlantic	Sobral	Ceará	NF	NF	2015	36
Fuel	NF	Ocean	Southeast Atlantic	Santos	São Paulo	Fish	NF	2015	37
Unspecified	NF	Stream	Paraná	Santa Isabel	São Paulo	Fish	NF	2015	37
Unspecified	NF	Reservoir	Paraná	Gastão Vidigal	São Paulo	Fish	NF	2015	37
Fuel	NF	Stream	East Atlantic	Ipira	Bahia	Fish	NF	2016	38
Unspecified	NF	River	Southeast Atlantic	Itatiaia	Rio de Janeiro	Fish	NF	2016	39
Liquid asphalt	30,000 L	River	Uruguay	Flores da Cunha/ Antônio Prado	Rio Grande do Sul	NF	NF	2017	40
Liquid fertilizer	NF	Reservoir (possibly reaching a river)	Paraná	Canápolis	Minas Gerais	Fish	NF	2017	41
Sodium hypochlorite	ca. 7,000 L	River-Ocean	Southeast Atlantic	São Sebastião	São Paulo	Fish and crustaceans	NF	2017	42
Sulfuric acid	NF	River	Southeast Atlantic	Cajati	São Paulo	Fish	NF	2017	43
Fuel	ca. 10,000 L	River	Uruguay	Seara/ Arvoredo	Santa Catarina	NF	NF	2018	44
Fuel and pesticide	25,000 L and 13,000 L	River	South Atlantic	Guaratuba/ Garuva	Paraná/ Santa Catarina	Fish	3,000	2018	45

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Pollutant	Quantity of pollutant leaked -Liters (L) or kilograms (kg)	Affected environment	Hydrographic region	Municipality (County)	State	Impacts on biodiversity	Quantity of dead fish (kg)	Year	Key references
Multiple	NF	Stream	Tocantins-Araguaia	Niquelândia	Goiás	NF	NF	2018	46
Fuel	NF	Stream	Uruguay	Maraú/Passo Fundo	Rio Grande do Sul	NF	NF	2018	47
Fuel	NF	River	Southeast Atlantic	Magé	Rio de Janeiro	NF	NF	2018	48
Bovine blood	10,000 L	River	Tocantins-Araguaia	Goiás	Goiás	NF	NF	2018	49
Fuel	NF	Stream	Paraná	Cascavel	Paraná	NF	NF	2018	50
Fuel and osmose k33	NF	River	South Atlantic	Guaratuba	Paraná	Fish and crustaceans	200	2018	51 and 52
Fuel	~8,000 L	Groundwater	Southeast Atlantic	Santos	São Paulo	NF	NF	2018	53
Whey	NF	Stream	Uruguay	Mondaí	Santa Catarina	NF	NF	2018	54
Pesticide	NF	Stream	Paraguay	Alto Paraguai	Mato Grosso	NF	NF	2019	55
Fuel	~300 L	River	Uruguay	Nova Itaberaba	Santa Catarina	NF	NF	2019	56
Industrial oil	NF	River	South Atlantic	Guaratuba/ Garuva	Paraná/ Santa Catarina	NF	NF	2019	45 and 57
Fuel	NF	Stream	Paraná	Sorocaba	São Paulo	NF	NF	2019	58
Ink	NF	Stream	Uruguay	Farroupilha	Rio Grande do Sul	NF	NF	2019	59
Fuel	400 L	Stream	Paraná	Santa Bárbara d'Oeste	São Paulo	NF	NF	2019	60

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Table 1. ...continued

Pollutant	Quantity of pollutant leaked -Liters (L) or kilograms (kg)	Affected environment	Hydrographic region	Municipality (County)	State	Impacts on biodiversity	Quantity of dead fish (kg)	Year	Key references
Fuel	NF	Stream	South Atlantic	Corupá	Santa Catarina	NF	NF	2019	61
Asphalt emulsion	~30,000 kg	River	Amazon	Santarém	Pará	NF	NF	2019	62
Hydrochloric acid	NF	Lake	Paraná	Bragança Paulista	São Paulo	Fish	NF	2019	63
Fuel	NF	Stream	Southeast Atlantic	Guararema	São Paulo	Fish	NF	2019	63
Fuel	NF	Stream	Paraná	Mogi Mirim	São Paulo	Fish	NF	2019	63
Fuel	NF	River	Paraná	Mogi Guaçu	São Paulo	NF	NF	2020	64
Fuel	>35,000 L	Stream	Paraná	Monte Castelo	São Paulo	NF	NF	2020	65
Aerosol	4,000 L	River	Paraná	Campo Limpo Paulista	São Paulo	NF	NF	2020	66
Fuel	13,000 L	Stream	São Francisco	Belo Horizonte	Minas Gerais	NF	NF	2020	67
Vegetable oil	NF	Stream	Paraná	Prudentópolis	Paraná	NF	NF	2020	68
Fuel	22,000 L	Stream	Paraná	Três Lagoas	Mato Grosso do Sul	NF	NF	2020	69
Fuel and milk	ca. 100 L and ca. 7,000 L	Stream	Paraná	Ituiutaba	Minas Gerais	NF	NF	2020	70
Fuel	NF	Stream	Southeast Atlantic	Bela Vista de Minas	Minas Gerais	NF	NF	2020	71
Fuel	ca. 9 L	River	Amazon	Santarém	Pará	NF	NF	2020	72
Fuel	5,000 L	Stream	São Francisco	Oliveira	Minas Gerais	NF	NF	2020	73
Chromated copper arsenate	NF	River	South Atlantic	Guaratuba/ Garuva	Santa Catarina	Fish	NF	2021	74 and 75

Fish was the taxonomic group with the greatest number of records of death due to truck leaks. In general, individuals of this group are relatively large organisms (as compared, for instance, with aquatic insect larvae), and they are easy to detect when dead. We also believe that, in contrast to other taxonomic groups such as aquatic insects, the fact that fish are commonly used directly by humans for food or as pets may increase the focus that this group receives when news or technical reports are written.

Some events found here were extremely harmful, as in the case of pesticide released into the Paraíba do Sul River basin, killing >20,000 tons of fish in the region (Table 1). Numerous species in this watershed are threatened with extinction (ICMBio 2018), and this single event may have affected them. For example, a report (Key reference 11 in Table 1) mentioned an impacted fish, the "cascudo preto," presumably *Pogonopoma parahybae* (Steindachner, 1877) — a species listed as "endangered" (EN) in the Brazilian Red List (Akama *et al.* 2018). This case in the Paraíba do Sul River shows that the country's authorities need to rethink the free transit of trucks with dangerous cargoes close to large rivers or freshwater areas with threatened species.

The records found here draw attention to a number of concerns. For example, practically all federal roads cross major rivers in Brazil (Figure 1). The situation is even more complex if we consider the countless streams that are crossed by federal, state or municipal roads. As shown here, traffic accidents and the consequent leakage of pollutants can result in large losses of biodiversity in aquatic environments. Biodiversity in marine protected areas may also be affected by truck leaks in continental areas (*e.g.*, coastal rivers) due to the connectivity of fluvial ecosystems with the ocean [see Azevedo-Santos *et al.* (2019) on the propagation of negative impacts]. This is reinforced by the fact that half of the pollution events at sea reported here occurred through truck leaks into continental waterbodies (Table 1).

The leakage of pollutants from trucks suggests that current plans for new infrastructure should be reviewed, especially in areas with high aquatic biodiversity. For example, Brazil has extensive plans for road construction in the Amazon (Ferrante *et al.* 2020), which is the world's richest region in aquatic organisms (Azevedo-Santos *et al.* 2016). The record of truck leaks and fish deaths in an Amazon tributary (Table 1) suggests that new roads will put aquatic biodiversity at risk (Fearnside *et al.* 2021), along with terrestrial ecosystems and traditional communities (Ferrante & Fearnside 2020, Ferrante *et al.* 2020). For example, the route of the controversial highway BR-319 (Manaus-Porto Velho) in the Amazon region, which is planned for reconstruction to allow truck traffic, intersects 242 watercourses (Stegmann *et al.* 2019).

In Brazil, transport of cargo (*e.g.*, fuel) is largely handled by trucks. This became notorious during the recent truckers' strike, which left various parts of the country without basic supplies (de Paula Junior & Lopes 2020). Considering the intense movement of cargo, especially highly hazardous cargo (*e.g.*, fuel and pesticides), measures must be adopted to prevent the entry of pollutants into waterbodies through truck leaks.

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REFERENCES

Akama, A., Netto-Ferreira, A.L., Paixão, A.C., Zanata, A.M., Calegari, B.B., Polaz, C.N.M., Figueiredo, C.A.A., Caneppele, D. *et al.* 2018. *Pogonopoma parahybae* (Steindachner, 1877). In: Livro Vermelho da Fauna Brasileira Ameaçada de Extinção: Volume VI – Peixes / -- 1. ed. -- Brasília, DF: ICMBio/MMA,7 v.: il.. Retrieved from http://www.icmbio.gov.br/portal/component/content/article/10187

Ana (Agência Nacional de Águas e Saneamento Básico). 2018. Rios Principais (Principal Rivers). Retrieved from https://metadados.ana.gov.br/geonetwork/srv/pt/main.home?uuxml:id=fb206e35-a86e-44b3-ac3b-5c4d6833c48e

Ana (Agência Nacional de Águas e Saneamento Básico). 2020. Divisões Hidrográficas (Hydrographic Divisions). Retrieved from https://www.ana.gov.br/aguas-no-brasil/panorama-das-aguas/copy_of_divisoes-hidrograficas

Azevedo-Santos, V.M., Garcia-Ayala, J.R., Fearnside, P.M., Esteves, F.A., Pelicice, F.M., Laurance, W.F., & Benine, R.C. 2016. Amazon aquatic biodiversity imperiled by oil spills. Biodiversity and Conservation, 25, 2831–2834. DOI: 10.1007/s10531-016-1192-9

Azevedo-Santos, V.M., Coelho, P.N., & Deprá, G.C. 2018. Ichthyofauna of the Ribeirão Frutal and tributaries, upper Rio Paraná basin, Minas Gerais, Southeastern Brazil. Biota Neotropica, 18(3), e20180517. DOI: 10.1590/1676-0611-BN-2018-0517

Azevedo-Santos, V.M., Frederico, R.G., Fagundes, C.K., Pompeu, P.S., Pelicice, F.M., Padial, A.A., Nogueira, M.G., Fearnside, P.M., Lima, L.B., Daga, V.S., Oliveira, F.J.M., Vitule, J.R.S, Callisto, M., Agostinho, A.A., Esteves, F.A., Lima-Junior, D.P., Magalhães, A.L.B., Sabino, J., Mormul, R.P., Grasel, D., Zuanon, J., Vilella, F.S., & Henry, R. 2019. Protected areas: A focus on Brazilian freshwater biodiversity. Diversity and Distributions, 25, 442–448. DOI: 10.1111/ddi.12871

Azevedo-Santos, V.M., Arcifa, M.S., Brito, M.F.G., Agostinho, A.A., Hughes, R.M., Vitule, J.R.S., Simberloff, D., Olden, J.D., & Pelicice, F.M. 2021. Negative impacts of mining on Neotropical freshwater fishes. Neotropical Ichthyology, 19(3), e210001. DOI: 10.1590/1982-0224-2021-0001

Bueno, S.L.S., & Shimizu, R.M. 2008. Reproductive biology and functional maturity in females of *Aegla franca* (Decapoda: Anomura: Aeglidae). Journal of Crustacean Biology, 28(4), 652-662.

Brejão, G.L., Teresa, F.B., & Gerhard, P. 2020. When roads cross streams: fish assemblage responses to fluvial fragmentation in lowland Amazonian streams. Neotropical Ichthyology, 18(3), e200031. DOI: 10.1590/1982-0224-2020-0031

Carvalho-Roel, C.F., Alves, G.B., Jácomo, A.T.A., Moreira, R.A., Tôrres, N.M., & Silveira, L. 2021. Wildlife roadkill in the surroundings of Emas National Park, Cerrado biome, Brazil. Oecologia Australis, 25(4),795–806. DOI: 10.4257/oeco.2021.2504.01

Castro, R.M.C., & Polaz, C.N.M. 2020. Small-sized fish: the largest and most threatened portion of the megadiverse neotropical freshwater fish fauna. Biota Neotropica, 20(1), e20180683. DOI: 10.1590/1676-0611-BN-2018-0683

Castro, D.M.P., Silva, P.G., Solar, R., & Callisto, M. 2020. Unveiling patterns of taxonomic and functional diversities of stream insects across four spatial scales in the neotropical savanna. Ecological Indicators, 118, 106769. DOI: 10.1016/j.ecolind.2020.106769

CETESB (Companhia Ambiental do Estado de São Paulo). 2020. Retrieved from https://cetesb.sp.gov.br/aguas-interiores/publicacoes-e-relatorios/

Coelho, I.P., Kindel, A., & Coelho, A.V.P. 2008. Roadkills of vertebrate species on two highways through the Atlantic Forest Biosphere Reserve, southern Brazil. European Journal of Wildlife Research, 54(4), 689–699. DOI: 10.1007/s10344-008-0197-4

de Paula Junior, A., & Lopes, R.L. 2020. Truck drivers' strike: the most affected sectors and their space dependences. Revista Brasileira de Gestão e Desenvolvimento Regional, 16(2), 472–483.

El Bizri, H.R., Morcatty, T.Q., Lima, J.J.S., & Valsecchi, J. 2015. The thrill of the chase: uncovering illegal sport hunting in Brazil through YouTube™ posts. Ecology and Society, 20(3), 30. DOI: 10.5751/ES-07882-200330

Etkin, D.S. 2011. Spill occurrences: a world overview. In: M. Fingas (Ed.). Oil spill science and technology. 1st edition. Gulf Professional Publishing. pp. 7–48.

Fearnside, P.M. 1987. Deforestation and international economic development projects in Brazilian Amazonia. Conservation Biology, 1(3), 214–221.

Ferrante, L., Gomes, M. & Fearnside, P.M. 2020. Amazonian indigenous peoples are threatened by Brazil's Highway BR-319. Land Use Policy, 94, 104548. DOI: 10.1016/j.landusepol.2020.104548

Ferrante, L., & Fearnside, P.M. 2020. The Amazon's road to deforestation. Science, 369, 634. DOI: 10.1126/science.abd6977

Fearnside, P.M., Berenguer, E., Armenteras, D., Duponchelle, F., Guerra, F.M., Jenkins, C.N., Bynoe, P., García-Villacorta, R., Guerra, F.M., Macedo, M., Val, A.L., & de Almeida-Val, V.M.F. 2021. Drivers and impacts of changes in aquatic ecosystems. Chapter 20 In: C. Nobre, & A. Encalada (Eds.) Amazon Assessment Report 2021. Science Panel for the Amazon (SPA). United Nations Sustainable Development Solutions Network, New York, USA. Part II, pp.

305-343. https://www.theamazonwewant.org/amazon-assessment-report-2021/

Ferraz, J.D., Garcia, D.A.Z., Casimiro, A.C.R., Yabu, M.H.S., Geller, I.V., Magalhães, A.L.B., Vidotto-Magnoni, A.P., & Orsi, M.L. 2019. Descarte de peixes ornamentais em águas continentais brasileiras registrados no Youtube™: Ausência de informação ou crime ambiental deliberado? Revista Brasileira de Zoociências, 20(2), 1–20.

Firmiano, K.R., Cañedo-Argüelles, M., Gutiérrez-Cánovas, C., Macedo, D.R., Linares, M.S., Bonada, N., & Callisto, M. 2021. Land use and local environment affect macroinvertebrate metacommunity organization in Neotropical stream networks. Journal of Biogeography, 48, 479–491.

Grilo, C., Coimbra, M.R., Cerqueira, R.C., Barbosa, P., Dornas, R.A.P., Gonçalves, L.O. et al. 2018. Brazil road-kill: a data set of wildlife terrestrial vertebrate road-kills. Ecology, 99, 2625–2625.

ICMBio. 2018. Instituto Chico Mendes de Conservação da Biodiversidade - Livro Vermelho da Fauna Brasileira Ameaçada de Extinção: Volume VI - Peixes / -- 1. ed. -- Brasília, DF: ICMBio/MMA, 2018.7 v.: il.. In: http://www.icmbio.gov.br/portal/component/content/article/10187

Kociolek, A.V., Clevenger, A.P., ST. Clair, C.C., & Proppe, D.S. 2011. Effects of road networks on bird populations. Conservation Biology, 25(2), 241–249. DOI: 10.1111/j.1523-1739.2010.01635.x

Laurance, W.F., Goosem, M., & Laurance, S.G.W. 2009. Impacts of roads and linear clearings on tropical forests. Trends in Ecology & Evolution 24(12): 659–669. DOI: 10.1016/j.tree.2009.06.009

Laurance, W.F. & Arrea, I.B. 2017. Roads to riches or ruin? Science, 358, 442–444. DOI: 10.1126/science.aao0312

Magalhães, A.L.B., Azevedo-Santos, V.M., & Pelicice, F.M. 2021. Caught in the act: Youtube™ reveals invisible fish invasion pathways in Brazil. Journal of Applied Ichthyology, 37, 125–128. DOI: 10.1111/jai.14159

Makrakis, S., Castro-Santos, T., Makrakis, M.C., Wagner, R.L., & Adames, M.S. 2012. Culverts in paved roads as suitable passages for Neotropical fish species. Neotropical Ichthyology, 10(4), 763–770. DOI: 10.1590/S1679-62252012000400009

Manoel, P.S., & Uieda, V.S. 2021. Impacts of different monoculture types on stream benthic macroinvertebrate and fish communities. Hydrobiologia, 848, 691–703. DOI: 10.1007/s10750-020-04476-8

Masnik, M.T., Stauffer, J.R., Hocutt, C.H. & Wilson, J.H. 1976. The effects of an oil spill on the macroinvertebrates and fish in a small southwestern Virginia creek. Journal of Environmental Science and Health. Part A: Environmental Science and Engineering, 11(4-5), 281–296. DOI: 10.1080/10934527609385771

McCleneghan, K., Reiter, G.A., Hardwick, J.E., & McGovern, P.T. 2002. Management of oil spill response and cleanup in a River Under Severe Winter Conditions. Spill Science & Technology Bulletin, 7, 163–172. https://doi.org/10.1016/S1353-2561(02)00058-0

ONTL (Observatório Nacional de Transporte e Logística). 2020. ONTL. Retrieved from https://ontl.epl.gov.br/

QGIS Development Team. 2018. QGIS Geographic Information System. Open Source Geospatial Foundation Project. Retrieved from https://www.qgis.org/en/site/

Ryan PG. 2018. Entanglement of birds in plastics and other synthetic materials. Marine Pollution Bulletin, 135, 159–164. DOI: 10.1016/j.marpolbul.2018.06.057

Stegmann, L.F., Leitão, R.P., Zuanon, J., & Magnusson, W.E. 2019. Distance to large rivers affects fish diversity patterns in highly dynamic streams of Central Amazonia. PLoS One, 14(10), e0223880. DOI: 10.1371/journal.pone.0223880

Trevisan, A., & Santos, S. 2014. Population dynamics of *Aegla manuinflata* Bond-Buckup and Santos 2009 (Decapoda: Aeglidae), an threatened species. Acta Limnologica Brasiliensia, 26, 154-162.

Supplementary Material

Key references. Links for the news and technical reports cited in Table 1.

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