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REVISIONES

Classification systems for secondary forests in four neotropical countries: Synthesis and conceptual analysis

Sistemas de clasificación de bosques secundarios en países tropicales: una síntesis y análisis de conceptos

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ABSTRACT

A forest successional stage classification system is an important tool for forest management and ecosystem protection. This review aimed to compare the legal definitions and classifications of primary and secondary forests adopted by four tropical countries: Brazil, Argentina, Panama, and Costa Rica. Two socio-economic and four structural criteria were established and compared among the countries. Only Argentina clearly underpins its ratings with scientific studies, and only in this country do social groups participate in the development of the law. Brazil and Argentina had the highest number of parameters to differentiate forest types. According to our findings, we encourage all countries to update their legal systems based on scientific information and include popular participation in the discussion. This would reduce conflicts of interest and allow for a better reconciliation of forest conservation and sustainable development.

Keywords: classifications of forests, four tropical countries, socio-economic criteria, structural criteria.

RESUMEN

Una herramienta importante para la gestión forestal y la protección de los ecosistemas es un sistema de clasificación de etapas de sucesión forestal. En esta revisión, nuestro objetivo fue comparar las definiciones y clasificaciones legales de bosques primarios y secundarios adoptadas por cuatro países tropicales: Brasil, Argentina, Panamá y Costa Rica. Se establecieron y compararon entre países dos criterios socioeconómicos y cuatro estructurales. Solo Argentina sustenta claramente sus calificaciones en estudios científicos y solo en este país participan grupos sociales durante la elaboración de la ley. Brasil y Argentina presentaron el mayor número de parámetros para diferenciar tipos de bosques. De acuerdo con nuestros hallazgos, alentamos a todos los países a actualizar sus sistemas legales, basados en información científica e incluir la participación popular en la discusión, reduciendo los conflictos de interés y permitiendo conciliar mejor la conservación forestal y el desarrollo sostenible.

Palabras clave: clasificaciones de bosques, cinco países tropicales, criterios socioeconómicos, criterios estructurales.

INTRODUCTION

Currently, it is estimated that 58 % of the total forest cover on the planet is composed of naturally regenerating forests (FAO 2015). Between 2000 and 2012, there was a negative balance in global forest coverage, resulting in a reduction of an estimated 1.5 million km² of forest area, with tropical and subtropical regions experiencing the greatest proportional losses (Hansen *et al.* 2013). Potentially, at least part of these areas will be subject to the establishment of native vegetation, leading to the formation of secondary forests in the coming years (Hansen *et al.* 2013).

Important initiatives, such as the Bonn Challenge launched in 2011 to restore 150 million hectares of degraded areas, the formulation of the Aichi Biodiversity Targets (SCDB 2010), and the development of guidelines for sustainable management of secondary forests in tropical countries (ITTO 2002), have been introduced in the past. These efforts reflect the hope that the regeneration of natural forests can play a crucial role in restoring or maintaining ecological balance in highly degraded or threatened tropical ecosystems, while also directly benefiting the livelihoods of millions of people who depend on these forests (Chazdon 2014). To achieve these objectives, there

is a strong emphasis on the development of appropriate public policies related to land usage and management. This emphasis aims to ensure the effective conservation and maintenance of biodiversity and ecosystem services in human-modified tropical landscapes (HMTL) through the sustainable use of landscape resources, especially secondary forests (MacDicken *et al.* 2015).

However, the efficacy of appropriate measures and management guidelines depends fundamentally on clear definitions and delineations of secondary forests (Chokkalingam and Jong 2001, Chazdon *et al.* 2016). These definitions should account for the high structural, taxonomic, and functional heterogeneity of HMTLs. In addition to management, objective classifications of secondary vegetation can aid in monitoring efforts and conservation actions related to its biodiversity and ecological functions (ITTO 2002). Therefore, secondary vegetation can be classified based on different criteria associated with its nature, such as type and intensity of disturbance (Chokkalingam and Jong 2001), physiognomic characteristics, indicator species, and stages of secondary succession (Siminski *et al.* 2013).

Given the importance of secondary forests in the contemporary environmental context, this study aims to compare the classification and definition systems of primary and secondary forest vegetation used by certain tropical countries in accordance with their respective forest laws governing management practices.

METHODS

We selected four tropical countries with a successional stage classification system, meaning they have forest legislation that classifies or differentiates between primary and secondary forests, to explore the similarities and differences between them. While we acknowledge the presence of numerous tropical countries worldwide, the selected nations share a common biogeographic history within the same continent and similar biomes (*i.e.* tropical forest). By limiting our scope, we can delve deeper into the specific characteristics, patterns, and dynamics within these regions. We utilized a structured model to describe the classification systems of each country, providing context to their current environmental legislation and its alignment with the adopted forest classifications and definitions. A comparative analysis, utilizing six predetermined criteria, was conducted to assess the evaluated forest classification systems. Socioeconomic criteria consist of elements that define the legal principles related to the classification, management, exploitation, and utilization of native forests (see table 1). Conversely, structural criteria aim to employ objective elements in forest legislation to characterize the aspect, composition, and structure of forests.

Given that environmental laws and their applications are influenced by diverse social, historical, cultural, economic, and environmental factors, it is expected that forest classification systems and definitions may vary signifi-

Table 1. Criteria used to compare the forest classification / definition systems used in Brazil, Argentina, Panama, and Costa Rica.

Criterios utilizados para comparar los sistemas forestales de clasificación / definición forestal utilizados en Brasil, Argentina, Panamá y Costa Rica.

Dimension	Criterion	Description	Parameter
Socioeconomic	Impact on management permission	It reveals whether the classification of vegetation directly or indirectly impacts the development of forestry activities by the private or public sector.	Direct: there are restrictions on the use of forests according to their category / typology. Indirect: there are no restrictions on the use between forest categories / typologies.
	Participation of social groups	It assesses whether there was participation of social groups in the development of the classification of forest typologies adopted in each country.	Presence / absence.
Structural	Year of publication	Indicates whether the classification / definition of forest terms is recent.	Recent: < 10 years since its publication, considering the year in which this study was conducted (*e.g.* 2019).
	Technical sampling guidelines	It considers whether the forestry legislation provides specific norms on vegetation sampling to determine its structure.	Presence / absence of: inclusion criteria (dbh, H); sampling effort; and / or error limit.
	The basis for scientific studies	If the classification / definition of forest typologies is based on scientific studies.	Presence / absence.
	Forest classification parameters	Consider the number of qualitative and quantitative parameters used in the classification / differentiation of forest typologies.	Basal area, average height, average DBH, number of individuals, indicator species, understory, among others.

dbh: diameter breast height; H: height.

cantly between countries. Therefore, the implementation of standardized criteria was crucial for the execution of the present study and for the examination of similarities and differences among the evaluated systems.

ANALYSIS OF FOREST CLASSIFICATION SYSTEMS

Brazil (Atlantic Forest). Brazil possesses specific environmental legislation tailored to the country's distinct ecosystems, referred to as biomes by IBGE (2012). Here, we focus on the Atlantic Forest, as this biome is governed by specific national legislation (Law N° 11,428 2006; Resolution CONAMA N° 4 1994a). Our attention is directed towards the Resolution of the National Council for the Environment for the State of Santa Catarina (Resolution CONAMA N° 4 1994a), which outlines definitions and classifications of primary and secondary forests across three successional stages. This choice is motivated by the fact that all the states encompassing the Atlantic Forest within their territories have resolutions aimed at classifying primary and secondary forests using the same variables, though qualitative and quantitative parameters may vary. Santa Catarina is entirely covered by Atlantic Forest, and the state's classification has been the subject of studies assessing its applicability and efficiency (Siminski and Fantini 2007, Siminski *et al.* 2013). Moreover, Santa Catarina stands out as one of the most well-studied areas, with a continuous Forest Inventory publishing data since 2007.

The Atlantic Forest Law (Law Nº 11,428 2006) delineates permissible land uses and stipulates the percentage of forest cover that can be removed in each fragment based on its successional stage. The law explicitly prohibits the removal of native vegetation classified as primary, except in specific instances of public utility, scientific research, and preservationist practices. Conversely, native secondary vegetation in advanced and medium stages, contingent on their territorial context (urban or rural area), can undergo partial removal for certain purposes subject to authorization from the competent environmental agency.

In Santa Catarina, the vegetation classification is defined by CONAMA Resolution No. 4 of 1994 (Resolution CONAMA N° 4 1994a), later validated by CONAMA Resolution No. 388 of 2007 (Resolution CONAMA N° 388 2007). According to the Resolution, primary vegetation is characterized as having maximum local expression, substantial biological diversity, and minimal anthropic influence, to the extent that it does not significantly alter its original structure and species characteristics. Threshold values for structural characteristics of primary forests are defined as mean basal area greater than 20.00 m^2 ha^{-1}, mean diameter at breast height (dbh) exceeding 25 cm, and mean total height surpassing 20 m. Conversely, secondary or regenerating vegetation emerges from natural succession processes subsequent to the complete or partial removal of primary vegetation due to anthropic actions or natural causes, with the possibility that trees remain from primary vegetation.

CONAMA Resolution encompasses a significant number of benchmarks, particularly of a qualitative nature (table 2). This implies a high degree of complexity when determining the succession stage of a forest. It requires consideration of the basal area, average height, and average diameter of the forest community, along with various parameters determined subjectively due to their qualitative nature (physiognomy, forest strata, understory, litter, biological diversity, epiphytes, and vines). However, despite this complexity, there is no evidence that the proposed classification was based on scientific studies that support the adopted reference parameters. Moreover, it lacks technical guidelines for vegetation sampling and determining quantitative parameters (Siminski *et al.* 2013), potentially complicating the practical application of the classification.

Table 2. Analysis of structural and conceptual criteria related to the classification of forest typologies established by CONAMA Resolution No. 4 of 1994 for the state of Santa Catarina, Brazil.

Análisis de criterios estructurales y conceptuales relacionados con la clasificación de tipologías forestales establecidas por la Resolución CONAMA N° 4 de 1994 para el estado de Santa Catarina, Brasil.

Structural criteria		
Year of publication		1994
Technical sampling guidelines		Absent
Basis for scientific studies		Absent
Parameters to differentiate forest categories	Quantitative	3
	Qualitative	8
Conceptual criteria		
Impact on management permission		Direct
Participation of different social groups	In the legislation	Present
	In the classification	Absent

In the literature, certain studies have sought to evaluate the applicability of the CONAMA classification in specific federal states, examining whether the existing classifications effectively distinguish forests in different succession stages (Siminski *et al.* 2013). Overall, these studies revealed numerous inconsistencies related to vegetation sampling, indicator species, and the reference values established for each stage.

Among the 17 CONAMA resolutions that delineate the successional stages of the Atlantic Forest in each Brazilian federal state, only the resolution for Paraná standardizes the inclusion criterion as a vegetation sampling guideline (Resolution CONAMA N° 2 1994b). The absence of this guideline may compromise the effectiveness of the classification since the calculation of quantitative parameters depends on the chosen inclusion criterion. The Siminski's 2013 studies confirm this issue by employing different inclusion criteria in samples to determine the successional stage of forest fragments with known ages in Santa Catarina. In these studies, fragments of the same age were classified into different stages based on the adopted criterion, resulting in significant differences in calculated values of basal area, average height, and average diameter between the criteria. Consequently, the classification of a forest in a particular stage can be manipulated by the chosen criterion, rendering it inconsistent with its intended purpose.

Argentina (Provinces of Salta and Chaco). In Argentina, the current legislation concerning native forests is primarily embodied in National Law No. 26,331/2007, commonly referred to as the "Ley Forestal" (Law N° 26,331 2007). This law encompasses the principles of protection, management, use, restoration, and enrichment related to native forests and their ecosystem services. According to the second article of this law, native forests are defined as "natural forest ecosystems composed predominantly of native tree species, with several species of flora and fauna associated with the environment — soil, subsoil, atmosphere, climate, water resources — forming an interdependent system with its own characteristics and multiple functions, which in their natural state provide a condition of dynamic balance and supply of natural resources with the possibility of economic use".

Among the objectives outlined in the National Law, the Territorial Ordering of Native Forests (TONF) stands out as the primary conservation measure for native forests across the provinces of the country. TONF categorizes native forests into three conservation classes, based on ten technical and social criteria for environmental sustainability. This classification determines the level of protection and possible uses for the classified remnants. According to the Law, cutting native forests in categories I and II, corresponding to areas of high and medium conservation value, is prohibited. Conversely, forests in categories II and III may be subject to sustainable management, facilitated by public and / or private initiatives. This involves the development of management plans that adhere to minimum requirements for the protection and maintenance of environmental services.

Upon the enactment of the Law in 2007, each province was responsible for developing its TONF within one year. For this review, TONFs from the provinces of Chaco (Law N° 6,409 2010) and Salta (Provincia de Salta 2008) were selected due to their predominantly forested vegetation and subtropical climate, making them the most detailed TONFs among the northern Argentine provinces (Collazo *et al.* 2013). In the province of Chaco, TONF prohibits the suppression of forests in category I, allows the removal of up to 70 % of the vegetation in category II, and permits the removal of 50 to 90 % of vegetation in category III, contingent on their size (Law N° 6,409 2010). Concerning the province of Salta, removal of forests classified in category I is prohibited, sustainable use is allowed in category II, and forests in category III can be entirely removed (Law N° 7,543 2008).

The Law stipulates that TONFs must undergo periodic updates every 5 years (Law N° 26,331 2007). However, as of the present study, the provinces highlighted have not yet completed the full update of their TONFs. The only modification, involving the alteration and inclusion of areas in category I, was implemented in 2013 by Law 7,238 in the province of Chaco (Law N° 7,238).

Unlike most "traditional" classifications adopted by other countries, the Argentine method does not rely on structural reference values, such as basal area, height, or average diameter of individual plants in a given forest. Instead, it is based on a diverse range of scientific studies (table 3). Furthermore, this classification explicitly considers various sectors of society, including indigenous and peasant communities.

The diversity of criteria employed (social, environmental, and economic) has resulted in the formulation of highly heterogeneous TONFs among the provinces. Additionally, some provinces have allowed the use or alteration of forests in categories I and II, contrary to the principles established by the Ley Forestal. Figueroa (2018) highlighted this heterogeneity in the 23 TONFs produced until 2017, demonstrating the varied use and interpretation of sustainability criteria in each province. The author presented TONFs that utilized only three of the ten requested criteria, in contrast to those that incorporated eight or ten criteria in their formulation. This heterogeneity is evident in the forest zoning maps when analyzed collectively, revealing a lack of integration and coherence among provincial cartographies (Schmidt 2015).

The participatory process in the formulation of TONFs also proved to be contradictory in certain provinces, such as Córdoba (Silvetti *et al.* 2013) and Salta (Seghezzo *et al*. 2011). During the creation of the bill aimed at developming the TONF in Córdoba, participating social actors divided themselves into two groups with conflicting interests. One group was represented by rural and political entities ad-

Table 3. Analysis of structural and conceptual criteria related to the classification of forest typologies established by Law 26,331 of 2007 and by the Territorial Ordering of Native Forests of the provinces of Salta and Chaco, Argentina.

Análisis de criterios estructurales y conceptuales relacionados con la clasificación de tipologías forestales establecidas por la Ley 26.331 de 2007 y por el Ordenamiento Territorial de Bosques Nativos de las províncias de Salta y Chaco, Argentina.

Structural criteria		
Year of publication		2008
Technical sampling guidelines		Absent
Basis for scientific studies		Yes
Parameters to differentiate forest categories	Quantitative	4
	Qualitative	6
Conceptual criteria		
Impact on management permission		Direct
Participation of different social groups	In the legislation	Present
	In the classification	Present

vocating for the expansion of agribusiness and livestock, while the other comprised peasant, academic, and social organizations with shared interests, such as the valorization of peasant communities and the sustainable management of native forests (Silvetti *et al.* 2013). The discussions primarily focused on which uses would be allowed in forests with medium conservation value (category II).

In turn, the approval of Law No. 9,814 of 2010, which established the TONF in Córdoba (Law N° 9,814 2010), introduced a contradictory concept of "sustainable use", considering activities for livestock purposes, such as the suppression of the understory and introduction of exotic species, as sustainable practices. This demonstrates the influence exerted by the livestock-industrial sector during the creation of the bill, highlighting the political power of these social actors in incorporating their interests into the legislation, neglecting the participatory process and the rights and interests of other more vulnerable social groups, such as peasants (Silvetti *et al.* 2013). In Salta, the TONF creation process was also affected by conflicts of interest between representatives of different sectors and social groups, with leaders from aboriginal communities attesting that the participatory process was "useless", and that their proposals were ignored by the authorities (Serghezzo *et al.* 2011).

Panama. Panama's forestry legislation is primarily constituted by "Law Nº 1 de 3 de febrero de 1994" (Panama 1994), responsible for the protection, conservation, improvement, education, research, management, and rational use of the country's forest resources. According to this law, natural and planted forests on government lands belong to the State Forest Heritage, and are subject to its regulations. These forests are divided into categories that determine their possible uses, such as protection forests (preservation of ecosystem services), production forests (sustainable management and use, through a state concession), and special forests (social, scientific, historical, cultural, educational, tourist or recreational values).

To manage the use of forest resources in Panama, the Law created the "Instituto Nacional de Recursos Naturales Renovables" (INRENARE), currently called "Autoridad Nacional del Ambiente" (ANAM), responsible for the application and compliance with jurisdictions regarding forests. In 1998 INRENARE created the "Resolución de Junta Directiva 05 de 1998" (INRENARE 1998), where the legal requirements for any use of forests in private properties or the State Forest Heritage are defined.

This resolution establishes the definitions of forest terms, covering degraded, natural, primary, secondary, and *rastrojo* (pioneer) forest. According to the resolution, primary forest is a forest formation that has not been altered by the direct action of man, especially by extraction of forest products, such as wood, palm hearts, and others. Secondary forest is defined as a forest cover that develops naturally after the total or partial disappearance of vegetation, whose characteristics, in terms of composition and size, are different from the tree cover that has been replaced. It is a plant formation consisting of woody, shrub, and tree species, is represented by fast-growing pioneer species, and may contain dispersed trees of various sizes and species.

The Law stipulates that in areas of the State Forest Heritage, any activity involving the cutting or burning of vegetation is prohibited, except in concessions or in production forests. In private or legal properties, logging is permitted in agricultural areas without prior authorization, but it requires authorization if the area is of primary or secondary natural forest. It should be noted that, according to Resolution 5 of 1998, once a forest exceeds 5 years of age and reaches an average height of 5 meters, it is considered secondary and no longer pioneer (rastrojo), becoming subject to restrictions for its suppression in private properties.

Published in 1998, the forest definitions governed by specific legislation in Panama are primarily conceptual, with limited characterizations of the elements that make up each forest typology, such as vegetation life forms and anthropic influence. Quantitative parameters are introduced only in the pioneer vegetation category called rastojo, corresponding to the age and height of the forest fragment. The concepts and reference values used in the descriptions apparently do not demonstrate a basis in scientific studies, considering this criterion is absent in this classification. Nor do the laws provide norms on vegetation sampling, as structural parameters such as average diameter and basal area are not required in the classification of forests (table 4).

In the 1980s, to safeguard the ecological services provided by riparian vegetation along the Panama Canal, the country underwent a brief period of complete restriction on clearing forests in response to the high deforestation rates recorded in the Canal region in the preceding decades (Whelan 1988). The prohibition on cutting any forest over 5 years old in the national territory was imposed in 1987 by Resolution Nº 0013 of 1987 (INRENARE 1987), remaining in effect for 5 years from its publication.

Carse (2012) notes that rural landowners and farmers recall this period with disdain, during which the ban adversely affected itinerant agriculture, a widely practiced method by rural communities in the Canal region. For these communities, secondary forests play a crucial role in colonize newly harvested areas to restore soil fertility, persisting for at least ten years until they are cleared for a new harvest. However, rural landowners began to reduce the cutting cycle of secondary forests to a maximum of 5 years, aiming to avoid the loss of a productive area due to the cutting prohibition. Consequently, the shortened cutting cycles may have contributed to increased soil erosion and sedimentation on the banks of the channel, countering the intentions of the prohibition (Carse 2014).

Costa Rica. The legal framework for the forestry sector in Costa Rica is primarily outlined in Forest Law No. 7,575 of 1996 (Decreto Ejecutivo Nº 27,998 1996). This legislation emerged in the fragile environmental context of the 1990s, responding to decades of high deforestation rates in the county (Morse *et al.* 2009), and reflecting its strong conservationist orientation. According to this law, forest land and natural forests under public administration fall under the category of State Natural Heritage (PNE) and are under the jurisdiction of the Ministry of Environment and Energy (MINAE) for administration.

The PNE encompasses areas with various levels of protection, including national parks, biological reserves, mangroves, protected areas, national wildlife refuges, forest reserves, natural monuments, and wetlands, as well as properties on behalf of municipalities or public institutions. As outlined in Forest Law, PNE forests cannot be suppressed or exploited, with a few exceptions for low-impact activities such as research, training, and ecotourism, subject to approval by MINAE. Natural forests on private properties can be converted to restricted uses with authorization from the State Forestry Administration (SFA), specifically for scientific, preventive, and ecotourism purposes. It is prohibited to convert or exploit forests on private properties for any other use. For such cases, the formulation of a management plan, signed by a certified professional in the sector, is mandatory and must be submitted for approval by the SFA.

Following the enactment of the Forest Law in 1996, MINAE issued Executive Decree Nº 25,721 to provide detailed regulations (Decreto Ejecutivo Nº 25,721 1997). This decree established the National Forest Certification Commission (NFCC) with the objective of developing principles, criteria, and sustainability indicators mandated in the management plans for private properties. Compliance with these parameters became obligatory for evaluation

Table 4. Analysis of structural and conceptual criteria related to the classification of forest typologies established by Resolution No. 5 of 1998, Panama.

Análisis de criterios estructurales y conceptuales relacionados con la clasificación de tipologías forestales establecidas por la Resolución No. 5 de 1998, Panamá.

Structural criteria		
Year of publication		1998
Technical sampling guidelines		No
Basis for scientific studies		No
Parameters to differentiate forest categories	Quantitative	2
	Qualitative	1
Conceptual criteria		
Impact on management permission		Direct
Participation of different social groups	In the legislation	Present
	In the classification	Absent

by the SFA. In the following years, NFCC published decree Nº 27,388 (Decreto Ejecutivo Nº 27,388 1998) outlining ten sustainable principles of forest management and certification; decree Nº 27,998 (Decreto Ejecutivo Nº 27,998 1999) which established the legal definition of secondary forest, specifying criteria and indicators for this vegetation; and the Decree Nº 39,952 (Decreto Ejecutivo Nº 39,952 2016) which provided criteria and indicators for the sustainable management of secondary forests and forest certification. According to these resolutions and the Forest Law, any area of vegetation that falls under the "Forest" category is legally protected from cutting or utilization, whether in public or private areas.

The Forest Law introduced general concepts for the classification of forests in Costa Rica, consolidating the country's forest typologies into two main categories: "forest" and "secondary forest". Law 7,575 of 1996 defines "forest" as a native or autochthonous ecosystem, whether degraded or not, regenerated through natural succession or other forestry techniques. It occupies an area of two or more hectares, characterized by the presence of mature trees of varying ages, species, and sizes, with one or more canopy layers covering more than seventy percent (70 %) of the surface, and with more than sixty trees per hectare of fifteen or more centimeters in diameter measured at breast height (dbh).

In contrast, a "secondary forest" is defined as an area with woody vegetation of secondary successional character that arises once the original vegetation has been eliminated by human activities and / or natural phenomena. These areas have a minimum surface area of 0.5 hectares and maintain a density of no less than 500 trees of any species per hectare, with a minimum dbh of 5 cm. This definition also includes land devoid of woody vegetation that is voluntarily registered with the State Forestry Administration to promote natural succession process Moreover, land with secondary forest immediately after use in a regeneration cutting system is incorporated, as stipulated in the Standards of Sustainability for the Management of Secondary Forests (SINAC 2021).

The primary variable distinguishing the two forest categories is the density of arboreal individuals, which are sampled within a pre-established inclusion criterion. There is no explicit mention of the use of scientific studies in establishing the reference values for these parameters, indicating an absence of this criterion in the formulation of the classification (Navarro and Thiel 2007). The classification process can be considered of low complexity and high objectivity due to the limited number of forest categories and parameters used in their description (table 5).

In general, studies evaluating the impact of the prohibition imposed by Law No. 7,575 of 1996 on forest cover changes in specific regions of the country indicate significant reductions in deforestation and conversion of mature forests after 1996 (Morse *et al.* 2009). According to Fagan *et al.* (2013), deforestation bans may provide better protection for mature forests compared to older forest regrowth and may be more effective in restricting clearing for large-scale crops than for pasture. However, there has been a reduction in secondary vegetation, herbaceous cover, and shrubby pioneer vegetation, suggesting that the ban has not contributed to a greater establishment of naturally regenerated forests. On the contrary, the ban may have prompted a decrease in these areas, particularly considering the practices of ranchers and farmers who regularly clear secondary forests and herbaceous and shrubby pioneer vegetation to avoid legal protection, thereby preserving their right to use the area (Sierra and Russman 2006).

From a more technical standpoint, it is noteworthy that the sole parameter used to differentiate secondary and primary forests in Costa Rican legislation is the density of individuals by size class. However, this parameter is directly influenced by several factors other than the age of the fo-

Table 5. Analysis of structural and conceptual criteria for the classification of forest typologies established by Executive Decree No. 27,998, Costa Rica.

Análisis de criterios estructurales y conceptuales para la clasificación de tipologías forestales establecidas por Decreto Ejecutivo N° 27.998, Costa Rica.

Structural criteria		
Year of publication		1999
Technical sampling guidelines		Yes
Basis for scientific studies		No
Parameters to differentiate forest categories	Quantitative	1
	Qualitative	0
Conceptual criteria		
Impact on management permission		Direct
Participation of different social groups	In the legislation	Present
	In the classification	Absent

rest, such as species composition, climatic variables, soil type, topography, and anthropic influences, rendering it a highly heterogeneous variable in tropical forests (Clark and Clark 2000). For instance, in northwestern Costa Rica, tropical forests in the La Selva region exhibit varying densities of individuals in response to variations in soil type and topography, with higher densities in sloping areas with ultisols compared to flat areas with gleisols (Clark and Clark 2000). This variability renders the density of individuals an unreliable indicator of the successional stage or age of a forest, with other parameters, particularly basal area, typically demonstrating more distinct patterns associated with the dynamics of secondary succession (Siminski *et al.* 2013).

Therefore, the classification employed by Costa Rica may lack effectiveness in accurately distinguishing primary and secondary forests, relying solely on one structural parameter that, in turn, may be inconsistent and thereby impede appropriate and effective discernment. The inclusion of additional parameters, such as basal area, could improve the current classification.

YEAR OF PUBLICATION AND BASIS OF SCIENTIFIC STUDIES

All the rating systems analyzed were published 10 or more years prior to 2019. Half of them originated in the 1990's, as is the case with Brazil, Panama, and Costa Rica. These classifications have not been updated since their initial publication.

In recent years, a significant amount of scientific information and ecological data on global biodiversity has been generated, facilitated by the development and use of methods and technologies enabling the acquisition of large amounts of data, such as large-scale continuous inventories and remote sensing techniques (Vibrans *et al.* 2013). Therefore, the information utilized to formulate classifications of primary and secondary forests by the studied countries may be outdated, as they lack the contributions of more recent research on the ecology and current conservation status of forests.

In this context, Argentina stands out as the only country that justifies the parameters and variables used in classifications based on scientific information. The Argentine federal government mandates regular updates of the classifications formulated by the provinces within 5 years, addressing the issue of using outdated information. In contrast, the forestry legislation of the other studied countries lacks references to the origin of the parameters and values adopted to differentiate one forest typology from another.

The lack of a scientific basis for classifications of forest typologies suggests that the parameters used to differentiate these categories were established generically, with inflexible and arbitrary reference values. Given that the analyzed classifications are intended for tropical or subtropical forests, the generalization of these parameters and values may lead to inefficient classification of forest categories, as it does not consider the complex heterogeneity of these environments.

Therefore, establishing forest classifications based on scientific studies that investigate the composition, structure, and ecology of forests can provide more appropriate and flexible parameters and values tailored to the specific characteristics of a given phytophysiognomy. This approach can result in more accurate classifications, offering a closer representation of the reality of these ecosystems.

FOREST CATEGORIES

A wide variety of parameters were identified to differentiate forest categories, with structural quantitative parameters standing out at higher frequencies, such as basal area and average canopy height. The classifications and definitions utilized by Brazil and Argentina employ a greater number of parameters for differentiation (10), while Panama and Costa Rica use up to three parameters each, generally quantitative in nature.

The use of qualitative parameters for forest classification can introduce greater subjectivity into the process of differentiation between categories compared to the use of quantitative parameters, which are measured objectively. This subjectivity may hinder the identification of clear patterns between these categories.

The analysis of criteria results reveal that the majority of parameters utilized by Brazil and Argentina are qualitative, subject to subjective interpretation by those who determine them. In Brazil, the *in situ* classification of a forest directly impacts its management or cutting possibilities. In Argentina, forest categorization occurs on a regional scale, by provinces, based on economic, social, and environmental variables. Therefore, the potential bias introduced by subjectivity in the use of qualitative parameters manifests differently in these contexts. In Argentina, this is evident in cartographic maps showing the conservation categories with incongruous and disconnected zoning between the provinces. This results from different provinces classifying similar or contiguous forests into different categories. In Brazil, implications arise from professionals using field classification, potentially leading to the classification of the same forest in different stages of succession based on different interpretations of qualitative parameters.

IMPACT ON MANAGEMENT PERMISSIONS

Forestry classifications, as analyzed in this study, arise from diverse socio-economic, political, and environmental landscapes. These contextual variations significantly influence how each country determines the scope of forest management and regulates vegetation cutting. In the countries studied, the classification of a forest into established categories dictates the potential for management and cutting.

However, the practical implications of stringent policies can be contentious, affecting both biodiversity conservation

and the livelihoods of communities reliant on forest resources, particularly small-scale farmers and indigenous populations. Excessive restrictions on forest use, with limited allowances for management or low reference thresholds for forest protection, can be detrimental to rural communities. These communities may face limitations in managing parts of their forests or be compelled to adopt costly management plans, directly jeopardizing their economic stability.

In response to these restrictions, some communities have taken preemptive measures by clearing vegetation in its early stages, thereby avoiding categorization as protected forests and preserving their right to utilize these resources. This phenomenon has been observed among rural populations in Panama (Carse 2012), Costa Rica (Sierra and Russamn 2006), and even in Brazil, as reported by Siminski and Fantini (2007) in Santa Catarina. In Brazil, small-scale farmers have expressed frustration due to restrictions imposed on forests in medium and advanced stages of regeneration, hindering traditional agricultural practices.

The suppression of vegetation areas in early stages by rural populations can negatively impact forest conservation in HMTLs. However, there are cases where restrictive forest use policies are accompanied by policies that encourage forest protection on private properties, helping to mitigate the potential negative impacts of the restriction. An example is Costa Rica and its policy of paying for environmental services provided by forests on private properties (Morse *et al.* 2009).

Effective resolution of conflicts between rural populations and forest use restrictions can also be achieved through the incorporation of specific uses for secondary vegetation in legally established classifications, aligning with the subsistence needs of these communities. Despite ongoing conflicts within the Brazilian Atlantic Forest, the Atlantic Forest Law acknowledges the possibility of agricultural, livestock, and silvicultural uses of secondary vegetation by traditional populations and small producers in cases of essential subsistence (Law N° 11,428 2006). Given the diverse socio-economic and environmental contexts that shape forest management policies, it is advisable for countries with tropical forests to engage in collaborative, science-based efforts involving multiple stakeholders, including local communities, to design classifications that balance the imperatives of biodiversity conservation with the sustainable livelihoods of those reliant on forest resources.

ROLE OF SOCIAL GROUPS IN THE CLASSIFICATION OF FOREST CATEGORIES

The analysis of the involvement of different social groups is centered solely on the formulation and legal establishment of forest category classifications. Concerning the adverse consequences of policies restricting forest use, the social groups most significantly impacted are those reliant on the forest for survival, as observed in countries where the participation of these groups was not taken into account during the classification development process. If representatives of these groups were actively involved in the formulation of forest classifications, the ensuing impacts could be properly discussed and possibly avoided or reduced.

Despite the acknowledgement of these groups in the primary forest legislation documents of all studied countries, only Argentina actively incorporated the participation of diverse social groups in the development of their forest category classifications. However, studies investigating the participatory processes in specific provinces have revealed instances where this involvement was questionable, vulnerable to the influence of conflicts of interest and political-economic polarizations among representatives, as exemplified by the case of Córdoba and Salta (Seghezzo *et al.* 2011, Silvetti *et al.* 2013). In the context of Brazil, the consulted scientific literature attributes some of the issues arising from classifications to the absence of a participatory process involving different social groups during its formulation (Siminski *et al.* 2013), emphasizing the importance of considering these groups in the implementation of such policies.

CONCLUSIONS

The analysis of forest classification systems revealed significant variations among countries, rooted in a diverse range of qualitative and quantitative parameters. The utilization of standardized criteria in our investigation unveiled commonalities within these systems. It became apparent that many of these classifications were shaped by concepts, parameters, and definitions of forest terminology lacking robust scientific foundations, making them prone to subjective interpretations, particularly due to the overemphasis on qualitative parameters in certain instances. Furthermore, the meaningful engagement of various relevant social groups in the formulation of these systems was largely absent.

It is essential that other ecosystems and forest typologies also develop their classification systems based on successional stages for improved land use management. The importance of this approach lies in fostering a comprehensive understanding and management of these ecosystems, potentially leading to more effective conservation and sustainable utilization practices. This classification not only facilitates communication and collaboration among various stakeholders, including scientists, policymakers, and local communities, but also enhances the collective effort toward environmental stewardship and sustainable development.

In light of the aforementioned context, the significance of developing and implementing precise forest classification systems, grounded in scientific insights into forest ecology and characterized by inclusivity that recognizes the constraints faced by local communities and farmers in their forest management practices, becomes paramount. Such an approach is crucial for fostering mutual contributions to environmental preservation and sustainable development, especially in human-modified tropical landscapes. Achieving

a comprehensive and integrated perspective within these classification systems can be realized through several key mechanisms, including the utilization of up-to-date scientific knowledge pertaining to forest ecology, the establishment of robust conceptual frameworks and differentiation parameters among categories, and the active involvement of diverse social groups and sectors of society. This approach, in theory, holds the promise of enhancing existing classifications and creating more favorable conditions for attaining long-term objectives in environmental restoration and conservation within tropical forest countries.

AUTHOR CONTRIBUTIONS

ALG and FFP designed the study. FFP wrote the first draft and KF revised the manuscript.

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