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Opinion

Pesticide Pollution in the Brazilian Pampa: Detrimental Impacts on Ecosystems and Human Health in a Neglected Biome

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Abstract: The Brazilian Pampa biome covers half of Rio Grande do Sul state, in the extreme south of Brazil, creating an ecotone zone with the Atlantic Forest and bordering Pampa's territory belonging to Uruguay and Argentina. Pampa is a non-forest biome mainly composed of grasslands and mosaics of grassland-forest vegetation. This biome shows significant animal and plant diversity, contributing to the maintenance of important ecosystem services, including CO_2 capture, pollination, and water cycle regulation. However, forestry plantations, inappropriate cattle ranching, mining activities, unplanned urbanization, and the cultivation of monocultures (soy, rice, tobacco, and other cash crops) significantly threaten the conservation of the Pampa biome. A major problem observed in the Pampa, due to the great connection of this biome with agricultural areas, is pesticide pollution, which significantly affects the health of humans and animals that occupy the region. A robust body of evidence indicates that aquatic and terrestrial ecosystems in the Brazilian Pampa are extensively contaminated with pesticides, as indicated by studies involving animal biomarkers and pesticide analyses performed on water and soil samples. Human studies also suggest that pesticides affect different body systems, facilitating the onset of various chronic diseases. Brazil's conservation actions and policies have a special focus on forest ecosystems, neglecting non-forest biomes and thus aggravating the problems related to Pampa's conservation. In this article, we discuss some problems caused by pesticide pollution in the Brazilian Pampa, drawing attention to the need for intensification of policies focused on the promotion of human and environmental health. Finally, we suggest the bioecological bioeconomy as an alternative for Rio Grande do Sul to progress its economic development but with less dependency on detrimental activities to the Pampa biome.

Keywords: agrochemicals; Brazil; conservation; disease; environmental health; grasslands; Pampa; Rio Grande do Sul; pesticide; pollution

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1. Environmental Health and the Pampa Biome

Environmental health refers to the influence of physical, chemical, and biological aspects of the environment on the health of humans, animals, and ecosystems. It usually deals with environmental factors that can be modified, such as anthropogenic land use and climate changes, chemical and biological pollution levels, and pesticide exposure. The World Health Organization estimated that 23% of all global deaths are linked to environmental factors [1]. Environmental health is a concept strongly linked to the One Health perspective, which considers that the health of humans, animals, and the environment is interlinked, influencing the occurrence of diseases in both urban [2] and (non-urban) natural environments [3,4].

Environmental pollution contributed to the premature deaths of 9 million people in 2015, and it was recently considered the main trigger of premature death in the world, being ahead of more recognized risk factors such as (i) interpersonal violence, (ii) road injuries, (iii) AIDS, tuberculosis, and malaria, (iv) drug and alcohol use, (v) malnutrition, and (vi) smoking [5]. According to the "Pollution and Health Metrics—Global, Regional, and Country Analysis December 2019" (based on data retrieved from the IHME Global Health Data Exchange Tool) [6], it is estimated that 109,438 premature deaths/year are related to pollution in Brazil [6]. The expression "environmental pollution" encompasses the contamination of air, soil, water, and the domestic environment by different types of pollutants, such as radioactive compounds, heavy metals, particulate matter, chemical industry by-products, toxic gases, plastics, pesticides, and many other classic and emerging pollutants (e.g., pharmaceuticals, nanomaterials, microplastics, and personal care products) [5,7,8].

Pesticide pollution impacts ecosystems, animals, and the human population worldwide [9]. However, in some regions where economic development is strongly connected with agricultural activities, especially in developing countries, pesticide-related health issues gain more evidence [10–12]. This is the case in the Brazilian Pampa biome, where agricultural and livestock activities are currently important for the maintenance of the region's economy but, at the same time, significantly threaten this ecologically sensitive biome.

The Pampa (Figure 1) is distributed between Brazil, Argentina, and Uruguay and is characterized by grasslands, isolated shrubs, and mosaics of grassland-forest vegetation [13,14]. In Brazil, the Pampa is limited to the territory of Rio Grande do Sul, the southernmost state of Brazil, where it connects with the Atlantic Forest biome, creating an ecotone zone of great natural beauty and complex biodiversity [15–18]. It is one of the four Brazilian non-forest biomes, along with Cerrado, Pantanal, and Caating [19]. The Brazilian Pampa occupies an area of 176,496 km^2 (about 2% of the national territory and 63% of the Rio Grande do Sul state), is within the South Temperate Zone, and shows 1200–1600 mm of annual precipitation volume [13].

Many human inhabitants of the Pampa are European descendants since the Brazilian colonization process encouraged many Europeans (Spanish, Portuguese, German, and Italian, among others) to occupy the Pampa territory. The colonization process of Pampa, including the introduction and dissemination of cattle, brought some economic development to the region, but on the other hand, it contributed to the exploitation of traditional peoples and environmental degradation of the biome [13]. Remnants of Indigenous peoples and other traditional peoples still inhabit the Pampa in current days, contributing to the preservation of its socio-diversity and cultural heritage [13,20].

The Pampa has huge biodiversity, with species belonging to several taxonomic groups. A recent study reported more than 12,500 species of plants, animals, fungi, and bacteria occurring in the Brazilian Pampa, representing 9% of all Brazilian biodiversity in an area that occupies 2% of Brazil's territory [21]. This biome performs several ecosystem services, such as CO_2 capture, pollination, pest and disease control, and water cycle regulation [19,22]. Pampa's vegetation also has great ornamental [23,24], food, medicinal [25], and cosmetic [26] potential.

Currently, just 43.2% of the Pampa is covered by native vegetation [27]. Anthropogenic activity has suppressed native vegetation in 46.7% of the biome's territory, and the 10.1% remaining area is covered by water and sand [27]. Forestry plantations for cellulose production, inappropriate cattle ranching, mining activities, unplanned urbanization, illegal hunting, and cash crop plantations (soy, rice, corn, wheat, and tobacco, among others) are some anthropogenic activities triggering major environmental problems in the biome [13,28–30].

The Pampa's soil originated from sedimentary rocks, usually showing a sandy texture [13]. The natural fragile characteristics of the soil, in combination with climatic conditions and anthropic activities such as the cultivation of monocultures, facilitate the erosion and impoverishment of the soil in the Pampa. Many "sandification" areas are observed in the biome due to water and wind erosion associated with a lack of native vegetation [13].

These problems affect not only the Pampa's biodiversity but also the living conditions of the human population. Although Rio Grande do Sul is one of the richest states in Brazil in economic terms, there is a concentration of municipalities with a reduced Human Development Index located in the Pampa region [31]. Of note, socioeconomic issues intensify the multiple environmental challenges observed in the Pampa.

In this article, we draw attention to the pesticide pollution in the Pampa biome, highlighting the need for Brazil, especially Rio Grande do Sul, to expand protection policies focused on this biome, which is usually neglected in terms of public attention and environmental protection policies [18,32]. The bioecological bioeconomy for Rio Grande do Sul's sustainable development is suggested as an alternative to economic activities linked to the degradation of the Pampa biome.

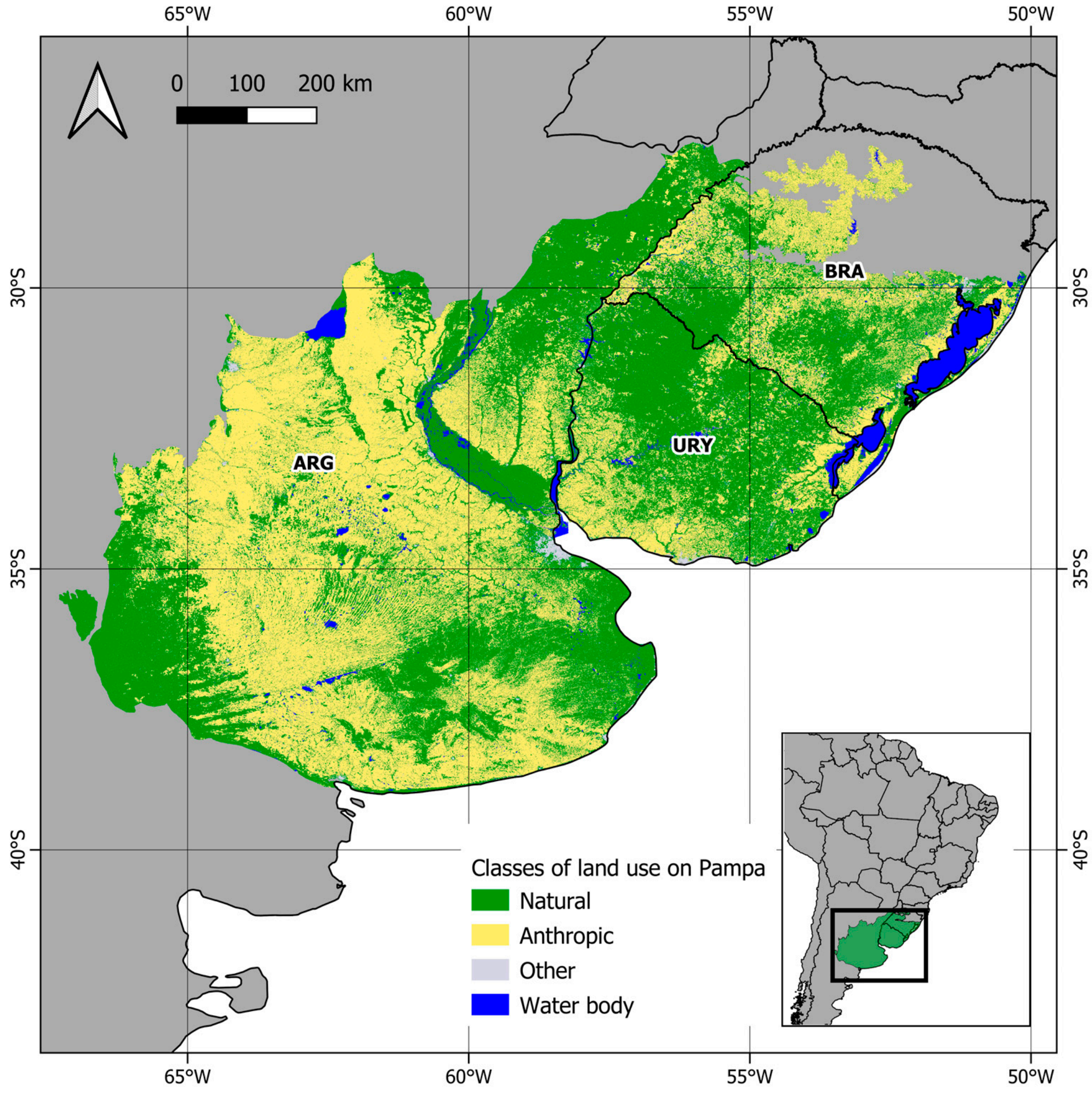

Figure 1. Map showing the territory of the Pampa biome distributed between Brazil (BRA), Uruguay (URY), and Argentina (ARG). In Brazil, the Pampa is limited to Rio Grande do Sul state. Classes of land use on Pampa are highlighted. Of note, anthropic use refers especially to areas of agriculture, forestry plantations, and pasture. Urban areas are included in the class "other".

2. Pesticide Pollution in the Pampa Biome

2.1. Current Scenario

Pesticides (synthetic agrochemicals) broadly refer to herbicides, fungicides, insecticides, and plant growth regulators used especially in agriculture. Brazil is a world leader in agricultural production and, consequently, a world's leading pesticide consumer, with ~20% of worldwide pesticide usage occurring in the country [33,34].

Soybean, corn, and sugar cane production are together responsible for 82% of pesticide consumption in Brazil. Rio Grande do Sul is one of the Brazilian states that uses the most pesticides (~130 million L/year), along with Mato Grosso and Paraná. Soybean, rice, wheat, corn, and tobacco are the predominant crops in Rio Grande do Sul; all these cash crops are major pesticide consumers [35]. Of note, tobacco production uses the highest mean quantity of pesticides per hectare (60 L/ha) [35]. Therefore, the Pampa is considered a region with intense pesticide use [36]. Excessive use combined with inappropriate application of pesticides causes environmental contamination, especially in water bodies and soil [33,34].

2.1.1. Pesticides in Water

In an analysis performed by Albuquerque et al. [33] that considered only 11% of pesticides approved for use in Brazil in 2016, 34 pesticides were detected in 14% of 6350 freshwater samples from five Brazilian states. In Rio Grande do Sul, many substances were detected, including propanil (concentration range above the limit of quantification—LOQ, from 1998 to 2013: 0.58–12.9 $\mu g\ L^{-1}$), bentazone (0.088–3.6 $\mu g\ L^{-1}$), imazethapyr (0.1–1.2 $\mu g\ L^{-1}$), diuron (0.124 $\mu g\ L^{-1}$), clomazone (0.046–23.0 $\mu g\ L^{-1}$), quinclorac (0.48–6.6 $\mu g\ L^{-1}$), atrazine (0.19–0.63 $\mu g\ L^{-1}$), tebuconazole (0.06 $\mu g\ L^{-1}$), carbofuran (0.1–0.8 $\mu g\ L^{-1}$), imidacloprid (0.38–2.18 $\mu g\ L^{-1}$), and fipronil (0.05–26.2 $\mu g\ L^{-1}$) [33]. In the same study [33], the potential risk to aquatic life was evaluated using the Risk Quotient (RQ) method (by dividing the concentration range of each pesticide by the lowest water quality criteria (WQC), with values > 1 indicating risk), and the authors observed potential risk to aquatic life for 59% of the pesticides detected in Brazil [33].

Another study detected tebuconazole (detected concentration range: 1.99–3.66 $\mu g\ L^{-1}$), imazethapyr (1.46–2.48 $\mu g\ L^{-1}$), and clomazone (3–11.76 $\mu g\ L^{-1}$) in water samples from the Uruguay River, Uruguaiana city, Rio Grande do Sul state [37]. Tests carried out with pesticide-contaminated water samples indicated that both the survival and reproductive viability of the free-living nematode *Caenorhabditis elegans* were altered in relation to controls, suggesting a risk to aquatic life [37].

2.1.2. Pesticides in Soil

Pesticide contamination also affects terrestrial ecosystems. Imidazole contamination (concentration range < LOQ–37.77 $\mu g\ Kg^{-1}$) was detected in agricultural soil samples from Rio Grande do Sul and Bahia states [34,38], consistent with data showing that phenylurea and imidazole are the chemical classes of pesticides with higher usage in the country [34]. In the same study [34], the potential risk of different pesticide classes to terrestrial life and human health was assessed using the RQ method, but no data concerning imidazole was available [34], indicating the urgent need to assess the potential impacts of pesticides found in soil on human and animal health.

2.1.3. A Neglected and Evolving Problem

The extension of pesticide pollution in Brazil is probably even greater than suggested by the available literature, since environmental contamination data for some states are scarce or non-existent [33] and the legislation for the use of pesticides has been relaxed in Brazil in recent years [39,40], including authorization for the use in Brazilian territory of an additional 562 pesticides (since 2021), many of them banned in Europe and North America [40]. Registration for the use of new pesticides in Brazil has been significantly facilitated since 2016 [39]. In fact, political pressure exerted by some politicians (*bancada ruralista*, or "ruralist bench") and members of the agribusiness sector facilitates the expansion of pesticide use in Rio Grande do Sul [41].

To the best of our knowledge, there is no data on the distribution of pesticide pollution levels in the different regions of the Brazilian Pampa. However, it is known that different regions of the biome show important variations in terms of geomorphology, landscape, socioeconomic development, and agricultural practices [13]. Indeed, while some areas have significant livestock activities, others are dominated by monocultures. Taken together, this information suggests that pesticide pollution is heterogeneously distributed in the Pampa, being concentrated mainly in areas of greater monoculture production.

It is important to stress that pesticide pollution also significantly affects the Argentine and Uruguayan Pampas. In the global analysis concerning the risk of pesticide pollution carried out by Tang et al. [9] and associated with additional data [42–46], it is evident that these risks are distributed throughout the international territory of the Pampa, encompassing Brazil, Argentina [42–44], and Uruguay [45,46], but in a heterogeneous way. Of note, Argentina was considered a "high-concern" region [9].

Finally, in addition to the amounts of pesticides used in agricultural practices, differences in pesticide-related issues are also affected by climatic aspects such as wind, sun radiation, and rainfall patterns [47,48] that can degrade or transport pesticide residues over significant distances. Climate change will therefore affect multiple aspects of pesticide pollution [48] in ways that are still difficult to predict.

2.2. Impacts on Animals and Ecosystems

Environmental pesticide contamination is detrimental to wildlife, affecting the immune, nervous, and endocrine systems, as well as reproduction and behavior, and interfering with the survival of several animal groups. Pesticide-related neurotoxicity can alter animal behavior, foraging, and learning. Endocrine disruption induced by pesticides can trigger reproductive failure, higher mortality rates, and thus population decline. These detrimental changes affect several animal groups at varied intensities, including mammals, birds, reptiles, amphibians, fish, and invertebrates [49]. Additionally, pesticide-induced immunotoxicity can cause an increased infection rate by various pathogens, facilitating the spread of infectious and parasitic diseases in animal populations [49,50]. For example, pesticides were linked to increased trematode (parasitic flatworm) infection rates in amphibians (i.e., *Rana pipiens*), which were considered contributing factors to the global decline of amphibian populations [51].

The detrimental effects of pesticides are particularly evident on invertebrate populations, including economically relevant insect pollinators such as bees [49,52]. Gill et al. [53] showed that pesticide exposure affects bees at individual and colony levels. Pesticide exposure can trigger altered behavior in bees, resulting in reduced brood success and decreased colony size. Pesticide exposure was also associated with impaired foraging, an altered gut microbiome, and mortality due to homing failure in bees [49,54].

The effects of pesticides on wildlife can be direct (e.g., cellular toxicity, biochemical changes) or indirect (e.g., impairment of species interaction, disruption of food webs) [49], which may hinder a direct causal association of pesticide pollution with consequences for animals and ecosystems, making the deleterious effects of pesticides often neglected or even undetected. However, evidence of pesticide pollution in the Pampa is emerging from studies performed with animal samples.

Analyzing fish (*Astyanax* sp.) sampled in rivers of the Rio Grande do Sul, several researchers detected pesticides in fish tissues as well as biochemical changes associated with exposure to pesticides in the Pampa biome [55–57]. Biochemical changes were also observed in fish (*Danio rerio*) exposed in the laboratory to urban and agricultural effluents from the Pampa biome [55]. Moreover, changes in levels of lipid peroxidation and acetylcholinesterase (AChE), glutathione S-transferase (GST), and catalase (CAT) enzymes were reported in a study performed with *D. rerio* embryos exposed to water from the Vacacaí River contaminated with pesticides (ten fungicides, eight herbicides, and six insecticides were detected in the water) [58]. In a recent study [59], changes in levels of carbonyl proteins and activity of AChE and GSH in tissues of fish (*Rhamdia quelen*) experimentally placed in three sites of Vacacaí River reinforced the effects of pesticide pollution on the Pampa's aquatic fauna. The fungicide tebuconazole (0.30 $\mu g\ L^{-1}$) and the herbicides bentazon (0.77–1.80 $\mu g\ L^{-1}$), clomazone (0.31–0.41 $\mu g\ L^{-1}$), clorimuron (<LOQ), and quin-

clorac (0.40–0.45 μg L^{-1}) were detected in water, and fish exposed to the sites closest to agricultural areas showed higher levels of biochemical changes compared to a control [59].

Phyllomedusa iheringii (leaf frog) tadpoles sampled in nearby agricultural areas of the Pampa biome also showed altered biochemical markers linked to environmental imbalances, especially pesticide pollution [60]. Pires et al. [61] reported that agricultural land use and related changes in water chemistry affected the taxonomic heterogeneity of the Brazilian Pampa's communities of Odonata (hemimetabolous insects with an aquatic larval stage). It is possible that pesticide pollution is at least partially associated with this result, although pesticides were not evaluated in the study [61].

Pesticide pollution in the Pampa is not limited to aquatic environments. Traces of pesticides were detected in honey samples from Rio Grande do Sul, evidencing the widespread presence of these pollutants in the environment and their entry into food webs [62]. Of note, recently the death of millions of bees in Rio Grande do Sul was associated with pesticide exposure [63], although other factors (e.g., pathogens, nutritional problems) may have contributed to the illness and death of bees in the state [64].

The ecosystem services attributed to different species can be categorized as (i) provisioning services (e.g., food, ornamental resources, fiber, fuel, genetic resources), (ii) regulating services (e.g., pollination, pest regulation, air quality regulation, seed dispersal), (iii) supporting services (e.g., provisioning of habitat, nutrient and water cycling, soil formation), and (iv) cultural services (e.g., education, recreation, ecotourism, sense of place, cultural heritage) [65]; and many of these ecosystem services are affected by the use of pesticides [66]. Knowledge about the specific ecosystem services provided by the different animal, plant, and microbial species of the Pampa biome is still limited. Similarly, knowledge about the impacts of pesticide use on the reduction of ecosystem services in Pampa is scarce. It is essential that this knowledge be advanced so that we can develop specific protection goals focused on the conservation of Pampa's biodiversity and ecosystem services. Finally, protection goals must consider the Precautionary Principle, the Pollution Prevention concept, the Ecological Threshold concept, the Ecological Recovery concept, and the Functional Redundancy concept to elaborate strategies of risk assessment and management and to better define protection goals for this biome (see Nienstedt et al. [66] for more information about these principles and concepts, as well as the selection of protection goals).

2.3. Consequences of Pesticides on Human Health

The human health problems associated with pesticides are also extremely worrying in Brazil [52]. Human pesticide intoxication increased by 126.8% between 2007 and 2011 in the country [67]. More recently, Buralli and Souza [68] reported a 94% increase in human pesticide intoxication in Brazil, considering the 2009–2019 period. This data indicates a continuous increase in the detrimental impacts of pesticides on the health of Brazilians in the last 15 years. In Rio Grande do Sul state, the pesticide poisoning rate increased from 1.99/100,000 inhabitants in 2011 to 7.56/100,000 inhabitants in 2018, with 60% of poisoning cases linked to agricultural practices (poisoning by "pesticide for agricultural use"). The remaining poisoning cases were associated with pesticides used in non-agricultural practices ("pesticide for domestic use", "pesticide for public health use", "rodenticide", and "product for veterinary use"). Spraying and dilution were the main triggers of pesticide poisoning [69]. Cases of pesticide intoxication are probably even more frequent because there is a huge under-notification, especially in acute intoxication cases [35,67].

The indiscriminate use of pesticides goes beyond acute intoxication, causing chronic health problems. Agricultural workers in Rio Grande do Sul suffer from increased DNA damage and chromosome instability (e.g., micronuclei, nuclear buds) due to pesticide exposure [70–73]. Pesticides are associated with neurodegenerative diseases, including dementia [74], Parkinson's [75–77], and Alzheimer's diseases [74,78], as well as cancer [52,79], reproductive and fetal development problems, and psychiatric disorders [52].

Epidemiological evidence indicates an association between pesticide use/poisoning and suicide behavior in Brazil [80], a problem particularly relevant in Rio Grande do Sul, where a high suicide rate of 11.3 cases per 100,000 inhabitants/year is observed (for comparison, Brazil's rate is 5–6 cases per 100,000 inhabitants/year) [81]. Easy access to pesticides, the potential effects of these products on the central nervous system, and socioeconomic pressures linked to agricultural production, among other factors, can contribute to the increased suicide rate observed in the Rio Grande do Sul, which, many times, even involves the use of pesticides as a death-inducing agent [69,80,82].

Beyond the direct effects caused by pesticides on multiple organisms and ecosystems, environmental contamination by heavy metals and other potentially toxic elements (PTEs) resulting from the production and application of pesticides chronically harms human health [83]. In this sense, increased concentrations of Mg, Al, Si, P, S, and Cl were observed in cells from agricultural workers from Espumoso city (Rio Grande do Sul) exposed to pesticides, and these findings were associated with genetic damage [73]. Although Espumoso is located in the Atlantic Forest biome, its proximity to the Pampa indicates that issues concerning human exposure to pesticide-related PTEs extend far beyond the Pampa biome and agricultural areas.

Finally, pesticides can cause imbalances in food webs and induce changes in ecological niches and natural habitats directly through their effects on animals (as discussed in the previous topic) and indirectly through the facilitation of major land-use changes. These processes are strongly associated with the emergence and spread of human infectious disease outbreaks, especially those triggered by vector-borne pathogens [84,85].

3. Conclusions and Perspectives

In addition to the abusive use of pesticides, the Pampa is increasingly challenged by several other problems and human activities that threaten its biodiversity, especially the loss of vegetation cover for agriculture, livestock, and forestry plantations [18,30,86,87]. These problems further aggravate the impacts of pesticide pollution on the health of humans, animals, and ecosystems.

Historically, Rio Grande do Sul had a prominent role in the Brazilian environmentalist movement [88]. This leading role has gradually fallen into oblivion over the years and is currently quite limited. Rio Grande do Sul needs to recover its prominent position in the Brazilian environmental agenda. Since grassland receives less media attention than Amazon or rainforest biodiversity, it is fundamental to realize the problems faced by the Pampa biome with the expansion of environmental policies focused on Pampa conservation. Initiatives and organizations such as the *Coalizão pelo Pampa*—Pampa Coalition [89], *Instituto Curicaca*—Curicaca Institute [90], *Rede Campos Sulinos*—South Brazilian Grasslands Network [91], and the *Comitê dos Povos e Comunidades Tradicionais do Pampa*—Committee of the Traditional Peoples and Communities of the Pampa [92] must be strengthened and expanded. In addition, political will and the legal apparatus aimed at reducing the use of pesticides need to be stepped up.

Monitoring and inspection of the use and commercialization of pesticides in the Rio Grande do Sul are carried out by the Secretary of Agriculture, Livestock, Sustainable Production, and Irrigation of the state [93]. However, although Rio Grande do Sul is one of the Brazilian states that most commonly uses pesticides, specific laws and public policies concerning pesticide use are insipient in the state. Of note, Rio Grande do Sul is part of the "Uruguay-Argentina-Brazil" triple border, a region where large amounts of illegal pesticides enter Brazil [93]. Considering this aspect and the huge impacts of pesticide use on Rio Grande do Sul's ecosystems and human population [94], state authorities must increase inspections of pesticide use and curb the entry of illegal pesticides through the triple border. The growing and indiscriminate use of pesticides must be controlled by frequent testing of pesticide residues in food and drinking water, which are important contamination sources for the population [95]. Even with all these actions being put into practice, it could be difficult to measure the effects of pesticides on Pampa's ecosystems and biodiversity [94].

Research institutions can collaborate with the conservation of this biome by developing more studies concerning Pampa's biodiversity and the impacts of anthropogenic activities on the biome. We stress that limited information about pesticide pollution in the Pampa is available, and therefore additional studies need to be carried out to better describe the impact of this problem in southern Brazil.

Actions to prevent, mitigate, and restore the impact of land-use changes and related pesticide pollution must also be investigated and applied. Environmental education actions should be promoted to make rural producers aware of the inappropriate use of pesticides. The use of adequate personal protective equipment by workers handling pesticides must be reinforced by continuous surveillance and education campaigns. In addition, food production strategies less dependent on the use of pesticides (e.g., permaculture, integrated pest management) should be encouraged.

It is important to stress that a high and abrupt reduction in pesticide use will result in losses in production per area that could impact especially smaller producers that have lower revenues from their production. Therefore, it is essential that measures to reduce pesticide use be accompanied by economic alternatives for farmers impacted by potential reductions in their income. Training, courses, and financial subsidies to support the development of businesses based on agroecology and artisanal products are viable alternatives. In Rio Grande do Sul, free fairs and e-commerce are also means that help producers of organic and traditional crops market their products in large centers (e.g., Porto Alegre city) [96,97], with great potential for expansion of sales of organic products through these means. In addition to these alternatives, farmers' stores, producers' markets, door-to-door sales (box schemes), and direct harvesting by consumers at production units (pick your own) are emerging options to advance the trade in pesticide-free products in Rio Grande do Sul. These above-mentioned alternatives make up the so-called "short chains and alternative agrifood networks" [98].

Rio Grande do Sul must also develop programs to strengthen the "bioecological bioeconomy", the arm of the bioeconomy based on biodiversity and processes that "optimize the use of energy and nutrients, promote biodiversity, and avoid monocultures and soil degradation" [99] in a regionally concentrated system (e.g., focused on products with territorial identity) [99], in addition to the "biomaterial bioeconomy", which emphasizes upgrading and conversion of biological raw materials into higher value-added products [99,100]. In the context of the problems discussed in this article, bioeconomy includes the use of Pampa's biodiversity as a source of useful molecules for the pharmaceutical, cosmetic, and food industries; increasing ecotourism focused on the diverse Pampa's landscapes; and the better use of native plant species in gastronomy and gardening. More information about these and other bioeconomic alternatives can be found in Ellwanger et al. [100].

Developing a bioecological bioeconomy would help the Rio Grande do Sul reduce its economic dependence on activities that are highly harmful to the environment, such as cash crop plantations. The basic conditions for this transition already exist. Rio Grande do Sul (i) has one of the highest gross domestic products (GDPs) in Brazil [101]; (ii) has a robust higher education system; (iii) is considered a leader in the field of technological innovation; (iv) is one of the Brazilian states that produce the most scientific research (reaching 11.5% of the national production) [102]; in addition to (v) bordering two countries, Argentina and Uruguay, which would facilitate integrated conservation programs, also based on tourism. These and other factors could facilitate the bioeconomy's development in Rio Grande do Sul and should be better used to overcome economic models that contribute to the pollution and degradation of the Pampa biome.

Finally, we recognize that the alternatives to facing the problems related to pesticide pollution in the Pampa biome described in this article are limited compared to the size of the problem. However, we hope that this article will contribute to expanding the discussions about the most effective actions and ways to limit the harmful impacts of pesticides on Pampa's biodiversity and human population.

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References

1. Prüss-Ustün, A.; Wolf, J.; Corvalán, C.; Bos, R.; Neira, M. *Preventing Disease through Healthy Environments: A Global Assessment of the Burden of Disease from Environmental Risks*; World Health Organization: Geneva, Switzerland, 2016.
2. Ellwanger, J.H.; Byrne, L.B.; Chies, J.A.B. Examining the paradox of urban disease ecology by linking the perspectives of Urban One Health and Ecology with Cities. *Urban Ecosyst.* **2022**, *25*, 1735–1744. [CrossRef]
3. Essack, S.Y. Environment: The neglected component of the One Health triad. *Lancet Planet. Health* **2018**, *2*, e238–e239. [CrossRef]
4. Ellwanger, J.H.; Kulmann-Leal, B.; Kaminski, V.L.; Valverde-Villegas, J.M.; Veiga, A.B.G.; Spilki, F.R.; Fearnside, P.M.; Caesar, L.; Giatti, L.L.; Wallau, G.L.; et al. Beyond diversity loss and climate change: Impacts of Amazon deforestation on infectious diseases and public health. *An. Acad. Bras. Cienc.* **2020**, *92*, e20191375. [CrossRef]
5. Fuller, R.; Landrigan, P.J.; Balakrishnan, K.; Bathan, G.; Bose-O'Reilly, S.; Brauer, M.; Caravanos, J.; Chiles, T.; Cohen, A.; Corra, L.; et al. Pollution and health: A progress update. *Lancet Planet. Health* **2022**, *6*, e535–e547. [CrossRef]
6. Fuller, R.; Sandilya, K.; Hanrahan, D. *Pollution and Health Metrics. Global, Regional, and Country Analysis December 2019*; Global Alliance on Health and Pollution (GAHP): New York, NY, USA, 2019.
7. Clarke, R.M.; Cummins, E. Evaluation of "classic" and emerging contaminants resulting from the application of biosolids to agricultural lands: A review. *Hum. Ecol. Risk Assess.* **2015**, *21*, 492–513. [CrossRef]
8. Bertoldi, C.; Lara, L.Z.; Mizushima, F.A.L.; Martins, F.C.G.; Battisti, M.A.; Hinrichs, R.; Fernandes, A.N. First evidence of microplastic contamination in the freshwater of Lake Guaíba, Porto Alegre, Brazil. *Sci. Total Environ.* **2021**, *759*, 143503. [CrossRef]
9. Tang, F.H.M.; Lenzen, M.; McBratney, A.; Maggi, F. Risk of pesticide pollution at the global scale. *Nat. Geosci.* **2021**, *14*, 206–210. [CrossRef]
10. Wilson, C.; Tisdell, C. Why farmers continue to use pesticides despite environmental, health and sustainability costs. *Ecol. Econ.* **2001**, *39*, 449–462. [CrossRef]
11. Atreya, K.; Sitaula, B.K.; Johnsen, F.H.; Bajracharya, R.M. Continuing issues in the limitations of pesticide use in developing countries. *J. Agric. Environ. Ethics* **2011**, *24*, 49–62. [CrossRef]
12. Tudi, M.; Ruan, H.D.; Wang, L.; Lyu, J.; Sadler, R.; Connell, D.; Chu, C.; Phung, D.T. Agriculture development, pesticide application and its impact on the environment. *Int. J. Environ. Res. Public Health* **2021**, *18*, 1112. [CrossRef]
13. Roesch, L.F.W.; Vieira, F.C.B.; Pereira, V.A.; Schünemann, A.L.; Teixeira, I.F.; Senna, A.J.T.; Stefenon, V.M. The Brazilian Pampa: A fragile biome. *Diversity* **2009**, *1*, 182–198. [CrossRef]
14. Overbeck, G.E.; Vélez-Martin, E.; Menezes, L.S.; Anand, M.; Baeza, S.; Carlucci, M.B.; Dechoum, M.S.; Durigan, G.; Fidelis, A.; Guido, A.; et al. Placing Brazil's grasslands and savannas on the map of science and conservation. *Perspect. Plant Ecol. Evol. Syst.* **2022**, *56*, 125687. [CrossRef]
15. Müller, S.C.; Overbeck, G.E.; Blanco, C.C.; de Oliveira, J.M.; Pillar, V.D. South Brazilian Forest-Grassland Ecotones: Dynamics Affected by Climate, Disturbance, and Woody Species Traits. In *Ecotones Between Forest and Grassland*; Myster, R.D., Ed.; Springer: New York, NY, USA, 2012; pp. 167–187. [CrossRef]

16. Copatti, C.E.; do Amaral, A.D.; de Moura, C.F.A. Aves em ecótono Mata Atlântica-Pampa no Sul do Brasil. *Ciência Nat.* **2013**, *35*, 30–40. [CrossRef]
17. Viera, L.F.S. A Valoração da Beleza Cênica da paisagem do Bioma Pampa do Rio Grande do Sul: Proposição Conceitual e Metodológica. Ph.D. Thesis, Instituto de Geociências, Programa de Pós-Graduação em Geografia, Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, 2014.
18. Porto, A.B.; Rolim, R.G.; da Silveira, F.F.; Overbeck, G.E.; Salatino, A. Consciência Campestre: Um chamado para o (re)conhecimento aos campos. *Bio Diverso* **2021**, *1*, 164–188.
19. Overbeck, G.E.; Vélez-Martin, E.; Scarano, F.R.; Lewinsohn, T.M.; Fonseca, C.R.; Meyer, S.T.; Müller, S.C.; Ceotto, P.; Dadalt, L.; Durigan, G.; et al. Conservation in Brazil needs to include non-forest ecosystems. *Divers. Distrib.* **2015**, *21*, 1455–1460. [CrossRef]
20. Mazurana, J.; Dias, J.E.; Laureano, L.C. *Povos e Comunidades Tradicionais do Pampa*; Fundação Luterana de Diaconia: Porto Alegre, Brazil, 2016.
21. Andrade, B.O.; Dröse, W.; de Aguiar, C.A.; Aires, E.T.; Alvares, D.J.; Barbieri, R.L.; de Carvalho, C.J.B.; Bartz, M.; Becker, F.G.; Benck, G.A.; et al. 12,500+ and counting: Biodiversity of the Brazilian Pampa. *Front. Biogeogr.* **2023**, *15*, e59288. [CrossRef]
22. Krob, A.D.; Overbeck, G.E.; Mähler, J.J.F., Jr.; Urruth, L.M.; Malabarba, L.R.; Chomenko, L.; Azevedo, M.A. Contribution of southern Brazil to the climate and biodiversity conservation agenda. *Bio Diverso* **2021**, *1*, 132–144.
23. Stumpf, E.T.; Romano, C.M.; Barbieri, R.L.; Heiden, G.; Fischer, S.Z.; Corrêa, L.B. Características ornamentais de plantas do Bioma Pampa. *Ornam. Hortic.* **2009**, *15*, 49–62. [CrossRef]
24. Carrion, A.A.; Brack, P. Eudicotiledôneas ornamentais dos campos do bioma Pampa no Rio Grande do Sul. *Ornam. Hortic.* **2012**, *18*, 23–37. [CrossRef]
25. Severo, S.A.; da Silva, L.F.; Trevisan, A.C.D. Plantas nativas da sociobidiversidade do bioma Pampa. *Salão Integr. Ensino Pesqui. Extensão Uergs* **2021**, *1*, 10.
26. De Souza, B.R. Cosmética Para o SocioBioCotidiano: Uma Análise da Emergência da Cadeia de Cosméticos Ecológicos a Partir da Flora Nativa dos Biomas Pampa e Mata Atlântica Sul, Brasil. Universidade Federal do Rio Grande do Sul—UFRGS. 2022. Available online: https://lume.ufrgs.br/bitstream/handle/10183/240086/001141934.pdf?sequence=1&isAllowed=y (accessed on 25 February 2023).
27. MapBiomas—Mapeamento Anual de Cobertura e Uso da Terra no Pampa—Coleção 7. Destaques do Mapeamento Anual da Cobertura e uso da Terra no Brasil de 1985 a 2021: Pampa. 2022. Available online: https://mapbiomas-br-site.s3.amazonaws.com/MapBiomas_PAMPA_2022_11.10__1_.pdf (accessed on 22 February 2023).
28. Echer, R.; da Cruz, J.A.W.; Estrela, C.C.; Moreira, M.; Gravato, F. Usos da terra e ameaças para a conservação da biodiversidade no bioma Pampa, Rio Grande do Sul. *Rev. Thema* **2015**, *12*, 4–13. [CrossRef]
29. Lima, J.A.M.C.; Labanowski, J.; Bastos, M.C.; Zanella, R.; Prestes, O.D.; de Vargas, J.P.R.; Mondamert, L.; Granado, E.; Tiecher, T.; Zafar, M.; et al. "Modern agriculture" transfers many pesticides to watercourses: A case study of a representative rural catchment of southern Brazil. *Environ. Sci. Pollut. Res. Int.* **2020**, *27*, 10581–10598. [CrossRef] [PubMed]
30. Ellwanger, J.H.; Ziliotto, M.; Chies, J.A.B. Protect Brazil's overlooked Pampa biome. *Science* **2022**, *377*, 720. [CrossRef] [PubMed]
31. Governo do Estado do Rio Grande do Sul, Secretaria de Planejamento, Governança e Gestão, Atlas Econoômico do Rio Grande do Sul, Índice de Desenvolvimento Humano—IDH e IDHM. 2022. Available online: https://atlassocioeconomico.rs.gov.br/indice-de-desenvolvimento-humano-idh-e-idhm (accessed on 11 April 2023).
32. Overbeck, G.E.; Müller, S.C.; Fidelis, A.; Pfadenhauer, J.; Pillar, V.D.; Blanco, C.C.; Boldrini, I.I.; Both, R.; Forneck, E.D. Brazil's neglected biome: The South Brazilian *Campos*. *Perspect. Plant Ecol. Evol. Syst.* **2007**, *9*, 101–116. [CrossRef]
33. Albuquerque, A.F.; Ribeiro, J.S.; Kummrow, F.; Nogueira, A.J.A.; Montagner, C.C.; Umbuzeiro, G.A. Pesticides in Brazilian freshwaters: A critical review. *Environ. Sci. Process Impacts* **2016**, *18*, 779–787. [CrossRef] [PubMed]
34. Fernandes, C.L.F.; Volcão, L.M.; Ramires, P.F.; Moura, R.R.; Da Silva Júnior, F.M.R. Distribution of pesticides in agricultural and urban soils of Brazil: A critical review. *Environ. Sci. Process Impacts* **2020**, *22*, 256–270. [CrossRef]
35. Pignati, W.A.; Lima, F.A.N.S.; Lara, S.S.; Correa, M.L.M.; Barbosa, J.R.; Leão, L.H.C.; Pignatti, M.G. Spatial distribution of pesticide use in Brazil: A strategy for Health Surveillance. *Cien. Saude Colet.* **2017**, *22*, 3281–3293. [CrossRef]
36. Burity, V.T.A.; Melgarejo, L.; Gonzáles, J.C.M.; Prates, L.A.; Rocha, N.C. *Pesticides in Latin America: Violations against the Right to Adequate Food and Nutrition*, 1st ed.; FIAN Brasil: Brasília, Brazil, 2020.
37. Kuhn, E.C. Avaliação Ecotoxicológica do rio Uruguay e Efluentes pré e pós Aplicação de Pesticidas Utilizando *Caenorhabditis elegans* Como Biomonitor. 2018. Universidade Federal do Pampa–UNIPAMPA. Available online: https://dspace.unipampa.edu.br/bitstream/riu/4970/1/EUG%c3%8aNIA%20CARLA%20KUHN.pdf (accessed on 26 February 2023).
38. Kemmerich, M.; Bernardi, G.; Adaime, M.B.; Zanella, R.; Prestes, O.D. A simple and efficient method for imidazolinone herbicides determination in soil by ultra-high performance liquid chromatography-tandem mass spectrometry. *J. Chromatogr. A* **2015**, *1412*, 82–89. [CrossRef]
39. Coelho, F.E.A.; Lopes, L.C.; Cavalcante, R.M.S.; Corrêa, G.C.; Leduc, A.O.H.C. Brazil unwisely gives pesticides a free pass. *Science* **2019**, *365*, 552–553. [CrossRef]
40. Carneiro, L.; Faria, L.; Miiller, N.; Cavalcante, A.; Murata, A.; Vitule, J.R.S. Brazilian pesticides law could poison the world. *Science* **2022**, *376*, 362. [CrossRef]

41. Schaffner, R. Facilitação do Registro de Agrotóxicos Amplia Debate Sobre Impactos dos Produtos. 2022. Available online: https://gauchazh.clicrbs.com.br/politica/noticia/2022/02/facilitacao-do-registro-de-agrotoxicos-amplia-debate-sobre-impactos-dos-produtos-ckzhis00m001b0188o4z7ry7m.html (accessed on 24 February 2023).
42. Viglizzo, E.F.; Franke, F.C.; Carreño, L.V.; Jobbágy, E.G.; Pereyra, H.; Clatt, J.; Pincén, D.; Ricard, M.F. Ecological and environmental footprint of 50 years of agricultural expansion in Argentina. *Glob. Chang. Biol.* **2011**, *17*, 959–973. [CrossRef]
43. Iturburu, F.G.; Calderon, G.; Amé, M.V.; Menone, M.L. Ecological Risk Assessment (ERA) of pesticides from freshwater ecosystems in the Pampas region of Argentina: Legacy and current use chemicals contribution. *Sci. Total Environ.* **2019**, *691*, 476–482. [CrossRef]
44. Pérez, D.J.; Iturburu, F.G.; Calderon, G.; Oyesqui, L.A.E.; De Gerónimo, E.; Aparicio, V.C. Ecological risk assessment of current-use pesticides and biocides in soils, sediments and surface water of a mixed land-use basin of the Pampas region, Argentina. *Chemosphere* **2021**, *263*, 128061. [CrossRef]
45. Harriet, J.; Campá, J.P.; Grajales, M.; Lhéritier, C.; Pajuelo, A.G.; Mendoza-Spina, Y.; Carrasco-Letelier, L. Agricultural pesticides and veterinary substances in Uruguayan beeswax. *Chemosphere* **2017**, *177*, 77–83. [CrossRef] [PubMed]
46. Rodríguez-Bolaña, C.; Pérez-Parada, A.; Tesitore, G.; Goyenola, G.; Kröger, A.; Pacheco, M.; Gérez, N.; Berton, A.; Zinola, G.; Gil, G.; et al. Multicompartmental monitoring of legacy and currently used pesticides in a subtropical lake used as a drinking water source (Laguna del Cisne, Uruguay). *Sci. Total Environ.* **2023**, *874*, 162310. [CrossRef]
47. Delcour, I.; Spanoghe, P.; Uyttendaele, M. Literature review: Impact of climate change on pesticide use. *Food Res. Int.* **2015**, *68*, 7–15. [CrossRef]
48. Galon, L.; Bragagnolo, L.; Korf, E.P.; Dos Santos, J.B.; Barroso, G.M.; Ribeiro, V.H.V. Mobility and environmental monitoring of pesticides in the atmosphere—A review. *Environ. Sci. Pollut. Res. Int.* **2021**, *28*, 32236–32255. [CrossRef]
49. Köhler, H.R.; Triebskorn, R. Wildlife ecotoxicology of pesticides: Can we track effects to the population level and beyond? *Science* **2013**, *341*, 759–765. [CrossRef] [PubMed]
50. Kiesecker, J.M. Global stressors and the global decline of amphibians: Tipping the stress immunocompetency axis. *Ecol. Res.* **2011**, *26*, 897–908. [CrossRef]
51. Rohr, J.R.; Schotthoefer, A.M.; Raffel, T.R.; Carrick, H.J.; Halstead, N.; Hoverman, J.T.; Johnson, C.M.; Johnson, L.B.; Lieske, C.; Piwoni, M.D.; et al. Agrochemicals increase trematode infections in a declining amphibian species. *Nature* **2008**, *455*, 1235–1239. [CrossRef] [PubMed]
52. Lopes, C.V.A.; Albuquerque, G.S.C. Agrotóxicos e seus impactos na saúde humana e ambiental: Uma revisão sistemática. *Saúde Debate* **2018**, *42*, 518–534. [CrossRef]
53. Gill, R.J.; Ramos-Rodriguez, O.; Raine, N.E. Combined pesticide exposure severely affects individual- and colony-level traits in bees. *Nature* **2012**, *491*, 105–108. [CrossRef] [PubMed]
54. Kakumanu, M.L.; Reeves, A.M.; Anderson, T.D.; Rodrigues, R.R.; Williams, M.A. Honey bee gut microbiome is altered by in-hive pesticide exposures. *Front. Microbiol.* **2016**, *7*, 1255. [CrossRef] [PubMed]
55. Costa-Silva, D.G.; Nunes, M.E.M.; Wallau, G.L.; Martins, I.K.; Zemolin, A.P.P.; Cruz, L.C.; Rodrigues, N.R.; Lopes, A.R.; Posser, T.; Franco, J.L. Oxidative stress markers in fish (*Astyanax* sp. and *Danio rerio*) exposed to urban and agricultural effluents in the Brazilian Pampa biome. *Environ. Sci. Pollut. Res. Int.* **2015**, *22*, 15526–15535. [CrossRef]
56. Nunes, M.; da Silva, F.W.; Costa-Silva, D.; Wallau, G.L.; Posser, T.; Franco, J.L. Assessment of water pollution signs in the Brazilian Pampa biome using stress biomarkers in fish (*Astyanax* sp.). *J. Ecosyst.* **2015**, *2015*, 415293. [CrossRef]
57. Gonçalves, C.; Marins, A.T.; do Amaral, A.M.B.; Nunes, M.E.M.; Müller, T.E.; Severo, E.; Feijó, A.; Rodrigues, C.C.R.; Zanella, R.; Prestes, O.D.; et al. Ecological impacts of pesticides on *Astyanax jacuhiensis* (Characiformes: Characidae) from the Uruguay river, Brazil. *Ecotoxicol. Environ. Saf.* **2020**, *205*, 111314. [CrossRef] [PubMed]
58. Severo, E.S.; Marins, A.T.; Cerezer, C.; Costa, D.; Nunes, M.; Prestes, O.D.; Zanella, R.; Loro, V.L. Ecological risk of pesticide contamination in a Brazilian river located near a rural area: A study of biomarkers using zebrafish embryos. *Ecotoxicol. Environ. Saf.* **2020**, *190*, 110071. [CrossRef] [PubMed]
59. Severo, E.; Marins, A.; de Menezes, C.; Nunes, M.; Murussi, C.; da Costa-Silva, D.G.; Storck, T.R.; Prestes, O.D.; Adaime, M.B.; Loro, V.L.; et al. Biomarkers' responses of *Rhamdia quelen* exposed in situ on a Brazilian river located in agricultural areas. *Water Air Soil Pollut.* **2023**, *234*, 144. [CrossRef]
60. Santos, T.G.; Melo, R.; Costa-Silva, D.G.; Nunes, M.E.M.; Rodrigues, N.R.; Franco, J.L. Assessment of water pollution in the Brazilian Pampa biome by means of stress biomarkers in tadpoles of the leaf frog *Phyllomedusa iheringii* (Anura: Hylidae). *PeerJ* **2015**, *3*, e1016. [CrossRef]
61. Pires, M.M.; Sahlén, G.; Périco, E. Agricultural land use affects the heterogeneity of Odonata communities in the Brazilian Pampa. *J. Insect Conserv.* **2022**, *26*, 503–514. [CrossRef]
62. Rodrigues, C.S.; Ferasso, D.C.; Prestes, O.D.; Zanella, R.; Grando, R.C.; Treichel, H.; Coelho, G.C.; Mossi, A.J. Quality of Meliponinae honey: Pesticides residues, pollen identity, and microbiological profiles. *Environ. Qual. Manag.* **2018**, *27*, 39–45. [CrossRef]
63. Grigori, P. Half a Billion Bees Dead as Brazil Approves Hundreds more Pesticides. 2019. Available online: https://news.mongabay.com/2019/08/half-a-billion-bees-dead-as-brazil-approves-hundreds-more-pesticides/ (accessed on 24 February 2023).

64. Caesar, L. Síndrome Anual da Abelha Mandaçaia (*Melipona quadrifasciata*)—O Papel de Simbiontes, Sistema Imune e Ambiente. Ph.D. Thesis, Postgraduate Program in Genetics and Molecular Biology, Universidade Federal do Rio Grande do Sul—UFRGS, Porto Alegre, Brazil, 2020. Available online: https://lume.ufrgs.br/bitstream/handle/10183/212107/001116139.pdf?sequence=1&isAllowed=y (accessed on 25 February 2023).
65. EFSA Scientific Committee. Guidance to develop specific protection goals options for environmental risk assessment at EFSA, in relation to biodiversity and ecosystem services. *EFSA J.* **2016**, *14*, 4499. [CrossRef]
66. Nienstedt, K.M.; Brock, T.C.; van Wensem, J.; Montforts, M.; Hart, A.; Aagaard, A.; Alix, A.; Boesten, J.; Bopp, S.K.; Brown, C.; et al. Development of a framework based on an ecosystem services approach for deriving specific protection goals for environmental risk assessment of pesticides. *Sci. Total Environ.* **2012**, *415*, 31–38. [CrossRef]
67. Rigotto, R.M.; Vasconcelos, D.P.; Rocha, M.M. Pesticide use in Brazil and problems for public health. *Cad. Saude Publica* **2014**, *30*, 1360–1362. [CrossRef]
68. Buralli, R.J.; Souza, F.N.F. Mortality and morbidity by work-related pesticide poisoning in Brazil, 2009–2019. In *ISEE Conference Abstracts*; National Institute of Environmental Health Sciences: Durham, NC, USA, 2021.
69. Freitas, A.B.; Garibotti, V. Characterization of notifications of exogenous pesticide poisoning in Rio Grande do Sul, Brazil, 2011–2018. *Epidemiol. Serv. Saude* **2020**, *29*, e2020061. [CrossRef]
70. Pacheco, A.O.; Hackel, C. Instabilidade cromossômica induzida por agroquímicos em trabalhadores rurais na região de Passo Fundo, Rio Grande do Sul, Brasil. Cad. Saúde Pública 2002, 18, 1675–1683. [CrossRef]
71. Bortoli, G.M.; Azevedo, M.B.; Silva, L.B. Cytogenetic biomonitoring of Brazilian workers exposed to pesticides: Micronucleus analysis in buccal epithelial cells of soybean growers. *Mutat. Res.* **2009**, *675*, 1–4. [CrossRef] [PubMed]
72. Remor, A.P.; Totti, C.C.; Moreira, D.A.; Dutra, G.P.; Heuser, V.D.; Boeira, J.M. Occupational exposure of farm workers to pesticides: Biochemical parameters and evaluation of genotoxicity. *Environ. Int.* **2009**, *35*, 273–278. [CrossRef]
73. Benedetti, D.; Nunes, E.; Sarmento, M.; Porto, C.; dos Santos, C.E.I.; Dias, J.F.; da Silva, J. Genetic damage in soybean workers exposed to pesticides: Evaluation with the comet and buccal micronucleus cytome assays. *Mutat. Res.* **2013**, *752*, 28–33. [CrossRef]
74. Hayden, K.M.; Norton, M.C.; Darcey, D.; Østbye, T.; Zandi, P.P.; Breitner, J.C.S.; Welsh-Bohmer, K.A.; Cache County Study Investigators. Occupational exposure to pesticides increases the risk of incident AD: The Cache County study. *Neurology* **2010**, *74*, 1524–1530. [CrossRef]
75. Ascherio, A.; Chen, H.; Weisskopf, M.G.; O'Reilly, E.; McCullough, M.L.; Calle, E.E.; Schwarzschild, M.A.; Thun, M.J. Pesticide exposure and risk for Parkinson's disease. *Ann. Neurol.* **2006**, *60*, 197–203. [CrossRef]
76. Hancock, D.B.; Martin, E.R.; Mayhew, G.M.; Stajich, J.M.; Jewett, R.; Stacy, M.A.; Scott, B.L.; Vance, J.M.; Scott, W.K. Pesticide exposure and risk of Parkinson's disease: A family-based case-control study. *BMC Neurol.* **2008**, *8*, 6. [CrossRef] [PubMed]
77. Ellwanger, J.H.; Molz, P.; Dallemole, D.R.; Pereira dos Santos, A.; Müller, T.E.; Cappelletti, L.; Gonçalves da Silva, M.; Franke, S.I.; Prá, D.; Pêgas Henriques, J.A. Selenium reduces bradykinesia and DNA damage in a rat model of Parkinson's disease. *Nutrition* **2015**, *31*, 359–365. [CrossRef] [PubMed]
78. Yan, D.; Zhang, Y.; Liu, L.; Yan, H. Pesticide exposure and risk of Alzheimer's disease: A systematic review and meta-analysis. *Sci. Rep.* **2016**, *6*, 32222. [CrossRef] [PubMed]
79. Alavanja, M.C.; Ross, M.K.; Bonner, M.R. Increased cancer burden among pesticide applicators and others due to pesticide exposure. *CA Cancer J. Clin.* **2013**, *63*, 120–142. [CrossRef]
80. Faria, N.M.X.; Fassa, A.G.; Meucci, R.D. Association between pesticide exposure and suicide rates in Brazil. *Neurotoxicology* **2014**, *45*, 355–362. [CrossRef]
81. Franck, M.C.; Monteiro, M.G.; Limberger, R.P. Suicide mortality in Rio Grande do Sul, Brazil: A cross-sectional analysis of cases, 2017-2018. *Epidemiol. Serv. Saude* **2020**, *29*, e2019512. [CrossRef]
82. Meneghel, S.N.; Victora, C.G.; Faria, N.M.X.; Carvalho, L.A.; Falk, J.W. Epidemiological aspects of suicide in Rio Grande do Sul, Brazil. *Rev. Saude Publica* **2004**, *38*, 804–810. [CrossRef]
83. Jaishankar, M.; Tseten, T.; Anbalagan, N.; Mathew, B.B.; Beeregowda, K.N. Toxicity, mechanism and health effects of some heavy metals. *Interdiscip. Toxicol.* **2014**, *7*, 60–72. [CrossRef]
84. Rohr, J.R.; Barrett, C.B.; Civitello, D.J.; Craft, M.E.; Delius, B.; DeLeo, G.A.; Hudson, P.J.; Jouanard, N.; Nguyen, K.H.; Ostfeld, R.S.; et al. Emerging human infectious diseases and the links to global food production. *Nat. Sustain.* **2019**, *2*, 445–456. [CrossRef]
85. Ellwanger, J.H.; Fearnside, P.M.; Ziliotto, M.; Valverde-Villegas, J.M.; da Veiga, A.B.G.; Vieira, G.F.; Bach, E.; Cardoso, J.C.; Müller, N.F.D.; Lopes, G.; et al. Synthesizing the connections between environmental disturbances and zoonotic spillover. *An. Acad. Bras. Cienc.* **2022**, *94*, e20211530. [CrossRef]
86. Oliveira, T.E.; de Freitas, D.S.; Gianezini, M.; Ruviaro, C.F.; Zago, D.; Mércio, T.Z.; Dias, E.A.; Lampert, V.N.; Barcellos, J.O.J. Agricultural land use change in the Brazilian Pampa Biome: The reduction of natural grasslands. *Land Use Policy* **2017**, *63*, 394–400. [CrossRef]
87. Ziliotto, M.; Ellwanger, J.H.; Chies, J.A.B. Geo-helmintíases no Rio Grande do Sul: Uma análise a partir da perspectiva de Saúde Única. *Bio Diverso* **2022**, *2*, 66–94.
88. Pereira, E.M. Movimentos ambientalistas no Rio Grande do Sul (décadas 1970-80). *Oficina Hist.* **2018**, *11*, 21–42. [CrossRef]

89. Menegassi, D. Coalizão pelo Pampa Publica Carta Aberta em Defesa do Bioma e Alerta Para Ameaças. 2022. Available online: https://oeco.org.br/noticias/coalizao-pelo-pampa-publica-carta-aberta-em-defesa-do-bioma-e-alerta-para-ameacas/ (accessed on 10 February 2023).
90. Instituto Curicaca. 2020. Available online: https://www.curicaca.org.br/ (accessed on 10 February 2023).
91. Rede Campos Sulinos. 2023. Available online: https://www.ufrgs.br/redecampossulinos/ (accessed on 10 February 2023).
92. Comitê dos Povos e Comunidades Tradicionais do Pampa. 2023. Available online: https://comitepampa.com.br/ (accessed on 10 February 2023).
93. Secretaria da Agricultura, Pecuária, Produção Sustentável e Irrigação. Agrotóxicos. 2016. Available online: https://www.agricultura.rs.gov.br/agrotoxicos-2016-12 (accessed on 20 March 2023).
94. Garibotti, V. Os agrotóxicos e o direito de escolha dos cidadãos. In *Boletim Epidemiológico*; Centro Estadual de Vigilância em Saúde do Rio Grande do Sul: Porto Alegre, Brazil, 2012; Volume 14, pp. 1–3.
95. Dapper, V.; Nussbaumer, L. Avaliação dos registros de intoxicações por agrotóxicos no Rio Grande do Sul. In *Boletim Epidemiológico*; Centro Estadual de Vigilância em Saúde do Rio Grande do Sul: Porto Alegre, Brazil, 2012; Volume 14, pp. 6–8.
96. Martil, G.C.D.; dos Anjos, F.S. Redes agroalimentares alternativas e consumo crítico: O caso das feiras orgânicas de Porto Alegre. *Política Soc.* **2020**, *19*, 172–203. [CrossRef]
97. Klein, A.D.; Klein, C.R.M.; Schultz, G. Os canais de distribuição on-line de alimentos orgânicos na região metropolitana em Porto Alegre. *Grifos* **2022**, *31*, 57. [CrossRef]
98. Schneider, S.; Gazolla, M. *Cadeias Curtas e Redes Agroalimentares Alternativas: Negócios e Mercados da Agricultura Familiar*; Editora da UFRGS: Porto Alegre, Brazil, 2017.
99. Bugge, M.M.; Hansen, T.; Klitkou, A. What Is the Bioeconomy? *A Review of the Literature. Sustainability* **2016**, *8*, 691. [CrossRef]
100. Ellwanger, J.H.; Nobre, C.A.; Chies, J.A.B. Brazilian Biodiversity as a Source of Power and Sustainable Development: A Neglected Opportunity. *Sustainability* **2023**, *15*, 482. [CrossRef]
101. IBGE—Instituto Brasileiro de Geografia e Estatística. Sistema de Contas Regionais: Brasil 2020. In *Contas Nacionais, n. 90*; IBGE: Rio de Janeiro, Brazil, 2022; pp. 1–12.
102. Balestrin, A. RS, Primeiro em Inovação no Brasil. 2022. Available online: https://estado.rs.gov.br/rs-primeiro-em-inovacao-no-brasil#:~:text=Na%20produ%C3%A7%C3%A3o%20cient%C3%ADfica%2C%20o%20nosso,e%20depositam%20centenas%20de%20patentes (accessed on 10 February 2023).
103. Instituto Brasileiro de Geografia e Estatística—IBGE. 2023. Available online: https://www.ibge.gov.br/ (accessed on 19 March 2023).
104. Projeto MapBiomas Pampa Trinacional—Coleção 2.0 da Série Anual de Mapas de Uso e Cobertura do Solo. 2023. Available online: https://pampa.mapbiomas.org/pt-BR (accessed on 11 April 2023).