

The Environmental Crossroads: Ecological Concepts, Regulations, and the Challenges of Protecting the Brazilian Cerrado

How to cite this article [Chicago]: Lara de Carvalho, Luciana, Eumar Evangelista de Menezes Júnior, Aline Cristiane Kamiya, and Sandro Dutra e Silva. "The Environmental Crossroads: Ecological Concepts, Regulations, and the Challenges of Protecting the Brazilian Cerrado." *Novum Jus* 20, no. 2 (2026): 169–200. <https://doi.org/10.14718/NovumJus.2026.20.2.6>

Luciana Lara de Carvalho /
Eumar Evangelista de Menezes Júnior /
Aline Cristiane Kamiya /
Sandro Dutra e Silva



The Environmental Crossroads: Ecological Concepts, Regulations, and the Challenges of Protecting the Brazilian Cerrado

Luciana Lara de Carvalho^{*}
Eumar Evangelista de Menezes Júnior^{**}
Aline Cristiane Kamiya^{***}
Sandro Dutra e Silva^{****}

Received: January 24, 2026 | **Evaluated:** March 3, 2026 | **Accepted:** March 5, 2026

Abstract

This article examines the process of regulatory consolidation to protect the Cerrado in Brazil, linking the scientific development of the biome concept to the formation of the legal-environmental framework. The qualitative, exploratory research is based on a bibliographic and documentary analysis of the works of authors in ecology and environmental law. It begins by noting that although Brazil has comprehensive environmental legislation, the effectiveness of regulations governing the Cerrado is limited by institutional, economic, and epistemological factors. The article highlights a lack of understanding among legal professionals of the scientific and ecological foundations that define the biome. This conceptual gap hampers the proper application of environmental regulations and undermines ecological protection. The article emphasizes the need for greater integration between science and legal practice, so that ecological knowledge informs legal interpretation and environmental governance. It concludes that the adequate protection of the Cerrado requires an interdisciplinary approach and legally grounded environmental education to transform the regulatory framework into an accurate tool for conservation and sustainability.

Keywords: Cerrado, Brazilian biomes, environmental law, political ecology, regulatory effectiveness.

^{*} MSc in Environmental Sciences (Evangelical University of Goiás), environmental lawyer at the law firm Luciana Carvalho Advocacia Ambiental, Goiânia, Brazil. Email: lucianalcarvalhoadv@gmail.com ORCID: <https://orcid.org/0009-0005-3136-9999>.

^{**} PhD in Religious Science (Pontifícia Universidade Católica de Goiás), professor and researcher at the Law School of Universidade Evangélica de Goiás, Anápolis, Brazil. Email: eumar.junior@docente.unievangelica.edu.br ORCID: <https://orcid.org/0000-0003-1419-163X>.

^{***} PhD in Science (Universidade de São Paulo), professor and researcher at the Universidade Evangélica de Goiás, Anápolis, Brazil. Email: linekamiya@gmail.com ORCID: <https://orcid.org/0009-0003-1915-582X>.

^{****} PhD in History (Universidade de Brasília), professor and researcher at the Department of Environmental Science, Universidade Estadual de Goiás and Universidade Evangélica de Goiás, Anápolis, Brazil. Email: sandrodutr@hotmail.com (corresponding author) ORCID: <https://orcid.org/0000-0002-0001-5726>.

La encrucijada ambiental: conceptos ecológicos, normativa y desafíos para la protección del Cerrado brasileño

Luciana Lara de Carvalho
Eumar Evangelista de Menezes Júnior
Aline Cristiane Kamiya
Sandro Dutra e Silva

Recibido: 5 de enero de 2026 | **Evaluado:** 3 de marzo de 2026 | **Aceptado:** 5 de marzo de 2026

Resumen

Este artículo examina el proceso de consolidación normativa para la protección del Cerrado en Brasil, vinculando el desarrollo científico del concepto de bioma con la formación del marco jurídico-ambiental. La investigación cualitativa y exploratoria se basa en un análisis bibliográfico y documental de autores de las áreas de la ecología y del derecho ambiental. Se parte de la observación de que, si bien Brasil cuenta con una legislación ambiental integral, la eficacia de las normas dirigidas al Cerrado se ve limitada por factores institucionales, económicos y epistemológicos. El artículo destaca la insuficiente comprensión por parte de los profesionales del derecho de los fundamentos científicos y ecológicos que definen el bioma, ya que dicha brecha conceptual dificulta la aplicación adecuada de las normas ambientales y perjudica la protección del medio ambiente. El artículo enfatiza la necesidad de una mayor integración entre la ciencia y la práctica jurídica para que el conocimiento ecológico influya en la interpretación jurídica y en la gobernanza ambiental. Se concluye que la adecuada protección del Cerrado requiere un enfoque interdisciplinario y una educación ambiental con fundamento jurídico, a fin de transformar el marco regulatorio en un instrumento eficaz para la conservación y la sostenibilidad.

Palabras clave: Cerrado, biomas brasileños, derecho ambiental, ecología política, efectividad normativa.

Introduction

This article results from academic research analyzing the process of regulatory consolidation to protect the Cerrado in Brazil. It connects the scientific development of the biome concept with the evolution of the legal and environmental framework. The Cerrado plays strategic ecological roles,¹ especially in maintaining the national water balance by harboring the headwaters of critical hydrographic basins, such as those of the São Francisco, Tocantins-Araguaia, and Paraná rivers, which grants it significant socio-environmental and economic importance.²

However, the ecological importance of the Cerrado contrasts with its historical vulnerability, driven by the expansion of the agricultural frontier and the exploitative use of its natural resources.³ In recent decades, the biome has experienced high rates of deforestation and fragmentation, making it the most threatened in the country.^{4,5} For the second consecutive year, the Cerrado remains the biome with the largest deforested area, accounting for more than half of the country's total deforestation (52.5 %) and totaling 652,197 hectares.⁶ This contradiction raises a key question: why, despite Brazil having one of the most advanced environmental legal frameworks worldwide, is adequate protection of the Cerrado still insufficient?

The central hypothesis of this study is that, although the 1988 Federal Constitution and subsequent infra-constitutional laws—such as the Environmental Crimes Act (1998) and the New Forest Code (2012)—have established a comprehensive legal framework, the effectiveness of these regulations is limited by structural and epistemological issues. Besides institutional weaknesses, economic interests, and lack of oversight, a less obvious but critical problem is the limited understanding

¹ Donald Sawyer et al., *Ecosystem Profile: Cerrado Biodiversity Hotspot* (Critical Ecosystem Partnership Fund, 2016).

² Paula Pimenta, “Berço das águas: Cerrado tem recursos hídricos pressionados pelo desmatamento,” *Senado Federal*, last modified March 15, 2024, <https://www12.senado.leg.br/noticias/infomaterias/2024/03/berco-das-aguas-cerrado-tem-recursos-hidricos-pressionados-pelo-desmatamento>.

³ Ariane A. Rodrigues et al., “Cerrado Deforestation Threatens Regional Climate and Water Availability for Agriculture and Ecosystems,” *Global Change Biology* 28, no. 2 (2022): 6807–22, <https://doi.org/10.1111/gcb.16386>.

⁴ Bernardo B. N. Strassburg et al., “Moment of Truth for the Cerrado Hotspot,” *Nature Ecology & Evolution* 1 (2017): 0099, <https://doi.org/10.1038/s41559-017-0099>.

⁵ Siyi Kan et al., “Identifying Global Hotspots of Agricultural Expansion into Non-Forest Ecosystems,” *Nature Communications* 16 (2025): 10739, <https://doi.org/10.1038/s41467-025-65769-x>.

⁶ MapBiomass, *Relatório Anual do Desmatamento no Brasil 2024* (MapBiomass, 2025).

among legal professionals of the scientific foundations that define the Cerrado as a biome and biogeographical system.

This conceptual gap reveals a disconnect between scientific knowledge and legal practice. Many in the legal field often use terms like biome, ecosystem, and natural system interchangeably, without recognizing their theoretical differences and practical implications for environmental protection. This lack of clarity weakens the interpretation of laws and narrows their protective scope, reducing them to a territorial approach that ignores the ecological dynamics that sustain the biogeographical balance. As a result, legal protection for the Cerrado remains fragmented, despite significant legislative and institutional progress.

In the scientific field, the concept of biome has evolved throughout the 20th century, establishing itself as a broad and complex ecological unit resulting from the interaction of climatic, geomorphological, floristic, and faunistic factors.⁷ However, this idea has not been fully integrated into Brazilian law. The 1988 Federal Constitution, although innovative in recognizing an ecologically balanced environment as a fundamental right, does not explicitly mention biomes or natural systems, creating an interpretative gap and limiting the consistent application of environmental protection.⁸

This study, therefore, aims to examine the intersection between science and environmental law, examining how well legal practitioners understand and appropriately apply key ecological concepts, such as biomes and biogeographical systems, and how this understanding (or lack thereof) influences the effectiveness of legal protections for the Cerrado. It is assumed that establishing a truly effective legal system depends not only on the existence of laws but also on the ability of those who interpret them to grasp the scientific principles underlying environmental protection.⁹

⁷ Ladislav Mucina, "Biome: evolution of a crucial ecological and biogeographical concept," *The New phytologist* 222, no. 1 (2019): 97–114, <https://doi.org/10.1111/nph.15609>.

⁸ Édís Milaré, *Direito do ambiente: a gestão ambiental em foco – doutrina, jurisprudência, glossário*, 12th ed. (Revista dos Tribunais, 2020).

⁹ Silvana Gino Fernandes de César et al., "Vegetação E Legislação Ambiental: Estudo De Regularização De Passivos Ambientais Aplicado No Município De Ipiranga De Goiás – Goiás – Brasil," *Fronteiras: Journal of Social, Technological and Environmental Science* 13, no. 1 (2024): 244–68, <https://doi.org/10.21664/2238-8869.2024v13i1.p244-268>; Raphael Melazzo de Faria Costa et al., "A Interseção Entre Legística E Princípios Ambientais: Caminhos Para a Criação De Normas Sustentáveis Efetivas," *Fronteira: Journal of Social, Technological and Environmental Science* 13, no. 4 (2024): 354–68, <https://doi.org/10.21664/2238-8869.2024v13i4.p354-36>; Eumar Evangelista de Menezes Junior et al., "Meio Ambiente, Políticas De Inovação E Tecnologia: Relações

This article analyzes the process of regulatory consolidation for protecting the Cerrado by linking science, law, and politics. Specifically, it seeks to: (i) trace the historical development of the concept of biome and its application to the Cerrado; (ii) review the evolution of Brazilian environmental legislation, from key constitutional milestones to modern laws; and (iii) explore how legal professionals understand the concepts of biome and biogeographical system, assessing how this epistemological perspective influences the effectiveness of legal protection. The research is qualitative, with an exploratory and descriptive approach based on bibliographic and documentary analysis. Classic ecology authors such as Clements, Whittaker, Odum, and Walter, Brazilian scholars such as Coutinho and Ribeiro & Walter, and jurists including Édis Milaré and Rosa & Guarda are used to develop the conceptual framework of the biome and its translation into legal norms. The legal analysis focuses on constitutional provisions, environmental laws, and critical literature regarding their implementation.

The reason for this study is the strategic importance of the Cerrado for Brazil's and the planet's environmental balance. As a biodiversity hotspot and a key player in water recharge and climate regulation, it is vital for the country's ecological and economic sustainability.¹⁰ However, the ongoing degradation of the Cerrado exposes not only the shortcomings of legislation but also the need to integrate scientific and legal knowledge to develop and implement public policies.

The central question guiding this research is: to what extent have Brazilian regulations evolved to effectively protect the Cerrado, given legal professionals' conceptual and interpretive limitations in understanding biogeographical systems? To address this, the article delves into three analytical areas: (i) the historical and scientific development of the concept of biome; (ii) the evolution of Brazil's legal-environmental framework; and (iii) the understanding of legal professionals and the current challenges of ensuring regulatory effectiveness.

Therefore, this article aims not only to trace the conceptual and legislative history of environmental protection but also to illuminate the practical challenges of enforcement. It argues that making environmental legislation effective depends on

E Correlações Nos Últimos Dez Anos No Brasil," *Fronteira: Journal of Social, Technological and Environmental Science* 13, no. 1 (2024): 213–26, <https://doi.org/10.21664/2238-8869.2024v13i1.p213-226>.

¹⁰ Regina Horta, "O Lobo Andarilho: Coexistência E Conflitos No Cerrado Brasileiro," *Historia Ambiental Latinoamericana y Caribeña (HALAC) Revista de la Solcha* 15, no. 2 (2025): 138–62, <https://doi.org/10.32991/2237-2717.2025v15i2.p138-162>.

an interdisciplinary approach that bridges law and the natural sciences. Protecting the Cerrado is thus not just an ecological issue, but also an epistemological, political, and legal challenge. Overcoming this requires deep dialogue between various fields and the development of an environmentally aware legal culture.

The Cerrado Within the Historical Concept of a Biome

The concept of the biome originated in ecological science in the early 20th century and has been continually refined by numerous researchers. Frederic Edward Clements was the first to systematically use the term in a lecture to the Ecological Society of America in 1916, defining it as a synonym for the biotic community. For Clements, a biome was a large ecological unit composed of interacting plants and animals, evolving through a successional process until reaching the ecological climax—a stage in which a relatively stable, self-sustaining ecosystem is established.¹¹ In this regard, Clements defined the biome as a biotic community composed of plants and animals, characterized by physiognomic uniformity. Clements also considers this biotic community a formation, composed of climax vegetation and the most prominent animals, and therefore characterized by a distinct biotic composition.¹²

Several authors expanded on Clements' original definition throughout the 20th century. Shelford contributed to the idea that a biome should be regarded as an ecological unit in which flora and fauna are interconnected.¹³ Later, Odum integrated other elements of the physical substrate into the concept of the biome, stating that regional climates interact with regional biota and help create large, recognizable community units.¹⁴ He also adopted the concept of a biome for these formations, confirming Clements' idea of the vegetational climax while also considering the climatic climax.¹⁵

Robert Whittaker, in turn, emphasized the significance of climatic factors, particularly temperature and precipitation, in determining the dominant vegetation of each biome, being among the first to propose graphic and comparative classifica-

¹¹ Mucina, "Biome," 97–114.

¹² Frederic E. Clements, "Nature and Structure of the Climax," *Journal of Ecology* 37, no. 1 (1949): 79–84.

¹³ Victor E. Shelford, *Bio-ecology* (Wiley, 1939), <https://doi.org/10.2307/1436903>.

¹⁴ Eugene P. Odum, *Fundamentals of Ecology*, 3rd ed (W. B. Saunders, 1971).

¹⁵ Leopoldo Magno Coutinho, "O conceito de bioma," *Anais da Academia Brasileira de Ciências* 78, no. 4 (2006): 60–66.

tions across different continents.¹⁶ Thus, decades after Clements' original idea, the concept of a biome still needed clarification. In this context, Whittaker developed a definition based on a primary type of community that forms in a specific geographic area, as defined by physiognomic terms, and can be classified as either a biome or a formation. Therefore, the term "formation" becomes relevant when categorizing plant communities. The term "biome," on the other hand, is more inclusive, encompassing both plants and animals.¹⁷

Dajoz emphasized that a biome is defined by a homogeneous physiognomy, regardless of its floristic composition. For him, biomes are also referred to as formations or complexes by various authors. In his view, a biome is a grouping characterized by uniform physiognomy, independent of its floristic makeup. It also covers a large area and is governed by the region's specific macroclimate. He concluded that, in terrestrial communities, biomes correspond to the main natural vegetation formations.^{18,19} This view was later expanded by Heinrich Walter, who introduced concepts such as the zonobiome (defined by climate), the pedobiome (soil), the orobiome (altitude), and the pyrobiome (influence of natural fire).²⁰

Colinvaux developed an ecological and functional perspective, defining a biome as a large geographic ecosystem in which vegetation is mainly shaped by climate.²¹ Botanist Leopoldo Coutinho helped broaden this idea, proposing that a biome would be a subcontinental territory and that biome type would be the sum of all biomes of a given kind across different continents. An example from Coutinho's analysis is that the Cerrado *sensu lato*, a tropical savanna, would be classified as a biome. Meanwhile, the global savannas would represent a biome type.²²

Mucina emphasizes that the concept of biome is constantly evolving, highlighting its dynamic, multifaceted character and its deep roots in evolutionary history and ongoing transformation. According to the author, this evolution has been marked by three key stages: (i) a first synthesis focused on understanding climatic zonality and the major ecological and biogeographical determinants; (ii) a second synthesis

¹⁶ Roberto Testolin et al., "Global Distribution and Bioclimatic Characterization of Alpine Biomes," *Ecography* 43, no. 6 (2020): 779–88, <https://doi.org/10.1111/ecog.05012>.

¹⁷ Robert H. Whittaker, *Communities and Ecosystems* (Macmillan, 1971).

¹⁸ Roger Dajoz, *Ecologia geral* (Vozes, 1973).

¹⁹ Coutinho, "O conceito de bioma," 60.

²⁰ Heinrich Walter and Elgene O. Box, *Biology of Ecosystems* (Edward Arnold, 1976).

²¹ Paul Colinvaux, *Ecologia: a busca de princípios* (Edgard Blücher, 1993).

²² Coutinho, "O conceito de bioma," 60.

characterized by the development of mechanistic and functional models capable of predicting the distribution of biomes; and (iii) a third synthesis, still underway, which seeks to integrate large-scale ecological and biogeographical phenomena through macroecological and macroevolutionary approaches.²³

In Brazil, Leopoldo Magno Coutinho made significant contributions to understanding the concept by defining a biome as: an area of geographic space larger than one million square kilometers, characterized by a uniform type of environment, identified and classified based on macroclimate, phytophysiology (formation), soil, and altitude—key elements that define the different continental environments.²⁴

Also within the Brazilian context, Ribeiro and Walter expanded the definition of the biome, viewing it as a large biogeographical territory that groups different ecosystems and supports interconnected communities of flora and fauna. These ecosystems are organized around the dominant environmental factors, such as climate, soil, and relief.²⁵

This dynamic understanding of the concept of biome is fundamental to interpreting the Cerrado, whose definition is neither unique nor static. The concept of the Cerrado biome is dynamic and diverse, shaped by the interactions among science, legislation, and public policies. The Cerrado should be seen not just as a defined geographical area but as a complex biological, ecological, and socio-environmental system, whose preservation is crucial for maintaining biodiversity and water resources in Brazil.

The historical understanding of the biome concept was vital in establishing the theoretical foundations that supported the scientific and political recognition of the Cerrado. This conceptual framework acknowledged the biome's ecological complexity, directly influencing the development of environmental legislation. This shift from the conceptual to the legal level connects to the next topic, which analyzes the evolution of regulations.

²³ Mucina, "Biome," 921.

²⁴ Coutinho, "O conceito de bioma," 60.

²⁵ José Felipe Ribeiro and Bruno Machado Teles Walter, "Fitofisionomias do bioma Cerrado," in *Cerrado: ambiente e flora*, ed. S. M. Sano and S. P. Almeida (Embrapa-CPAC, 1998), 87–166.

From Historical Formation to the Constitutional Framework: The Need for Regulatory Consolidation

Understanding the Cerrado as a biome helps us recognize this ecological space not only for its biological diversity and various subsystems but also as an increasingly important political and legal issue. The scientific definition of the Cerrado as a large ecological unit, composed of distinct plant physiognomies and abiotic and biotic factors, emphasizes its crucial role in the national water cycle and in providing ecosystem services. This view shows that it is not just a geographic area but a natural heritage of strategic importance for the country.

From this understanding, the development of Brazilian federal laws demonstrates a continuous, though limited, effort to include the Cerrado in environmental and economic policies. For instance, the 1934 Constitution was the first to include provisions for protecting natural resources. Later, the 1965 Forest Code advanced this by creating categories such as Permanent Preservation Areas (APPs) and Legal Reserves (RLs) and establishing a stronger system for protecting native vegetation. According to jurist Milaré, Brazil has a complex and comprehensive environmental legal system, but it suffers from poor practical enforcement, whether due to institutional issues or a lack of political will.²⁶ This jurist states that this broad legal framework results in a strong regulatory system that is, however, often ineffective.

This lack of effectiveness was also clear in water management. The creation of the National Water Resources Policy by Law No. 9,433/1997, although it came after the 1988 Constitution, has roots in discussions that began to take shape in the late 1970s and early 1980s, when concerns about the rational management of water began to take clearer regulatory form. The Water Act itself emphasizes, for the first time, that “water is a public domain asset, a limited natural resource with economic value, and that its management should always provide for the multiple use of water.”²⁷

Despite this regulatory innovation, the gap between theory and practice was wide.²⁸ The Cerrado, a strategic biome because it is the source of major hydrographic

²⁶ Milaré, *Direito do ambiente*, 12th ed.

²⁷ Brasil, “Lei nº 9.433, 8 de janeiro de 1997,” *Diário Oficial da União* (Brasília, January 9, 1997).

²⁸ Raphael Melazzo de Faria Costa et al., “O meio ambiente sob múltiplas perspectivas: interfaces entre direito, política e sociedade para a conservação ambiental e o desenvolvimento sustentável,” *Novum Jus* 19, no. 2 (2025), 287–327, <https://doi.org/10.14718/NovumJus.2025.19.2.10>.

basins, remained vulnerable to agricultural expansion, underscoring the inadequacy of regulations in preventing environmental degradation. The push for productive growth outweighed legal provisions, exposing the still sectoral and fragmented nature of Brazilian environmental law until the 1980s.

Another key point is that the National Environmental Policy Act—Law No. 6,938/1981, which came before the 1988 Federal Constitution—already highlighted the need for integration and more systemic management. This law aimed to establish broader environmental management, focusing on the preservation of all natural resources in a unified and comprehensive manner, and to create a new integrated system for environmental protection. To achieve this, the National Environmental System (SISNAMA) and the National Environmental Council (CONAMA) were established within the national governance and environmental policy framework.²⁹

Still, the limitation of the National Environmental Policy Act lay in its capacity for implementation, since, in practice, coordination among federative entities and the regulatory power of CONAMA resolutions proved insufficient to halt the degradation process. This set of factors underscores the need for a new stage in which the environment is recognized not just as an object of sectoral regulation but as a fundamental principle of the legal system. It is at this point that the 1988 Federal Constitution is introduced, as a response to the fragmentation and ineffectiveness of previous norms.

According to Article 225 of the Constitution, everyone has the right to an ecologically balanced environment, and it is the responsibility of public authorities and the community to defend and preserve it for current and future generations.³⁰ This formulation marked the shift from a legal model characterized by dispersed norms to an integrated system of environmental protection. Therefore, the historical trajectory presented shows that Brazilian environmental legislation has made significant progress in developing regulatory frameworks, particularly by introducing fundamental concepts related to the preservation of water and native vegetation. However, these advances have been accompanied by contradictions: on the one hand, pioneering and comprehensive provisions exist; on the other hand, they cannot be fully enforced due to economic pressures and the State's institutional fragility.

²⁹ Marcelo Rodrigues Rosa and Eduardo Carlos Guarda, "A Política Nacional do Meio Ambiente e seus desdobramentos institucionais," *Revista de Direito Ambiental* 24, no. 94 (2019): 57–74.

³⁰ Brasil, "Constituição da República Federativa do Brasil de 1988," *Diário Oficial da União* (Brasília, October 5, 1988).

The Cerrado, in particular, exemplifies this gap between law and reality. Although theoretically protected by instruments such as the 1965 Forest Code and, later, the 1981 National Environmental Policy, the biome continued to undergo systematic degradation, highlighting inadequate enforcement and the dominance of the agro-export development model. This situation contributed to the perception, before the 1988 Constitution, that Brazilian environmental regulations were a collection of fragmented provisions rather than a truly integrated system of protection.

The need to address this issue became clear as environmental degradation worsened and global awareness of the importance of sustainability and intergenerational solidarity grew stronger. In Brazil, this process led to the drafting of a Constitution that not only included environmental provisions but also established them as a guiding principle of the economic and social order.

In this context, it is fair to conclude that the rules before 1988 were important in paving the way for more substantial environmental protections. However, it was only the 1988 Federal Constitution that granted the environment the status of a fundamental right, creating the legal framework that supported the development of modern public policies. Therefore, the next section will focus on this transformation, exploring how the 1988 Constitution solidified the legal framework and paved the way for the development of more advanced and comprehensive legal tools for the integrated management of water resources and the preservation of the Cerrado as a national treasure.

The Consolidation of Brazil's Environmental Regulatory Framework: From the 1988 Constitution to Modern Policies for Water and Cerrado Preservation

The 1988 Federal Constitution marked a major milestone in Brazil's environmental history. For the first time, the environment was elevated to the status of a central constitutional value, breaking with the previous legislative tradition of scattered, fragmented provisions on natural resources. As Milaré notes, the 1988 Constitution was innovative and foundational, whereas earlier constitutions accorded little or no importance to environmental protection, whether in specific or broad terms. According to Milaré, earlier constitutions did not even use the term "environment," indicating total neglect of this vital issue in social control and protection. Similarly, the 1988 Constitution became known as the "Green Constitution," pioneering

comprehensive environmental protection by elevating it to a core national value. Therefore, unlike past constitutions that addressed environmental issues in specific provisions, the 1988 Constitution adopted a systemic approach, regulating the environment as a fundamental principle of the economic and social orders.³¹

Article 225 of the 1988 Constitution enshrined the rights of all citizens to an ecologically balanced environment, a common good for the people, and an essential element of a healthy quality of life. This constitutional article also stated that it was the duty of public authorities and the community to defend and preserve the environment for present and future generations. Simultaneously, this legislation laid the groundwork for the development of environmental public policy and for legal interpretation.

This regulatory text reinforced the idea of the environment as a fundamental third-generation right, a diffuse and collective one that extends beyond individual interests to encompass community concerns. The 1988 Constitution incorporated social values that reflected the national spirit at the time, fostering awareness of the need to learn to coexist harmoniously with nature. Consequently, this new legislation adopted more comprehensive and modern environmental protection systems. The focus on environmental issues was evident not only in specific provisions of the law but also in numerous other regulations integrated throughout the law, highlighting the subject's multidisciplinary nature.³²

The 1988 Constitution also redefined Brazil's water legal framework by characterizing water as a public good and establishing shared responsibility among the Union, States, and Municipalities for its protection. This change was directly reflected in the creation of the National Water Resources Policy (Law No. 9,433/1997), which established the National Water Resources Management System.

The National Water Resources Management System was seen as revolutionary because it introduced principles such as decentralization, public participation, and the recognition of water's economic value. By recognizing that water is a public good, limited, and economically valuable, Law No. 9,433/1997 created tools such as granting water-use rights, charging for water, and classifying water bodies into quality categories. However, water governance mainly focused on protecting water

³¹ Milaré, *Direito do ambiente*, 12th ed.

³² Milaré.

quantity, with less emphasis on quality, reflecting economic rather than ecological concerns.³³

This framework was complemented by Law No. 9,605/1998 (Environmental Crimes Act), which criminalized environmentally harmful conduct and strengthened the State's authority to impose sanctions on exploitative practices. Another important development was the enactment of Law No. 9,985/2000, which established the National System of Nature Conservation Units (SNUC).³⁴ This law officially structured the protection of natural areas, dividing them into two categories: those under full protection and those designated for sustainable use. In the Cerrado, this legal framework was critical because, despite being Brazil's second-largest biome, it has long been marginalized in conservation efforts.

Then, in 2012, following extensive political and scientific discussions, Law No. 12,651/2012 (New Forest Code) was enacted, introducing substantial changes while maintaining the importance of APPs and RLs.³⁵ In the Cerrado, these measures are vital for protecting springs, wetlands, and riparian forests, as their degradation threatens the sustainability of water resources. The establishment of specific conservation units in the Cerrado aimed to limit deforestation and habitat fragmentation, strengthening the protection of biodiversity and water resources in the region.

However, the main dilemma regarding the Cerrado centers on the complicated relationship between environmental conservation policies and the production of food and agricultural commodities.^{36,37} The establishment of Embrapa in 1973 marked a key step in agricultural development, and in this context, the focus on transforming the Cerrado—once seen as a region lacking agricultural potential

³³ Rosa and Guarda, "A Política Nacional," 57–74.

³⁴ Brasil, "Lei nº 9.985, de 18 de julho de 2000," *Diário Oficial da União* (Brasília, July 19, 2000).

³⁵ Brasil, "Lei nº 12.651, de 25 de maio de 2012," *Diário Oficial da União* (Brasília, May 28, 2012).

³⁶ Sandro Dutra e Silva, "Challenging the Environmental History of the Cerrado: Science, Biodiversity and Politics on the Brazilian Agricultural Frontier," *HALAC – Historia Ambiental Latinoamericana y Caribeña* 10, no. 1 (2020): 82–116, <https://doi.org/10.32991/2237-2717.2020v10i1.p82-116>.

³⁷ Carlos B. Rocha et al., "A Geo-historical Analysis of Expanding Soybean Frontiers in the Brazilian Cerrado," *Historia Ambiental Latinoamericana y Caribeña (HALAC) Revista de la Solcha* 12, no. 2 (2022): 217–52, <https://doi.org/10.32991/2237-2717.2022v12i2.p217-252>.

in Brazil—was unmatched.^{38,39,40} This dilemma continues today in the Cerrado, where environmental laws, although strong, face difficulties in implementation and enforcement, mainly due to pressure from agricultural expansion and the long-standing neglect of the biome.⁴¹

Environmental Accountability in Brazil: The Environmental Crimes Act of 1998 and the Forest Act of 2012

The 1988 Federal Constitution marked a crucial milestone in strengthening Brazil's environmental legal framework, elevating the right to a balanced environment to the status of a shared public good vital for quality of life. In doing so, it not only established a new legal paradigm but also imposed a collective duty on both the government and society to protect and conserve natural resources. However, the strength of this constitutional mandate required sub-constitutional tools capable of turning its provisions into action, ensuring that the text was not limited to a merely programmatic level.

As previously demonstrated, the 1988 Constitution prompted the development of public policies and legal instruments focused on sustainable development, ecosystem protection, and the recognition of water as a strategic resource. However, to ensure these principles do not remain just statements of intent, it became essential to develop specific laws that translate the constitutional guidelines into practical action. In this context, the Environmental Crimes Act (Law No. 9,605/1998)⁴² and the Brazilian Forest Code (Law No. 12,651/2012)⁴³ are key legal tools that bridge the gap between constitutional recognition and actual accountability by providing detailed regulations governing the use of native vegetation.

³⁸ Ryan Nehring, "Yield of Dreams: Marching West and the Politics of Scientific Knowledge in the Brazilian Agricultural Research Corporation (Embrapa)," *Geoforum* 77 (2016): 206–17, <https://doi.org/10.1016/j.geoforum.2016.11.006>.

³⁹ Dutra e Silva, "Challenging the Environmental History," 82–116.

⁴⁰ Karina J. Boaventura et al., "Building Soil Fertility: Embrapa and the Agronomic Development for the 'Conquest' of the Brazilian Cerrado (1975–95)," *Historia Agraria* 89 (2023): 247–78, <https://doi.org/10.26882/histagrar.089e08b>.

⁴¹ Sandro Dutra e Silva, "Lessons from the Brazilian Cerrado: Technological Achievements and Environmental Challenges," *ReVista: Harvard Review of Latin America*, last modified September 13, 2025, <https://revista.drclas.harvard.edu/lessons-from-the-brazilian-cerrado-technological-achievement-and-environmental-challenges/>.

⁴² Brasil, Lei nº 9.605, de 12 de fevereiro de 1998, *Diário Oficial da União* (Brasília, February 13, 1998).

⁴³ Brasil, Lei nº 12.651.

Therefore, if the 1988 Constitution established the fundamental principles and values of environmental law in Brazil, subsequent laws represent the necessary stage of regulatory institutionalization, creating legal tools to classify harmful behavior, impose sanctions, regulate uses, and establish conservation mechanisms.

The strengthening of Brazil's environmental legal framework, especially after the promulgation of the Magna Carta, was achieved through specific legislation aimed at enhancing the effectiveness of biodiversity protection and the sustainable use of natural resources. In this context, two key milestones stand out: the Environmental Crimes Act of 1998 and the Brazilian Forest Act of 2012, which, although targeting different immediate issues, share the goal of holding individuals accountable and regulating conduct related to the environment, establishing control and sanction mechanisms, as well as principles of preservation and sustainable development.

The Environmental Crimes Act made significant progress by consolidating criminal, administrative, and civil liability for environmentally harmful actions into a single legal framework. After the law was enacted in 1998, actions damaging the environment became punishable in civil, administrative, and criminal courts. Additionally, this legislation allowed civilians, private companies, and entrepreneurial entities to be held criminally responsible for conduct classified as environmental crimes.⁴⁴

The scope of the law is clear in the variety of conduct it covers, outlined across eight chapters, from crimes against wildlife and plants to violations related to environmental management and urban planning. Regarding its regulatory framework, the Environmental Crimes Act is organized into chapters that include general provisions defining the behaviors of individuals and organizations that constitute crimes. It also addresses accountability and compensation for environmental damages.⁴⁵

Besides establishing the liability of legal entities, the law introduced innovations by fostering international cooperation on environmental issues and, in some instances, prioritizing reparations over imprisonment. A key feature of the Environmental Crimes Act is its general rule against imposing imprisonment on individuals convicted, as regulated by the Special Courts Act (Law No. 9,099/95), and its focus on government intervention through authorizations, licenses, and permits. The

⁴⁴ Netanel de Carvalho Gomes Moura et al., "Evolução Histórica da Legislação Ambiental no Brasil," in *Direito, Meio Ambiente e Ecologia Humana: Contribuições para a Sustentabilidade Socioambiental*, vol. 1 (Editora Científica Digital, 2023), 173–88, <https://doi.org/10.37885/230412713>.

⁴⁵ Ivan Silva, *Crimes Ambientais e Juizados Especiais*, 3rd ed. (Juruá, 2021).

law's core is the offender's educational role and the restoration of nature. In this context, it recognizes that this conditional approach is more effective and better aligns with the legal process, since once the environment is harmed, regaining its complete integrity is very challenging.⁴⁶ Law No. 9,605/1998 embodies the principles of prevention and reparation, assigning Criminal Law a pedagogical role that prioritizes environmental restoration over punitive measures alone.

The Brazilian Forest Act (Law No. 12,651/2012) was enacted in response to pressure to amend the 1965 Forest Code. Its main goal was to balance the protection of native vegetation with the demands of agricultural growth, introducing new land regularization methods and redefining environmental protection standards.

Following the creation of the Brazilian Agricultural Research Corporation (Embrapa) in 1973, Brazil saw substantial growth in agricultural production, leading to the expansion of the agricultural frontier into various biomes, especially the Amazon and Cerrado.^{47,48} On one hand, development-focused policies supported and celebrated increased grain and commodity production nationwide. On the other hand, the environmental movement called for stricter controls on the clearing of native vegetation for farming. Additionally, farmers and the emerging agrarian elite pushed for new regulations, proposing legislation that favored the agricultural alliance's economic interests. Amid these changes and conflicts, legislation to protect native vegetation, known as the New Forest Code, was passed in 2012.

Despite differing interests, the 2012 Forest Code was viewed as a positive step toward regulating and managing native vegetation and as an essential political tool for the country's economic growth.⁴⁹ Therefore, beyond its environmental significance, the Forest Code became associated with the concept of sustainable development.⁵⁰

Although recognized as a significant milestone, the law faced criticism for relaxing environmental protection rules to favor agricultural activities. Its approval was heavily influenced by pressure from rural landowners, who argued that the previous

⁴⁶ Rayssa Kelly de Oliveira Nascimento et al., "Crimes Ambientais Durante o Governo Bolsonaro (2018–2022)," *Id on Line – Revista de Psicologia* 17, no. 66 (May 2023): 423–42, <https://doi.org/10.14295/online.v17i66.3786>.

⁴⁷ Dutra e Silva, "Challenging the Environmental History," 82–116.

⁴⁸ Boaventura, "Building Soil Fertility," 247–78.

⁴⁹ Carlos Frederico Lins et al., "Código Florestal Brasileiro: 1965–2012, da Ditadura à Democracia," *Revista Foco* 15, no. 6 (2022): e589, <https://doi.org/10.54751/revistafoco.v15n6-019>.

⁵⁰ Milare, *Direito do ambiente*, 12th ed.

regulations hindered agrarian development. This led to the introduction of concepts such as the “consolidated rural area,” in which illegally deforested native vegetation occupied for agriculture would be incorporated into designated agricultural zones.⁵¹ Essentially, this granted amnesty to farmers who had illegally deforested their land for crops and pasture. Consequently, the new code primarily served the interests of the agricultural sector by offering amnesty for illegal deforestation and environmental degradation committed up to July 22, 2008.⁵²

Another sensitive point was the reduction in protection in APPs. Studies indicate that the new law significantly reduced the extent of these areas, leaving them exposed to risks of biodiversity loss and compromise of water resources.^{53,54} Despite these weaknesses, the law also introduced significant institutional advances, such as the creation of the Rural Environmental Registry (CAR) and the Environmental Regularization Program (PRA). These mechanisms seek to integrate environmental information from rural properties, allowing for ecological monitoring and regularization.^{55,56}

Even so, the effectiveness of the 2012 Forest Code remains questioned. Although the 2012 Forest Code offers significant potential for biodiversity conservation and sustainable land use, it also presents challenges that must be addressed to ensure its effectiveness, especially in critical areas such as the Cerrado. Lack of enforcement can lead to continued illegal deforestation, undermining the law’s intended benefits for biodiversity conservation.⁵⁷

A joint analysis of the Environmental Crimes Act and the 2012 Forest Act reveals a dual trend in Brazilian environmental law: on one hand, strict accountability for conduct harmful to the environment; on the other, efforts to balance preservation

⁵¹ Mayra Stevanato et al., “Proteção das Florestas do Brasil: Contexto Histórico e Atual da Política Pública Ambiental Brasileira,” *Élisée – Revista de Geografia da UEG* 11, no. 2 (2022): e112226, <https://doi.org/10.31668/elisee.v1i02.13089>.

⁵² Mariana Martins de Oliveira et al., “Análise das Modificações Decorrentes da Reformulação do Código Florestal,” *Caderno Pedagógico* 21, no. 9 (2024): e761, <https://doi.org/10.54033/cadpedv21n9-056>.

⁵³ Britaldo Soares-Filho et al., “Cracking Brazil’s Forest Code,” *Science* 344, no. 6182 (2014): 363–64, <https://doi.org/10.1126/science.1246663>.

⁵⁴ Stevanato et al., “Proteção das Florestas.”

⁵⁵ Stevanato et al.

⁵⁶ Ariana do Rosário Rodrigues and C. J. Matavelli, “As Principais alterações Do Código Florestal Brasileiro,” *Revista Brasileira de Criminalística* 9, 1 (2020): 28–35, <https://doi.org/10.15260/rbc.v9i1.300>.

⁵⁷ Rebecca Catherine Brock et al., “Implementing Brazil’s Forest Code: A Vital Contribution to Securing Forests and Conserving Biodiversity,” *Biodiversity and Conservation* 30 (2021): 1621–35, <https://doi.org/10.1007/s10531-021-02159-x>.

and development, albeit with concessions to the production sector. While the former marked a punitive and preventative milestone, the latter shifted the debate toward sustainability and balancing conservation with economic use.

However, the effectiveness of both depends mainly on monitoring and practical enforcement, dimensions that remain fragile amid pressure from economic interests and institutional limitations. Therefore, consolidating Brazil's environmental regulatory framework involves more than just specific laws; it requires integrating legal instruments that combine criminal and administrative accountability with prevention mechanisms and incentives for ecological preservation. In this context, the Environmental Crimes Act (Law No. 9,605/1998) and the Forest Act (Law No. 12,651/2012) serve as complementary pillars of environmental protection in Brazil, integrating the legal framework to ensure both enforcement against environmental damage and the promotion of sustainable use of natural resources.

While the Environmental Crimes Act establishes a strong punitive system that holds individuals and legal entities responsible for environmental harm, the Forest Act introduces preventive and corrective management tools, such as the Rural Environmental Registry and native vegetation restoration programs. This combination of enforcement and prevention is emphasized by the Ministry of the Environment, which recognizes that Brazilian environmental legislation combines direct accountability of offenders with tools to promote environmental preservation and recovery. According to Brazil's primary nature protection agency, the country's environmental law system blends coercive and educational approaches, aiming for economic development and sustainability.⁵⁸

The complementarity of the laws is also clear in how protected areas are defined, and land use is monitored. While Law No. 9,605/1998 outlines crimes related to ecosystem degradation and pollution, Law No. 12,651/2012 details tools for preservation, ensuring that rural land use and exploitation adhere to transparent and verifiable ecological standards. The effectiveness of the environmental legal system depends on the interaction between punitive and preventive rules, so that

⁵⁸ Ministério do Meio Ambiente e Mudança do Clima (MMA), "Institucional – Quem é Quem: Missão e Competências," *Portal Gov.br*, accessed December 02, 2025, <https://www.gov.br/mma/pt-br/acesso-a-informacao/institucional-quem-e-quem>.

criminal liability for environmental harm is reinforced by planning, monitoring, and conservation incentives.⁵⁹

This framework enables the Brazilian environmental legal system to be flexible and multifaceted, adapting to modern demands for biodiversity conservation, regulation of economic activity, and the reduction of socio-environmental impacts. In this context, the integration of the two laws shows that environmental responsibility in Brazil goes beyond punishment; it also includes proactive regulation, environmental education, and the pursuit of sustainable development, reinforcing principles already embedded in the 1988 Federal Constitution.

Thus, the Environmental Crimes Act and the Forest Code work together strategically, forming an integrated legal system in which enforcement of laws against harmful conduct and the promotion of sustainability serve as core pillars of Brazilian environmental policies. This connection illustrates that environmental protection extends beyond punishment to include preventive, educational, and incentive measures for preservation, reflecting shared responsibility among the State, society, and the private sector.

More broadly, it can be argued that the consolidation of the Brazilian environmental regulatory framework, especially since the 1988 Federal Constitution, marks a significant shift: from a model focused on the economic and privatized exploitation of natural resources, such as water and native vegetation, to a legal system centered on collective, participatory, and diffuse protection. In this new approach, resources once viewed solely as tools for economic exploitation are now recognized as common goods, endowed with public value and vital to life, biodiversity, and human dignity.

These reflections lay the groundwork for the article's final considerations, which will be expanded to address regulatory gaps, implementation challenges, and opportunities for future research, particularly in the context of the convergence among environmental legislation, technological innovation, and territorial sustainability.

⁵⁹ M. M. Carvalho, "A legislação sobre a água no Brasil," in *Água e cultura: inventário de fontes de água da região de Ouro Preto*, ed. P. Lemos (Livraria e Editora Graphar, 2015), 134.

Legal Professionals' Understanding of Biomes and Ecological Concepts

Although Brazil's environmental legal framework is strong, it reveals an important conceptual gap: many legal professionals do not fully understand the terminology and scientific foundations of concepts such as "biome" and other ecological concepts. This disconnect between legal language and ecological science directly impacts the effectiveness of environmental protection efforts, especially since the 1988 constitutional text, while innovative, does not explicitly mention biomes or natural systems.

In general, many legal professionals—including judges, prosecutors, lawyers, and legislators—use terms such as biome, ecosystem, biogeography, and natural system interchangeably without understanding their scientific distinctions or legal implications. This lack of clarity can weaken the interpretation of environmental laws, particularly in cases that require a technical understanding of landscapes and ecological interactions.

While the term "biome" designates a large ecological unit characterized by climatic, phytophysiological, and faunistic features, its use in legal documents is not always accompanied by a clear definition. Similarly, legal documents use other ecological concepts at random, without clear justification. For example, although the concept of biome was created at the beginning of the 20th century, its hegemonic use in Brazil did not occur until 2004, after the publication of the Biome Map. Studies on the territorial delimitation of biomes were carried out by institutions dedicated to scientific research on territory and environmental public management, such as the Brazilian Institute of Geography and Statistics (IBGE) and the Ministry of the Environment (MMA), which coordinated this project.⁶⁰

In 2018, a report was published on cartographic delimitation of Brazilian biomes, based on studies conducted in 2004.⁶¹ According to technical information, for the cartographic consolidation of Brazilian biogeographical formations, delimitation into biomes was chosen. Thus, within the scope of the IBGE, it became necessary to establish a broad understanding of the concept of biome and its possible correlations

⁶⁰ Instituto Brasileiro de Geografia e Estatística – IBGE, *Mapa de biomas e de vegetação do Brasil* (IBGE, 2004).

⁶¹ Instituto Brasileiro de Geografia e Estatística – IBGE, *1º Workshop sobre Representação de Biomas Compatível com a Escala 1:250.000: Diretrizes para Definição de Limites* (IBGE, 2018).

with other phytogeographical concepts adopted in the old vegetation map for the 2004 version.⁶² In the conceptual orientation, the biome was defined as a biotic unit of greater geographical extent, comprising several communities at different evolutionary stages, each named after the dominant vegetation type.⁶³

Thus, in the Map of Biomes of Brazil, the territories delimited as biomes were defined by distinct characteristics that guided the classification of the six territories now recognized as Brazilian biomes. Among these characteristics, we highlight that the biome was classified as a set of vegetation types identifiable at the regional scale, along with their associated flora and fauna. They also considered the predominant physical conditions, whether climatic, lithological, geomorphological, or pedological, marked by a shared evolutionary history. The biomes should also exhibit unique biological diversity, distinguishing them from adjacent biomes.

In general, the adopted concept of biome prioritizes territories defined by contiguous, identifiable vegetation types on a regional scale, with similar geoclimatic conditions and a shared history of change, resulting in their own biological diversity.⁶⁴ We can argue that this definition is partially compatible with Coutinho's concept, which holds that biomes should constitute contiguous regional blocks, excluding discontinuous areas.⁶⁵ This definition can be understood, in a way, as a facilitator for territorial management, as it considers large contiguous areas, unlike the Vegetation Map of Brazil, published in 1988 by IBGE, which was based on phytophysionomies and therefore featured discontinuous areas. However, given the complexity of the concept of the biome, we can argue that this choice continues to spark debate, especially given doubts about the fragility of defining it within legal instruments.

However, legal documents issued before the biome map use different concepts to describe ecological formations, such as ecosystems, biogeographical systems, ecoregions, and others. For instance, the term "biome" did not appear in the 1988 Constitution, which instead referenced "Natural Heritage" and "ecosystem" without defining them in detail. It was only with the 2012 Forest Code that the term "biome" began to be used as a basis for rules protecting native vegetation, which must follow different standards for each Brazilian biome. By varying land-use and

⁶² IBGE, *1º Workshop*.

⁶³ Fundação Estadual de Engenharia do Meio Ambiente – FEEMA, *Conceitos Básicos de Meio Ambiente* (FEEMA/Petrobras, 1990).

⁶⁴ IBGE, *Mapa de biomas*.

⁶⁵ Coutinho, "O conceito de bioma," 60.

conservation standards and applying different percentages to areas designated as “legal reserve” (for conservation purposes), this regulation helped legitimize biogeographical differences, making certain biomes a higher conservation priority while prioritizing others for agricultural use. One reason for using the term “biome” was the publication of the Map of Brazilian Biomes in 2004. Nevertheless, there appears to be no clear legal definition of the concept, and at times, legal professionals are confused about the consistent application of various ecological terms.

Thus, our main argument is that legal professionals generally use ecological concepts, since the legislation itself does not define them, and these concepts are often complex and can be interpreted differently in ecology. This is an interesting point because, within ecological ideas, there is no single dominant concept but rather a variety of ideas that interact without a fixed paradigm. For example, Coutinho defines the biome broadly, emphasizing its ecological and geographical foundations and including territories larger than 1 million square kilometers. In this geographic space, the ecological base is represented by a uniform environment, characterized by macroclimate, phytophysognomy (formation), soil, and altitude—considered essential elements for characterizing various continental environments.⁶⁶

This conceptualization, even with different perceptions and variations of Clements’ original concept (1916), is generally accepted in ecological science. However, it is rarely understood adequately by legal professionals. Many see the biome only as an administrative boundary, ignoring the interactions that define its systemic functioning. Therefore, in addition to a more comprehensive view of the biome, other perspectives emphasize its dynamic and evolutionary nature. As a result, the biome is also seen as a living biological entity that retains links to its evolutionary past but is constantly changing, shaped by and valued in relation to large-scale ecological and biogeographical phenomena.⁶⁷

The lack of differentiation in the legal field reflects a broader epistemological issue: the absence of dialogue between science and environmental law. When legal professionals do not fully understand ecological concepts, they tend to limit regulatory interpretation to geographic or administrative levels, ignoring the ecological interdependencies that maintain biome integrity. This gap hampers the protection of natural areas by limiting legal protection to the territorial level, rather than addressing the systemic dynamics that sustain ecological health.

⁶⁶ Coutinho.

⁶⁷ Mucina, “Biome,” 921.

The interpretive challenge is heightened by the fact that the 1988 Constitution, while marking a milestone in recognizing the environment as a fundamental right, neither addresses nor incorporates ecological concepts in its definitions. An important historical point to highlight is the social role of Brazilian legislation in protecting nature. This is because the 1988 Constitution influenced Brazilian social awareness, establishing standards for harmonious coexistence with nature. This constitutional principle was reflected in various legal provisions, creating one of the most comprehensive and up-to-date environmental protection systems worldwide. However, Brazilian law does not provide a specific definition of biomes or natural systems as constitutional foundations.⁶⁸

This regulatory omission creates a legal vacuum, leading to fragmented and inconsistent interpretations that obstruct the uniform enforcement of environmental regulations nationwide. The Brazilian environmental regulatory system was designed to coordinate among various federal entities, but it lacks a unified conceptual foundation regarding what should be protected.⁶⁹ As a result, there are complex administrative uncertainties about how to protect nature in Brazil. For instance, the National Environmental Policy Act aims for a management approach that preserves all natural resources in a cohesive, comprehensive manner, ideally functioning as an integrated environmental protection system. However, cooperation among federal entities and the legal authority of environmental resolutions have proven inadequate to prevent environmental degradation in the country.

This analysis emphasizes that the effectiveness of environmental law relies not only on legal tools but also on an interdisciplinary understanding that combines science and legal practice. Legal professionals still lack a strong foundation in ecology, geography, and environmental sciences, as evidenced by their oversimplified interpretation of key concepts essential to protecting biomes. Brazil has complex and comprehensive environmental laws, but they often fall short in practice, either due to institutional failures or a lack of political commitment, resulting in a strong legal framework that is not very effective.⁷⁰

Therefore, the discussion about legal professionals' understanding of ecological concepts is more than mere terminology; it is vital to effective environmental pro-

⁶⁸ Milaré, *Direito do ambiente*, 12th ed.

⁶⁹ Rosa and Guarda. "A Política Nacional," 57–74.

⁷⁰ Édís Milaré, *Direito do ambiente: a gestão ambiental em foco – doutrina, jurisprudência, glossário*, 13th ed. (Revista dos Tribunais, 2021).

tection in Brazil. Legal professionals need to adopt sound scientific principles and foster interdisciplinary dialogue to support judicial decisions, public policies, and regulations that align with the country's ecological complexity. Merging science and law is both a challenge and a necessity for improving environmental governance and protecting key biomes, such as the Cerrado.

Final Remarks

The analysis presented in this article shows that the historical and conceptual trajectory of the term “biome” was crucial to the scientific and political valorization of the Cerrado, enabling its gradual inclusion in the Brazilian legal system. Initially understood only as a vegetation formation, the Cerrado came to be recognized as a complex ecological system with multiple phytophysiognomies and is essential for maintaining the country's hydrological and climatic balance. This theoretical evolution, supported by authors such as Clements,⁷¹ Whittaker,⁷² Coutinho,⁷³ and Mucina,⁷⁴ was decisive in transforming the Cerrado into an object of public policies and specific legal protection.

In the regulatory field, the 1988 Federal Constitution was found to mark a watershed, enshrining the environment as a fundamental third-generation right and a structuring principle of the economic and social order. However, despite advances provided by the Constitution and sub-constitutional legislation, such as the National Water Resources Policy (1997), the Environmental Crimes Act (1998), the National System of Conservation Units (2000), and the New Forest Code (2012), the effectiveness of Brazil's environmental legal framework remains limited in the face of pressure from agricultural expansion, predatory exploitation, and institutional fragility. This finding confirms Milaré's diagnosis that the country's environmental legislation is complex and comprehensive but lacks practical effectiveness.⁷⁵

However, the limitation of regulatory effectiveness stems not only from institutional factors but also from the lack of a solid scientific understanding among legal professionals—judges, prosecutors, lawyers, and legislators—of fundamental concepts in ecology and biogeography. Many of these professionals use the terms biome,

⁷¹ Clements, “Nature and Structure,” 79–84.

⁷² Whittaker, *Communities and Ecosystems*.

⁷³ Coutinho, “O conceito de bioma,” 60.

⁷⁴ Mucina, “Biome,” 921.

⁷⁵ Milaré, *Direito do ambiente*, 12th ed.

ecosystem, and biogeographical system interchangeably, ignoring their theoretical distinctions and legal implications. This imprecision compromises the interpretation and application of environmental regulations, reducing ecological protection to a merely territorial dimension.

According to Coutinho, a biome should be understood as a broad ecological unit that integrates macroclimate, soil, phytophysiology, and altitude, representing a uniform type of environment.⁷⁶ Although it is well established in ecological science, this concept is rarely incorporated into legal hermeneutics. The 1988 Federal Constitution, despite being innovative in recognizing the right to an ecologically balanced environment, does not expressly mention biomes or natural systems, creating an interpretive gap and weakening ecological protection, as Milaré observed.⁷⁷

This lack of a regulatory definition contributes to the fragmentation of environmental policies, leading to divergent interpretations of the scope of protection for certain territories. The lack of conceptual clarity is also reflected in the actions of administrative bodies and courts, which frequently decide without considering the ecological interdependence among biogeographical systems. According to Mucina, the concept of biome is dynamic and evolves as science advances, reinforcing the need for continuous dialogue between scientific and legal knowledge.⁷⁸

The integration of science and law is indispensable to strengthening environmental governance and improving the effectiveness of public policies. Rosa and Guarda highlight that although the SISNAMA was conceived as an instrument of integrated management, the coordination among the federative entities and the practical application of the norms remain insufficient to contain environmental degradation.⁷⁹

Given this scenario, it is concluded that protecting the Cerrado and other biomes requires more than legislation alone: it demands interdisciplinary technical training and systemic interpretation by legal professionals to integrate legal and scientific knowledge. Overcoming this barrier involves integrating environmental and ecological education into law courses, establishing interdisciplinary centers to provide technical support to the courts, and fostering dialogue among scientists, jurists, and public administrators.

⁷⁶ Coutinho, "O conceito de bioma," 60.

⁷⁷ Milaré, *Direito do ambiente*, 12th ed.

⁷⁸ Mucina, "Biome," 921.

⁷⁹ Rosa and Guarda, "A Política Nacional," 57–74.

Finally, the Cerrado stands at a historic crossroads: on the one hand, it has gained scientific, legal, and political recognition as a strategic biome; on the other hand, it faces accelerated degradation that threatens its ecological integrity and compromises essential environmental services. Protecting the Cerrado must be seen as a collective and intergenerational commitment, in accordance with the constitutional principles of human dignity, the socio-environmental function of property, and solidarity between generations.

Only from this integrated perspective, in which science and law mutually recognize each other, will it be possible to transform the existing legal framework into effective practice, ensuring that the Cerrado, a natural heritage of inestimable value, is preserved as a legacy for future generations.

Acknowledgments

The author and research coordinator, Sandro Dutra e Silva, thanks the National Council for Scientific and Technological Development (CNPq) for supporting the research project on the Brazilian Cerrado.

References

- Boaventura, Karina J., Carlos M. Silva, and Sandro Dutra e Silva. "Building Soil Fertility: Embrapa and the Agronomic Development for the 'Conquest' of the Brazilian Cerrado (1975–95)." *Historia Agraria* 89 (2023): 247–78. <https://doi.org/10.26882/histagrar.089e08b>.
- Brasil. "Constituição da República Federativa do Brasil de 1988." *Diário Oficial da União*. Brasília, October 5, 1988.
- Brasil. "Lei nº 9.433, de 8 de janeiro de 1997. Institui a Política Nacional de Recursos Hídricos." *Diário Oficial da União*. Brasília, January 9, 1997.
- Brasil. "Lei nº 9.605, de 12 de fevereiro de 1998. Dispõe sobre as sanções penais e administrativas derivadas de condutas lesivas ao meio ambiente." *Diário Oficial da União*. Brasília, February 13, 1998.
- Brasil. "Lei nº 9.985, de 18 de julho de 2000. Regulamenta o art. 225, §1º, incisos I, II, III e VII da Constituição Federal, institui o Sistema Nacional de Unidades de Conservação da Natureza." *Diário Oficial da União*. Brasília, July 19, 2000.
- Brasil. "Lei nº 12.651, de 25 de maio de 2012. Dispõe sobre a proteção da vegetação nativa." *Diário Oficial da União*. Brasília, May 28, 2012.

- Brock, Rebecca Catherine, Andy Arnell, Will Simonson, Aline C. Soterroni, Aline Mosnier, Fernando Ramos, et al. "Implementing Brazil's Forest Code: A Vital Contribution to Securing Forests and Conserving Biodiversity." *Biodiversity and Conservation* 30 (2021): 1621–35. <https://doi.org/10.1007/s10531-021-02159-x>.
- Césaro, Silvana Gino Fernandes de, Antonio Cezar Leal, and Sandro Dutra e Silva. "Vegetação e Legislação Ambiental: Estudo de Regularização de Passivos Ambientais Aplicado No Município de Ipiranga de Goiás – Goiás, Brasil." *Fronteiras: Journal of Social, Technological and Environmental Science* 13, no. 1 (2024): 244–68. <https://doi.org/10.21664/2238-8869.2024v13i1.p244-268>.
- Clements, Frederic E. "Nature and Structure of the Climax." *Journal of Ecology* 37, no. 1 (1949): 79–84. <https://doi.org/10.2307/2256278>.
- Colinvaux, Paul. *Ecologia: a busca de princípios*. São Paulo: Edgard Blücher, 1993.
- Coutinho, Leopoldo Magno. "O conceito de bioma." *Anais da Academia Brasileira de Ciências* 78, no. 4 (2006): 60–66. <https://doi.org/10.1590/S0102-33062006000100002>.
- Costa, Raphael Melazzo de Faria, Sandro Dutra e Silva, and Eumar Evangelista de Menezes Júnior. "A Interseção Entre Legística E Princípios Ambientais: Caminhos Para a Criação De Normas Sustentáveis Efetivas." *Fronteira: Journal of Social, Technological and Environmental Science* 13, no. 4 (2024): 354–68. <https://doi.org/10.21664/2238-8869.2024v13i4.p354-368>.
- Dajoz, Roger. *Ecologia geral*. São Paulo: Vozes, 1973.
- Dutra e Silva, Sandro. "Challenging the Environmental History of the Cerrado: Science, Biodiversity and Politics on the Brazilian Agricultural Frontier." *HALAC – Historia Ambiental Latinoamericana y Caribeña* 10, no. 1 (2020): 82–116. <https://doi.org/10.32991/2237-2717.2020v10i1.p82-116>.
- Dutra e Silva, Sandro. "Lessons from the Brazilian Cerrado: Technological Achievements and Environmental Challenges." *ReVista: Harvard Review of Latin America*. Last modified September 13, 2025. <https://revista.drclas.harvard.edu/lessons-from-the-brazilian-cerrado-technological-achievement-and-environmental-challenges/>.
- Fundação Estadual de Engenharia do Meio Ambiente. *Conceitos Básicos de Meio Ambiente*. Rio de Janeiro: FEEMA/Petrobras, 1990.
- Horta, Regina. "O Lobo Andarilho: Coexistência E Conflitos No Cerrado Brasileiro." *Historia Ambiental Latinoamericana y Caribeña (HALAC) Revista de la Solcha* 15, no. 2 (2025): 138–62. <https://doi.org/10.32991/2237-2717.2025v15i2.p138-162>.
- Instituto Brasileiro de Geografia e Estatística. *1º Workshop sobre Representação de Biomas Compatível com a Escala 1:250.000: Diretrizes para Definição de Limites*. Rio de Janeiro: IBGE, 2018.
- Instituto Brasileiro de Geografia e Estatística. *Mapa de biomas e de vegetação do Brasil*. Rio de Janeiro: IBGE, 2004.

- Kan, Siyi, Jing Meng, U. Martin Persson, Bin Chen, Samuel A. Levy, Elise Mazur, et al. "Identifying Global Hotspots of Agricultural Expansion into Non-Forest Ecosystems." *Nature Communications* 16 (2025): 10739. <https://doi.org/10.1038/s41467-025-65769-x>.
- Lins, Carlos Frederico, Samuel Nunes Moreira, Thiago F. S. Leitão, and Aline Nogueira Almeida. "Código Florestal Brasileiro: 1965–2012, da Ditadura à Democracia." *Revista Foco* 15, no. 6 (2022): e589. <https://doi.org/10.54751/revistafoco.v15n6-019>.
- MapBiomass. *Relatório Anual do Desmatamento no Brasil 2024*. São Paulo: MapBiomass, 2025.
- Melazzo de Faria Costa, Raphael, Eumar de Menezes Júnior, Lucas Bevilacqua Cabianca Vieira, and Sandro Dutra e Silva. "El medio ambiente desde múltiples perspectivas: interfaces entre derecho, política y sociedad para la conservación ambiental y el desarrollo sostenible." *Novum Jus* 19, no. 2 (2025), 287–327. <https://doi.org/10.14718/NovumJus.2025.19.2.10>.
- Menezes Junior, Eumar Evangelista de, Sandro Dutra e Silva, Mayana Ribeiro Oliveira, and Carlos Henrique Conde Silva. "Meio Ambiente, Políticas De Inovação E Tecnologia: Relações E Correlações Nos Últimos Dez Anos No Brasil." *Fronteira: Journal of Social, Technological and Environmental Science* 13, no. 1 (2024): 213–26. <https://periodicos.unievangelica.edu.br/index.php/fronteiras/article/view/7175>.
- Milaré, Édis. *Direito do ambiente: a gestão ambiental em foco – doutrina, jurisprudência, glossário*. 12th ed. São Paulo: Revista dos Tribunais, 2020.
- Milaré, Édis. *Direito do ambiente: a gestão ambiental em foco – doutrina, jurisprudência, glossário*. 13th ed. São Paulo: Revista dos Tribunais, 2021.
- Ministério do Meio Ambiente e Mudança do Clima (MMA). "Institucional – Quem é Quem: Missão e Competências." *Portal Gov.br*. Accessed December 02, 2025. <https://www.gov.br/mma/pt-br/aceso-a-informacao/institucional-quem-e-quem>.
- Moura, Netanel de Carvalho Gomes, Clecia Simone Gonçalves Rosa Pacheco, and Gina Gouveia Pires de Castro. "Evolução Histórica da Legislação Ambiental no Brasil." In *Direito, Meio Ambiente e Ecologia Humana: Contribuições para a Sustentabilidade Socioambiental*, vol. 1, 173–88. São Paulo: Editora Científica Digital, 2023. <https://doi.org/10.37885/230412713>.
- Mucina, Ladislav. "Biome: Evolution of a Crucial Ecological and Biogeographical Concept." *New Phytologist* 222, no. 1 (2019): 97–114. <https://doi.org/10.1111/nph.15609>.
- Nascimento, Rayssa Kelly de Oliveira, Geórgia de Abreu Barbosa Reis, Marcelo Henrique Pereira dos Santos, Alvany Maria dos Santos Santiago, and Bruno Cezar Silva. "Crimes Ambientais Durante o Governo Bolsonaro (2018–2022)." *Id on Line – Revista de Psicologia* 17, no. 66 (May 2023): 423–42. <https://doi.org/10.14295/idonline.v17i66.3786>.
- Nehring, Ryan. "Yield of Dreams: Marching West and the Politics of Scientific Knowledge in the Brazilian Agricultural Research Corporation (Embrapa)." *Geoforum* 77 (2016): 206–17. <https://doi.org/10.1016/j.geoforum.2016.11.006>.

- Odum, Eugene P. *Fundamentals of Ecology*. 3rd ed. Philadelphia: W. B. Saunders, 1971.
- Oliveira, Mariana Martins de, Adriano Lago, Carolina de Mattos Nogueira, Glenio Piran Dal' Magro, and Camila Weber. "Análise das Modificações Decorrentes da Reformulação do Código Florestal." *Caderno Pedagógico* 21, no. 9 (2024): e761. <https://doi.org/10.54033/cadpedv21n9-056>.
- Pimenta, Paula. "Berço das águas: Cerrado tem recursos hídricos pressionados pelo desmatamento." *Senado Federal*. Last modified March 15, 2024. <https://www12.senado.leg.br/noticias/infomaterias/2024/03/berco-das-aguas-cerrado-tem-recursos-hidricos-pressionados-pelo-desmatamento>.
- Ribeiro, José Felipe, and Bruno Machado Teles Walter. "Fitofisionomias do bioma Cerrado." In *Cerrado: ambiente e flora*, edited by S. M. Sano and S. P. Almeida, 87–166. Planaltina: Embrapa-CPAC, 1998.
- Rocha, Carlos B., Carlos de Majo, and Sandro Dutra e Silva. "A Geo-historical Analysis of Expanding Soybean Frontiers in the Brazilian Cerrado." *Historia Ambiental Latinoamericana y Caribeña (HALAC) Revista de la Solcha* 12, no. 2 (2022): 217–52. <https://doi.org/10.32991/2237-2717.2022v12i2.p217-252>.
- Rodrigues, Ariane A., Marcia N. Macedo, Divino V. Silvério, Leandro Maracahipes, Michael T. Coe, Paulo M. Brando, et al. "Cerrado Deforestation Threatens Regional Climate and Water Availability for Agriculture and Ecosystems." *Global Change Biology* 28, no. 2 (2022): 6807–22. <https://doi.org/10.1111/gcb.16386>.
- Rodrigues, Ariana do Rosário, and C. J. Matavelli. "As Principais alterações Do Código Florestal Brasileiro." *Revista Brasileira De Criminalística* 9, no. 1 (2020): 28–35. <https://doi.org/10.15260/rbc.v9i1.300>.
- Rosa, Marcelo Rodrigues and Eduardo Carlos Guarda. "A Política Nacional do Meio Ambiente e seus desdobramentos institucionais." *Revista de Direito Ambiental* 24, no. 94 (2019): 57–74.
- Sawyer, Donald, Beto Mesquita, Bruno Coutinho, Fábio Vaz de Almeida, Isabel Figueiredo, Ivana Lamas, et al. *Ecosystem Profile: Cerrado Biodiversity Hotspot*. Washington D.C.: Critical Ecosystem Partnership Fund, 2016.
- Shelford, Victor E. *Bio-ecology*. New York: Wiley, 1939.
- Silva, Ivan. *Crimes Ambientais e Juizados Especiais*. 3rd ed. Curitiba: Juruá, 2021.
- Soares-Filho, Britaldo, Raoni Rajão, Marcia Macedo, Arnaldo Carneiro, William Costa, Michael Coe, et al. "Cracking Brazil's Forest Code." *Science* 344, no. 6182 (2014): 363–4. <https://doi.org/10.1126/science.1246663>.
- Stevanato, Mayra, Ana Paula Colavite, and Mauro Parolin. "Protección de los Bosques Brasileños - Contexto Histórico y Actual de la Política Pública Ambiental Brasileña." *Élise – Revista de Geografia da UEG* 11, no. 2 (2022): e112226. <https://doi.org/10.31668/elisee.v11i02.13089>.

- Strassburg, Bernardo B. N., Thomas Brooks, Rafael Feltran-Barbieri, Alvaro Iribarrem, Renato Crouzeilles, Rafael Loyola, et al. "Moment of Truth for the Cerrado Hotspot." *Nature Ecology & Evolution* 1 (2017): 0099. <https://doi.org/10.1038/s41559-017-0099>.
- Testolin, Roberto, Fábio Attorre and Borja Jiménez-Alfaro. "Global Distribution and Bioclimatic Characterization of Alpine Biomes." *Ecography* 43, no. 6 (2020): 779–88. <https://doi.org/10.1111/ecog.05012>.
- Walter, Heinrich, and Eugene O. Box. *Biology of Ecosystems*. London: Edward Arnold, 1976.
- Whittaker, Robert H. *Communities and Ecosystems*. New York: Macmillan, 1971.