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Knowledge Management Practices and Ecological Restoration of the Tropical Dry Forest in Colombia

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Abstract: Ecological restoration is considered a nature-based solution to reduce ecosystem degradation, biodiversity loss, and combat climate change. In this sense, the objective of this study was to identify the knowledge management practices that are present in an ecological restoration process in the tropical dry forest. The empirical study was developed using a mixed approach over an area of 11,079 ha in Huila, Colombia. At first, the qualitative study was supported by a documentary review and participant observation between 2018 and 2020. On the other hand, the quantitative study was carried out through the application of the Delphi method with the participation of 64 experts. Twenty-two knowledge management practices were identified with orientation towards human factors, organization, information technologies, strategy, and intellectual protection. These findings show that all the knowledge management practices identified have an impact on the six components of the ecological restoration process (planning, diagnosis, implementation, monitoring, participation, and consolidation). Likewise, these practices contribute to the generation, transformation, and mobilization of local and scientific knowledge in the components of the ecological restoration process of the tropical dry forest.

Keywords: biodiversity conservation; forest management; social-ecological system; forest recovery; El Quimbo Hydroelectric Plant; Delphi method

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1. Introduction

Ecological restoration is defined as the process of assisting in the recovery of an ecosystem that has been degraded, damaged, or destroyed [1,2]. The practice of ecological restoration is identified by the integration of ecological knowledge (generated from scientific and local ecological knowledge), with practical knowledge obtained in the fields of restoration, botany, zoology, agronomy, seed production, soil and water management, engineering, landscaping, conservation management, and planning, among others [3]. Thus, restoration is an interdisciplinary strategy where scientific and traditional knowledge is articulated to respond to ecosystem management processes [4]. Furthermore, ecological restoration is a rapidly growing field that is advancing in both theory and practice [5]. Ecological restoration is gaining momentum globally, becoming a relevant international policy issue in the environmental sector [6], and is recognized worldwide as a key component of conservation programs; it is essential for the pursuit of long-term sustainability [7].

Various international agreements are encouraging different countries to implement large-scale ecological restoration to halt and reverse damage to ecosystems and help adapt to climate change [8]. One example of these ecological restoration initiatives is the Bonn Challenge, which proposed the restoration of 350 million hectares worldwide by 2030. On the other hand, the 20 × 20 Initiative aims to change the dynamics of land degradation in Latin America and the Caribbean by restoring 20 million hectares. Since 2014, Colombia has been linked to these global ecological restoration initiatives, committing to the restoration of one million hectares of degraded forest land [9]. Under the National Plan of Development, or PND 2018–2022, Colombia proposed implementing a national ecosystem restoration strategy over 301,900 ha land area and planting 180 million trees. Moreover, the National Restoration Plan called for the restoration of one million hectares by 2035 [8].

Furthermore, while the definition of ecological restoration targets is a good first step, the implementation of commitments continues to present difficulties. In this regard, there are growing concerns that several ambitious ecological restoration initiatives are not meeting key objectives of carbon sequestration, biodiversity restoration, and sustainable livelihoods [10]. Despite the rapid increase in knowledge about ecological restoration, the ability to scale up ecological restoration processes to a meaningful scale requires additional capacities that have yet to be developed or disseminated [8].

Knowledge management enables individuals, teams, and organizations, as well as networks, regions, and nations, to collectively and systematically create, share, and apply knowledge to achieve their strategic and operational objectives [11]. It is difficult to find a sector that has not embarked on a project or program to improve the use of knowledge within its organizations [12]. In this sense, the operational part of knowledge management is knowledge management practices (KMPs). KMPs are a series of activities undertaken in an organization aimed at improving the effectiveness and efficiency of organizational knowledge resources [13,14]. Studies on KMPs have recently been conducted in several countries such as India [15,16], Indonesia [17], Pakistan [18,19], and Colombia [20,21], in areas such as aerospace, telecommunications, construction, consumer goods, agriculture, health, environment, and nuclear energy, among others [12].

Despite the global relevance of ecological restoration and the incidence of knowledge management in different sectors and processes, there is still no evidence of specific empirical studies on KMPs associated with the components of the ecological restoration process. KMPs are presented as an opportunity that seeks to ensure key knowledge and generate learning processes and practices that promote the reduction of operational errors due to a lack of knowledge of the activity [22–24]. Because ecological restoration is a long-term process that can sometimes involve people from several generations, it is useful to identify and develop KMPs that can help to reduce the risk associated with staff turnover and retirement, as well as to transfer this knowledge to other components of the ecological restoration process.

Dry forests are considered among the most threatened ecosystems worldwide, due to transformation for agriculture and other uses [25–27]. The characteristics of the dry forest are due to low rainfall—with values between 400 and 800 mm—or its location in more humid environments but on calcareous coral and serpentine substrates, generating habitats with high biodiversity and endemicity [28]. In Andean and Caribbean regions such as the Dominican Republic, there are different types of forest formations; primary forest develops in deep soils due to water loss and deforestation produces a secondary forest of lower altitudes [29]. Ninety-seven percent of the existing tropical dry forest area is at risk, due to factors such as landscape transformation, habitat fragmentation, and climate change, among others [30]. Tropical dry forest comprises a variety of ecosystem types, from open forests to dense forests that may be mostly or partially deciduous [31–33], 54.2% of the global extent of tropical dry forest is found in South America [30].

In Colombia, the tropical dry forest has undergone the greatest transformation, because approximately 90% of the original cover has been replaced by pastures and agricultural fields over the last century [34]. According to the categories established by the International Union for Conservation of Nature (IUCN), in the red list of ecosystems for Colombia, the tropical dry forest is critically endangered [35]. Through the Human Spatial Footprint Index, it was evidenced that, in Colombia, between 1970 and 2015, ecosystems considered under the critical category such as the tropical dry forest were most affected by a high level of human impact, especially in the Andean and Caribbean regions [36]. Additionally, the tropical dry forest has been declared a strategic ecosystem by the Ministry of Environment and Sustainable Development, Colombia, so it is considered a top priority for conservation and restoration [37]. Progress in ambitious ecological restoration strategies in Colombia's dry forests is one of the greatest challenges in the conservation of Colombia's natural heritage, because this ecosystem poses unique challenges for its restoration due to the limited availability of water, which is likely to be further accentuated by climate change [8].

The United Nations formulated the Sustainable Development Goals (SDGs) to achieve minimum levels of well-being and prosperity for people and the conservation of the environment by the year 2030. Specifically, SDG 15 proposes to sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss [38]. In recognition of the fundamental role of restoration in ecosystem health, the United Nations General Assembly declared the United Nations Decade for Ecosystem Restoration (2021–2030), which aims to increase the large-scale restoration of degraded and destroyed ecosystems as a measure to combat climate change and improve food security, water supply and biodiversity [39].

The success of the SDG 15 is linked to the capacity to effectively and efficiently implement ecological restoration of ecosystems worldwide [3]. For example, in Oregon, USA, the ecological restoration of rangeland ecosystems degraded by forest encroachment results in significant hydrological improvements and potential water savings [40,41] while maintaining the potential for ecosystem carbon sequestration [42]. It is considered that ecosystem restoration can also contribute to achieving other SDGs, such as those related to climate action (SDG 13), ending poverty (SDG 1), zero hunger (SDG 2), and clean water and sanitation (SDG 6).

The success of ecological restoration will depend on the combination of local ecological and scientific knowledge [43]. Integration of this knowledge can also contribute to adaptive management [44]. A lack of communication with stakeholders and incorporation of external knowledge sources into restoration can limit conservation outcomes [10]. Incorporating local ecological knowledge and knowledge management can contribute to building a strong partnership for the successful implementation of restoration projects and increase their social acceptance, economic viability, and ecological feasibility [44]. In the field of restoration, more has been published on the integration of local ecological knowledge and scientific knowledge [3,43–46], but little has been published on organizational knowledge management.

Knowledge in restoration projects presents different degrees of structuring, from dispersed and unconnected information to highly developed knowledge-based models. In this sense, the management of knowledge generated from community experience and scientific research can contribute to systematically schematize and recover ecological knowledge [47]. In addition, properly organized knowledge forms an information system of data covering various aspects of the ecosystem, available for use by the locals and the scientific community, in the short and long term [48]. Therefore, knowledge management practices (KMPs) create a framework that allows taking advantage of available resources for the conservation and recovery of ecosystems such as tropical dry forests.

Thus, the objective of this study was to identify the KMPs that are present in the development of an ecological restoration process in the tropical dry forest through the Delphi method. This is the first study conducted in Colombia on the KMPs present in the components of the ecological restoration process that contribute to the integration, incorporation, and effective exchange of local ecological knowledge and scientific knowledge applied in restoration. Finally, the study provides new leadership, management tools and techniques for the work teams in charge of ecological restoration.

The choice of the study object was determined after the exploration of the tropical dry forest ecosystem which has been moderately studied in the specialized literature, although little research has been carried out in the Latin American context, together with other variables such as the KMPs. Likewise, the El Quimbo Hydroelectric Plant presents interesting characteristics for its exploration, such as its extension (11,079 ha) and the timeframe proposed for its restoration process (20 years). On the other hand, this ecosystem has been the subject of different academic studies, and has been continuously monitored by different national, regional, and local authorities. The ecological restoration process began with a pilot phase where trials of different ecological restoration treatments were designed over an area of 140 ha for a period of four years (2014–2018). Based on the information obtained in the pilot phase, a second phase was formulated to scale up the ecological restoration process in the tropical dry forest to the rest of the 11,079 ha (2018–2038).

2. Materials and Methods

2.1. Research Area

The El Quimbo Hydroelectric Plant is located in the center of the department of Huila, in southern Colombia, in the valley of the Magdalena River, between the central and eastern mountain ranges, 70 km south of the capital, Neiva (2°15′56.032″ N; 75°40′40.8576″ W). It is located between the municipalities of El Agrado, Gigante, Garzón, Paicol, and Tesalia, in the equatorial zone, with a maximum operation level between 520 and 720 masl, creating warm tropical lakes [49]. The environmental compensation area and the ecological restoration of El Quimbo Hydroelectric Plant are located in the life zone of the tropical dry forest, with altitude ranges from 720 to 1500 m, while the temperature varies from 20 to 26 °C [50]. The rainfall regime is bimodal, with two recognized dry seasons from June–August and December–January, and rainfall varies from 900 mm in the southern sector to 1900 mm in the western sector of the area [51]. The tropical dry forest restoration process is carried out due to the subtraction of part of the Amazon forest reserve and the impact that the construction of the El Quimbo hydroelectric power plant generated on the natural vegetation. In other words, it is the repair of the El Quimbo Hydroelectric Power Plant that affected the ecosystem. It has been developed since 2014, with a comprehensive approach to the ecological restoration process.

The tropical dry forest under study contains great biodiversity and a high level of endemism of animal, plant and microbial species, providing a great variety of ecosystem goods and services to humans and associated species. The early successional stages are dominated by the grasses and herbaceous species *Brachiaria decumbens* Stapf, *Rhynchospora nervosa* Vahl, *Andropogon bicornis* L., *Digitaria* cf. *horizontalis* Will, *Hyparrhenia rufa* Nees and *A. bicornis* and to a lesser extent, low-growing cacti, as low-growing shrub elements are the *Acacia farnesiana* (L.) Willd., *Croton glabellus* L. and *Guazuma ulmifolia* Lam. In the intermediate successional stages, grasses of smaller extension and scattered shrub elements of *G. ulmifolia*, *A. farnesiana*, *Chloroleucon mangense* Jacq, *Machaerium capote* Dugand and *Pseudosamanea guachapele* (Kunth) Harms, as well as some trees typical of dry formations such as *Casearia corymbosa* Kunth, *G. ulmifolia*, *M. capote*, *Croton hibiscifolius Kunth* ex Spreng, *Guapira pubescens* Kunth are found. On the other hand, in the late successional stages, there are palms such as *Attalea butyracea* (Mutis ex L.f.) Wess.Boer and typical dry forest trees such as *Anacardium excelsus* (Bertero ex Kunth), *Spondias mombin* L., *M. capote*, *Maclura tinctoria* and *Bursera simaruba* (L.) Sarg in addition to a consolidated understory. Finally, its avifauna stands out, where the *Tyrannidae* (flycatchers) was the richest family with 27 species, followed by tanagers and related species (*Thraupidae*) with 19 species [52].

2.2. Research Methodology

2.2.1. First Research Stage

The study methodology followed a mixed approach. Firstly, we used a documentary review and participant observation conducted between 2018 and 2020 on the ecological restoration process of the tropical dry forest. Regarding the document review, a literature search was carried out in different databases (e.g., Scopus, 84 documents, and Web of Science, 125 documents), repositories (e.g., Latindex, 29 documents, and EBSCO, 33 documents), and search engines (e.g., Google Scholar, 231 documents), with the objective of obtaining information to elaborate a categorization of KMPs. The largest number of documents consisted of articles, working papers, and technical reports. The words used in the search were "tropical dry forest", "TDF", "KMPs", "knowledge management practices", and "ecological restoration". As for participant observation, this covered the end of the pilot phase and the beginning of the second phase, where information was collected from the community (center of the department of Huila), mainly through observation and interaction with its members, recording the most important aspects in field notes (qualitative data) that allowed the organization of the information according to the study objective.

Based on the information collected and systematized, five main categories of KMPs were identified, which are associated with (1) human factors orientation, (2) organization, (3) information technologies, (4) strategy, and (5) intellectual protection [53–55]. In addition, six components were established in the ecological restoration process that have been considered successful: planning, diagnosis, implementation, monitoring, participation, and consolidation [56,57]. With the information collected and categorized, a new phase was designed for the development of the KMP categories and the components of the ecological restoration process.

2.2.2. Second Research Stage

Secondly, a two-round Delphi process was conducted. The Delphi method involves a systematic and iterative process, aimed at generating opinions from a group of experts, whose objective is to improve informed decision making by enabling decision makers to plan based on a broad pool of knowledge, experience, and expertise [58,59]. One hundred experts belonging to four stakeholders in the ecological restoration process of the tropical dry forest (25 academy/researcher, 25 communities/NGOs, 25 public institutions, and 25 companies) were contacted by e-mail. The profile of the pre-selected experts was varied among university professors and researchers from research centers, experts in the subject matter of the study, members of public government institutions and environmental authorities, professionals and managers of companies and associations, members of communities and environmental NGOs, whose activities are related to ecological restoration processes of tropical dry forest and who have good general experience.

For the first round, an email was sent to each of the 100 experts initially identified, with the invitation note to participate in the research. A link was included to answer the questionnaire created online, in the Google Forms platform. This medium was preferred for the advantages of allowing rapid communication, wide coverage regardless of geographical location and easy response by the experts, in addition to offering a good guarantee of receipt and attention by the experts. For the second round, the questionnaire was sent only to the experts who responded in the first round. The first round was conducted in July 2020 and the second round was between August and September 2020. Sixty-four responses were received in the first round, while for the second round, 51 responses were received (Table 1).

Table 1. The response rate of the first and second rounds of the Delphi by stakeholder groups.

Group of Interest	Experts Participating in the First Round	% Experts Participating in the First Round	Experts Participating in the Second Round	% Experts Participating in the Second Round	% Response of the Second Round vs. the First Round
Academy/researcher	24	37.5%	20	39.2%	83.3%
Communities/NGOs	19	29.7%	18	35.3%	94.7%
Public institutions	11	17.2%	7	13.7%	63.6%
Companies	10	15.6%	6	11.8%	60.0%

All groups were equally weighted in the analysis of the responses. Finally, for the closed questions, experts were asked to rate the items using a five-point Likert scale (1 = low incidence and 5 = high incidence). The survey (Appendix A) was developed based on the information obtained in the pilot phase and following international guidelines for the construction of measurement instruments in the social sciences [60].

For the interpretation of the results on the KMPs presented in an ecological restoration process in the tropical dry forest, an evaluation in percentages related to the five categories of the Likert scale was established, between 0% and 100%. In this way, the following categories were established: low incidence between 0% and 19.9%, limited incidence between 20% and 39.9%, medium incidence between 40% and 59.9%, good incidence between 60% and 79.9%, and high incidence between 80% and 100%. Finally, the quantitative and qualitative analysis of the data were carried out using IBM SPSS 25 and ATLAS.Ti 8, respectively. In IBM SPSS 25, the mean, median and percentages of the responses of the groups of interest to the Likert scale were analyzed and then categorized into the levels of incidence described (e.g., low, medium, etc.). In ATLAS.Ti 8 the information collected in the participant observation was organized, analyzed and interpreted following each step of the theoretical coding (open, axial, and selective coding) to obtain descriptive codes that made it possible to create the five main categories of KMPs and the six components in the ecological restoration process.

3. Results

3.1. Documentary Review and Participant Observation

A total of 22 KMPs oriented to human factors, organization, information technology, strategy, and intellectual protection were identified and documented. A detailed description of the KMPs considering the practices obtained in this research (Human factor-oriented, organization-oriented, information technology-oriented, strategy-oriented, and intellectual protection-oriented) is presented in Appendix B. Furthermore, Table 2 shows each of the KMPs associated with the components of the ecological restoration process in the tropical dry forest.

Table 2. KMPs associated with the components of the ecological restoration process in the tropical dry forest.

Knowledge Management Practices	Components of the Ecological Restoration Process					
	Planning	**Diagnostic**	**Implementation**	**Monitoring**	**Participation**	**Consolidation**
Human factors oriented						
KMP1. Knowledge-based human resource management practices including recruitment, selection, renewal, and promotion based on knowledge (technical knowledge and traditional knowledge).	X	X	X	X	X	X
KMP2. Non-monetary mechanisms to encourage employees to share their knowledge (visitor services).					X	X
KMP3. Methodologies to foster knowledge sharing such as communities of practice, quality circles, improvement groups, self-managed teams, or their equivalents (groups or crews with experienced and novice personnel).		X	X	X		
KMP4. A training plan that encourages continuous employee learning (support for technological, professional, and post-graduate training).			X	X		X
KMP5. General training for employees, who then apply what they have learned in their regular work activities (training on different topics such as fire control, cartography, working at heights, seeds, nurseries, restoration, MIPE, HSL, ophidian accidents, etc.).		X	X	X	X	X

Table 2. *Cont.*

Knowledge Management Practices	Components of the Ecological Restoration Process					
	Planning	Diagnostic	Implementation	Monitoring	Participation	Consolidation
KMP6. Systems for measuring and evaluating employee competencies (annual competency assessment).			X	X		
KMP7. Supervisors support and encourage employees to learn and exchange in open and equal communication and with a critical approach to existing knowledge and process (managerial support).	X	X	X	X	X	X
Organization oriented						
KMP8. Systems to codify and make knowledge explicit (documentation of procedures, instructions, formats, reports, etc.).		X	X	X	X	
KMP9. Adopt a system of thinking that integrates diverse disciplines and knowledge in theory and practice.	X	X	X	X	X	X
KMP10. Strategies that motivate the members of the organization to: take risks, understand mistakes, learn to have freedom of action, understand the variation of the context, have a balance between skills and challenges, and actively exchange ideas and knowledge.			X	X	X	X
KMP11. Continuous improvement system for processes that have achieved the established quality standards (quality, environmental, occupational health, and safety management systems).			X	X		
KMP12. Encourage interdisciplinary work (relationship with companies, universities, and technology centers, as well as participation in scientific networks).	X	X	X	X	X	X
Information technology oriented						
KMP13. Technology systems are integrated and user-friendly, supporting knowledge work, business processes, and decision-making.		X	X	X	X	
KMP14. Data-driven management: the organization has access to appropriate data and analysis.		X	X	X	X	X
KMP15. Light and easily accessible communication channels to create knowledge communities.		X	X	X	X	X
Strategy oriented						
KMP16. Planning and implementation activities consider the knowledge and competency needs of the current and future organization.	X	X		X		

Table 2. *Cont.*

Knowledge Management Practices	Components of the Ecological Restoration Process					
	Planning	**Diagnostic**	**Implementation**	**Monitoring**	**Participation**	**Consolidation**
KMP17. Referencing techniques for the improvement of employees' skills (study, learn, and exchange experiences on the ecological restoration).	X		X	X	X	X
KMP18. Adaptive management is based on the observation and monitoring of extreme climatic, ecological, and social phenomena.			X	X	X	
KMP19. Approach and collaborate with stakeholders (conducting guided tours).			X	X	X	X
Intellectual protection oriented						
KMP20. Strategic knowledge is protected through a variety of formal and informal means such as patents, licenses, non-disclosure agreements, confidentiality agreements, and partner orientation.		X		X		
KMP21. Knowledge repositories (information management protocol) and scientific and informative publications.		X	X	X	X	X
KMP22. Integral information capture and processing system for the different processes.		X	X	X	X	

Among the most outstanding results, three KMPs which were not previously reported in the literature were identified, viz., KMP18—Adaptive management from observation and monitoring of extreme climate, ecological and social phenomena, KMP19—Approach and collaboration with stakeholder actors, and KMP21—Knowledge repositories (information management protocol) and scientific and dissemination publications (Table 2). In addition, four KMPs were identified as present in all components throughout the ER process: KMP1—Knowledge-based human resource management practices, including knowledge-based recruitment, selection, renewal, and promotions (technical and traditional knowledge); KMP7—Supervisors support and encourage collaborators to learn and exchange, in open and equal communication and with a critical approach to existing and process knowledge (managerial support); KMP9—Adopt a system of thinking that integrates various disciplines and knowledge in theory and practice; KMP12—Encourage interdisciplinary work (relationship with companies, universities, and technology centers, and participation in scientific networks).

On the other hand, another group of KMPs was found to be present in five of the ecological restoration components (KMP5, KMP14, KMP15, KMP17, and KMP21). In addition, some KMPs that are used in few components were identified as KMP2, KMP6, KMP11, and KMP20. The KMPs recorded in each component of the ecological restoration process were: monitoring with 21 KMPs, followed by implementation with 19 KMPs, participation with 16 KMPs, diagnosis with 14 KMPs, consolidation with 13 KMPs, and planning with 6 KMPs. It should be noted that in KMP1, local people over 65 years of age who lived in the area and have extensive traditional knowledge were involved in the ecological restoration process. Finally, KMP5 has promoted the training of local personnel involved in the ecological restoration process, with ongoing training on different topics such as forest fire control, cartography, working at heights, seeds, nurseries, restoration, occupational safety, and ophidian accidents.

3.2. Delphi Study

The experts were asked to rate the importance of KMPs on the six components of the ecological restoration process in the tropical dry forest. According to the results of the two rounds, there was consensus that KMPs are important for all six components of the ecological restoration process, with the monitoring component standing out in round 2 (M = 4.71), followed by the implementation component (M = 4.64), and then the planning component (M = 4.47). The median (Mdn = 5) was the same for all components except diagnosis and consolidation (Mdn = 4). Therefore, it can be affirmed that the experts' assessment of the KMPs in the components of the ecological restoration process is quite homogeneous, since there is low dispersion of data in all components, with the greatest dispersion in planning (0.76) and the least in implementation (0.56).

The experts were also asked to rate the six components of the ecological restoration process. The results indicated that all six components of the ecological restoration process were considered important, being well rated in both rounds, with the planning component (M = 4.94) standing out in round 2, followed by the monitoring (M = 4.74), and diagnostic (M = 4.71) components. On the other hand, the median (Mdn = 5) was the same in all components, as in round 1. Thus, the experts' assessment of the impact of the components of the ecological restoration process is quite homogeneous, since there is a low dispersion of data in all components in both rounds 1 and 2, with the highest dispersion in round 2 for participation (0.58) and the lowest for planning (0.24).

Finally, the experts were asked to identify which of the 22 KMPs distributed in the five categories could have an impact on each of the six components of the ecological restoration process. Incidence percentages were determined and averages were established for each KMP in the two rounds for each of the components. According to the results, there is agreement between the experts in the two rounds, where the 22 KMPs identified in the five categories have a medium and good impact on the components of the ecological restoration process (Table 3). The KMPs with the highest average weighting percentage in the two rounds were KMP12, KMP9, KMP15, and KMP14. Among the components with the highest incidence of KMPs in the two rounds are monitoring (good), implementation (good), and participation (medium). Among the 22 KMPs identified, 10 had good incidence (KMP3, KMP4, KMP7, KMP9, KMP10, KMP11, KMP12, KMP13, KMP14, and KMP15), and 12 presented medium incidence (KMP1, KMP2, KMP5, KMP6, KMP8, KMP16, KMP17, KMP18, KMP19, KMP20, KMP21, and KMP22) for the components of the ecological restoration process in the tropical dry forest.

Table 3. Association of the KMPs in the components of the ecological restoration process in the tropical dry forest.

Knowledge Management Practices	**Components of the Ecological Restoration Process**								
	Round	**Planning**	**Diagnostic**	**Implementation**	**Monitoring**	**Participation**	**Consolidation**	**Mean**	**Incidence**
Human factor-oriented									
KMP1	1	58%	58%	83%	75%	47%	36%	59%	Medium
	2	51%	39%	86%	69%	49%	29%	54%	Medium
KMP2	1	42%	41%	58%	52%	70%	53%	53%	Medium
	2	39%	35%	63%	59%	69%	37%	50%	Medium
KMP3	1	53%	55%	73%	70%	75%	55%	64%	Good
	2	47%	45%	67%	63%	80%	41%	57%	Medium
KMP4	1	50%	47%	80%	77%	64%	50%	61%	Good
	2	41%	39%	86%	80%	65%	51%	60%	Good
KMP5	1	39%	36%	84%	77%	70%	48%	59%	Medium
	2	35%	37%	80%	86%	69%	45%	59%	Medium
KMP6	1	48%	41%	66%	61%	42%	47%	51%	Medium
	2	37%	37%	73%	69%	49%	41%	51%	Medium
KMP7	1	45%	59%	77%	73%	75%	47%	63%	Good
	2	35%	49%	78%	82%	80%	37%	60%	Good

Table 3. *Cont.*

Knowledge Management Practices	Components of the Ecological Restoration Process								
	Round	Planning	Diagnostic	Implementation	Monitoring	Participation	Consolidation	Mean	Incidence
Organizationally-oriented									
KMP8	1	34%	42%	53%	67%	53%	55%	51%	Medium
	2	31%	43%	63%	67%	41%	43%	48%	Medium
KMP9	1	77%	75%	66%	63%	56%	50%	64%	Good
	2	82%	73%	71%	65%	61%	59%	68%	Good
KMP10	1	55%	53%	78%	75%	47%	50%	60%	Good
	2	63%	41%	76%	69%	53%	49%	58%	Medium
KMP11	1	53%	48%	73%	88%	59%	64%	64%	Good
	2	43%	39%	65%	92%	53%	61%	59%	Medium
KMP12	1	77%	80%	73%	78%	73%	66%	74%	Good
	2	73%	65%	73%	82%	82%	71%	74%	Good
Information technology-oriented									
KMP13	1	63%	59%	63%	91%	48%	50%	62%	Good
	2	59%	67%	63%	88%	53%	37%	61%	Good
KMP14	1	61%	64%	58%	92%	50%	53%	63%	Good
	2	63%	67%	69%	84%	35%	53%	62%	Good
KMP15	1	44%	53%	52%	77%	89%	63%	63%	Good
	2	47%	39%	55%	78%	88%	71%	63%	Good
Strategy-oriented									
KMP16	1	80%	55%	63%	47%	39%	47%	55%	Medium
	2	88%	47%	57%	47%	37%	47%	54%	Medium
KMP17	1	52%	42%	56%	41%	39%	42%	45%	Medium
	2	55%	35%	57%	51%	47%	45%	48%	Medium
KMP18	1	38%	44%	69%	88%	53%	56%	58%	Medium
	2	35%	45%	67%	94%	43%	55%	57%	Medium
KMP19	1	30%	30%	48%	56%	91%	59%	52%	Medium
	2	41%	41%	43%	61%	88%	61%	56%	Medium
Intellectual protection-oriented									
KMP20	1	47%	31%	48%	52%	48%	61%	48%	Medium
	2	45%	37%	51%	53%	41%	53%	47%	Medium
KMP21	1	47%	48%	52%	66%	52%	59%	54%	Medium
	2	33%	47%	51%	71%	55%	67%	54%	Medium
KMP22	1	42%	53%	61%	86%	47%	48%	56%	Medium
	2	47%	57%	69%	90%	47%	67%	63%	Good
Mean	1	52%	51%	63%	71%	58%	53%	58%	Medium
	2	50%	48%	64%	73%	57%	53%	58%	Medium
Incidence	-	Medium	Medium	Good	Good	Medium	Medium	Medium	-

4. Discussion

Twenty-two KMPs were identified and documented. Likewise, an approach to KMPs was formed based on a conceptual framework from the knowledge-based approach [61,62] and KMP categories [53,55,63]. On the other hand, regarding KMPs documented and categorized in other sectors and reported in the literature [12,16,19,64], they evidenced three KMPs that have been developed since 2014, suggesting that organizations seem to develop and implement new KMPs to stay updated and take advantage of structural and cultural change concerning their operating environments, supply chains, among others. Also, organizations may have practices that have developed and evolved [63]. These background studies suggest that KMPs, categorized in different ways, are linked to the components of the ecological restoration process, which evidences their importance and relevance to consider in their study and implementation.

Among the findings, a greater number of KMPs were identified in the monitoring (21 KMPs) and implementation (19 KMPs) components, possibly because these are the components with the longest duration (more than 6 years) throughout the process, while the planning component reports the lowest number (6 KMPs) and the shortest duration (less than 1 year). The results suggest that a long period of execution of the components of the ecological restoration process could favor greater development and appropriation of organizational culture, generation of new ideas, training programs, improvement of collaborators' competencies, management systems, and continuous improvement [20]. In the ecological restoration process in the tropical dry forest, local ecological knowledge related to forests was considered, since it is relevant for ecological restoration, particularly in each region [64]. Recognition of local knowledge [65] was also evident from the beginning of the ecological restoration process, as evidenced in KMP1, KMP2, and KMP5. Finally, in most of the components and activities throughout the ecological restoration process in the tropical dry forest, multiple contributions of local knowledge are evidenced.

Three KMPs were identified that had not been previously reported in the literature. Thus, KMP18, KMP19, and KMP21 are related to adaptive management, collaboration with stakeholders, and the use of knowledge. These KMPs have been identified in the tropical dry forest studied, so they are factors that cause management failure. Given this situation, it is necessary to act to avoid these errors in management models. Among these actions are the constant monitoring of climatic, ecological, and social phenomena, as well as early intervention to reduce their negative impact; community involvement and participation in management; scientific dissemination of the results obtained in the area for subsequent use by other researchers; as well as the development of guides and manuals for successful ecological reforestation.

The social component becomes a determinant where its participation should be taken as an advantage so that people perceive the importance of the ecological restoration process, noting different individual and group benefits. Thus, not only is the technical and methodological planning of an ecological restoration process sufficient, but a popular consultation process is also necessary to gather local knowledge and consider it during the execution, since the lifestyle of the inhabitants can be negatively affected, endangering the ecological restoration process [66].

Due to the diverse knowledge used in ecological restoration projects, adequate management is necessary. Knowledge management practices are presented as facilitating factors for a successful implementation of an ecological restoration project, from the identification of knowledge to its acquisition. Across the globe, knowledge management is a necessity for organizational and social functioning, since it is present in several vital processes for the current context of globalization, such as innovation, production of goods and services, technological development, scientific production, and the pharmaceutical industry. Development in the aforementioned fields will make it possible to address problems that affect humanity such as poverty, inequalities, inequity in education and, focusing on this study, the life of terrestrial ecosystems, climate action, clean water, and sanitation.

The incorporation of local knowledge and knowledge management can contribute to building a solid partnership for the successful implementation of ecological restoration and increase its social acceptance, economic viability, and ecological viability [44]. Likewise, it is considered that incorporating KMPs in ecological restoration processes, in addition to impacting their outcomes, also contributes to favoring the incorporation of local knowledge, generation of new knowledge, facilitating stakeholder participation, and promoting governance and innovation in the ecological restoration process. Furthermore, ecological restoration should also consider socio-economic aspects and the expectations of the various stakeholders, since ecological restoration is a human activity that, to achieve ecosystem recovery, requires solid ecological knowledge, establishing connections and multidisciplinary collaborations between ecologists, social scientists, and the various stakeholders [50].

The contribution of this study is threefold. Firstly, it expands the literature on ecological restoration process in the tropical dry forest, as studies on this type of ecosystem remain scarce; researchers have focused their attention on the benefits for tourism, as well as the relevance for sustainability, and little has been explored on the impact that KMPs can have. Secondly, it has not yet been studied what KMPs are present in the ecological restoration process in the tropical dry forest. Therefore, we developed a study in the El Quimbo Hydroelectric Power Plant, located in the life zone of the tropical dry forest in Colombia. Thirdly, it explores KMPs, intending to help the ecological restoration process, and those directly responsible for it to design strategies for nature-based solutions to reduce ecosystem degradation, biodiversity loss, and combat climate change for the benefit of people.

Finally, the results share the second edition of the ecological restoration standards, whose second principle sustains that ecological restoration should be based on different types of knowledge, since the practice of ecological restoration requires a high degree of knowledge that can be extracted from local ecological knowledge, practical professional experience, and new scientific discoveries. These forms of knowledge are the product of observation, experimentation, trial, and error, whether formal or informal. In addition, sharing practical and scientific knowledge is considered key to implementing restoration efficiently and effectively [64,67]. Because large-scale ecological restoration initiatives face a variety of social, political, economic, legal, and technological challenges, which add complexity and uncertainty to restoration programs [68], the implementation of KMPs in ecological restoration processes has high potential. In this sense, the use of these KMPs could be extended to other ecological restoration processes at different scales, both in tropical dry forest and in other ecosystems.

5. Conclusions

Concerning the theoretical contribution, this work highlights the empirical study of KMPs in the performance of the components of the ecological restoration process, concepts that were not previously related. Likewise, the study allows for the identification and improved understanding of the KMPs that are present in the ecological restoration process in the tropical dry forest, and KMPs are recognized as possible generators, transformers, and mobilizers of knowledge in the ecological restoration process. On the other hand, it was evidenced that the KMPs have contributed to the development of the ecological restoration process and have a high potential to continue to be carried out and documented throughout Phase II until 2038. Because ecological restoration is a long-term process and several generations of people may be involved in its development, it is possible that, in the following stages of the process, the KMPs may be modified and new ones may even emerge.

According to the results, the consulted experts from different stakeholders have a similar perception of KMPs in the ecological restoration process, considering that KMPs can have a positive impact on ecological restoration components and outcomes. The implementation of KMPs in the components of the ecological restoration process is expected to proceed well and can contribute to facilitating enabling conditions to overcome the main obstacles identified, as well as promote and implement large-scale restoration. From this study, the relationships between KMPs and the components of the ecological restoration process may be studied in other restoration processes, in different contexts, ecosystems, and even in other countries. Having a better understanding of KMPs can contribute to public policies, with better performance and integral fulfilment of the objectives of ecological restoration.

Finally, to achieve a better understanding of how ecological restoration occurs in the tropical dry forest, future research must investigate the understanding of many of the obstacles to reforestation and how to overcome them, since this research focused mainly on knowing the facilitators or characteristics of a successful ecological restoration, supported by adequate knowledge management. In the same line, studies in other ecosystems will allow us to know if the KMPs identified in this study are present and affect the ecological restoration process in the same way. In addition, it is interesting to distinguish the type of knowledge that is managed in an ecological restoration process, to know the best practices in the management of local or traditional knowledge, involving the community even more, and valuing their contributions as the main inputs for a successful ecological restoration process.

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Appendix A

Likert-type survey for the two Delphi rounds

1. Rate the importance of the components that favor compliance with the ecological restoration processes (5 = high importance and 1 = low importance).
    - Planning.
    - Diagnostic.
    - Implementation.
    - Monitoring.
    - Participation.
    - Consolidation.
2. Rate the importance of the following ecological restoration processes performance criteria (5 = high importance and 1 = low importance).
    - Effective (meeting the objective ecologically).
    - Efficient (less time and cost to comply).
    - Attractive and participatory (accepted and legitimized by stakeholders).
3. Rate the impact of the KMPs on the components of the ecological restoration processes (5 = high impact and 1 = low impact).
4. Rate the importance of the KMPs in the components of the ecological restoration processes (5 = high importance and 1 = low importance).
    - Planning.
    - Diagnostic.
    - Implementation.
    - Monitoring.
    - Participation.
    - Consolidation.
5. Rate the importance of the KMPs in the overall performance of the ecological restoration processes (5 = high importance and 1 = low importance).
6. Rate the importance of KMPs in the effective performance (meeting the objective ecologically) of the ecological restoration processes (5 = high importance and 1 = low importance).
7. Rate the importance of KMPs in the efficient performance (meeting in less time and cost) of the ecological restoration processes (5 = high importance and 1 = low importance).
8. Rate the importance of KMPs in the attractive and participatory (accepted and legitimized by stakeholders) performance of ecological restoration processes (5 = high importance and 1 = low importance).

Appendix B

Table A1. Description of knowledge management practices.

Knowledge Management Practices	Description
Human factor-oriented	
KMP1	In the initial steps of the pilot plan, experts with postgraduate degrees and good experience in each topic were involved in the ecological analysis, prioritization of areas, design of strategies, and domestication of native species. At the same time, we sought to involve residents of the villages and stewards who were knowledgeable about the restoration area. We sought to involve people over 65 years of age with experience in the area and with extensive traditional knowledge. We also sought to involve young people with little experience, but with enthusiasm and a desire to learn. The aim was to complement scientific knowledge with traditional knowledge and experience with the desire to learn. Since 2014, we have tried to give continuity each year to people who have excelled in their work and who have gained knowledge on different topics. At the beginning of Phase II, the core group of approximately 15 people had 4 years of experience on average in the ecological restoration process. Technicians, crew chiefs, security guards, and engineers who carried out their degree work in the pilot plan have been promoted to field assistants as residents in charge of the nursery, monitoring, implementation, and maintenance activities. In addition, a safety inspector was promoted to supervisor. Enel-Emgesa, the manager of the ecological restoration process, has been continuously linked to the company for 8 years and has postgraduate training with two master's degrees. The related company managers have had continuity and know the ecological restoration process in detail.
KMP2	Some outstanding local people have been linked to support the attention of visitors and academic practices, encouraging them to explain and share their knowledge in their own words of the activities they carry out daily. This recognition encourages people to share their experiences and acquired knowledge.
KMP3	In the field activities, workgroups or crews are organized in which experienced and novice people are always available to share their knowledge and experience in each of the activities.
KMP4	Several people have been encouraged and supported to continue their studies, both technological (6 people) and postgraduate (3 people), with easier class schedules and better salaries.
KMP5	Since the pilot plan, training has been promoted for all personnel involved in the process, with continuous training and certification on different topics such as fire control, cartography, working at heights, seeds, nurseries, restoration, integrated management of pests and diseases, HSL, ophidian accidents, etc.
KMP6	Following the Fundación Natura quality management system, a competency assessment is carried out annually for all personnel involved in the ecological restoration process in the tropical dry forest. Enel-Emgesa also conducts an annual competency assessment.
KMP7	Fundación Natura, as a non-profit organization, promotes and encourages the generation of knowledge and the exchange of experience. The Foundation's principles include equity, inclusion, transparency, solidarity, responsibility, and independence. Enel-Emgesa also encourages the generation and exchange of knowledge, both for the company and the general public.
Organization oriented	
KMP8	In the pilot phase of the ecological restoration process in the tropical dry forest, procedures for the domestication of native species, implementation, maintenance, and monitoring of ecological restoration strategies were developed and documented, with their respective instructions, formats, and reports. In Phase II, the procedures, formats, and reports established since the Pilot Plan continue to be used. All the information in the formats is digitalized and stored with a protocol.
KMP9	The pilot plan promoted interdisciplinary work by linking professionals from different areas of knowledge, with different specialties, and from different universities. Professionals from different Colombian universities with doctoral and master's degrees or specialized postgraduate training in different areas such as GIS, geomatics, geography, hydrology, soils, climatology, administration, botany, ornithology, herpetology, and entomology, among others, were involved. Likewise, an attempt was made to integrate the schools of restoration from the more theoretical disciplines of biology and ecology with the more practical schools of forestry engineering and agronomy.

Table A1. *Cont.*

Knowledge Management Practices	Description
KMP10	Initially, a matrix management strategy was used in the pilot plan. For each main activity, a leader was designated for his or her knowledge, experience, or skills, and the other members of the team actively collaborated in the necessary tasks, discussions, workshops, and fieldwork, among other things. As several activities were developed simultaneously, a person could be a leader of one activity and collaborate in another. After the first part of the pilot plan, the scheme of leaders by activities has been maintained with the technical support of the group of professionals, with workshops and other discussion activities for work orientation and decision making.
KMP11	Fundación Natura has the ISO 9001:2015 Quality Management System, the ISO 14001:2015 Environmental Management System, and the OHSAS 18001:2007 Occupational Health and Safety Management System. Enel-Emgesa is also certified in ISO 9001:2015—ISO 14001:2015—ISO 50001-OHSAS—18001:2007.
KMP12	Since the pilot plan, collaboration with academia has been sought to investigate different topics, initially with the Universidad del Cauca and the Universidad Distrital, and later with the Universidad Nacional, the Universidad Javeriana, and the Universidad Externado de Colombia. Several undergraduate projects have been supported and different academic internships have been carried out in the area of restoration. Later, an internship program was agreed upon with the Universidad Surcolombiana and with SENA at the Garzón headquarters. Two students also volunteered for internships. For Phase II, work continues with the same universities supporting undergraduate, master’s, and doctoral degree projects, as well as internships and academic practices. Since 2014, 36-degree works have been supported: 3 doctoral, 11 master’s and 22 undergraduates, with 46 students, 15 internships, 31 productive stages in SENA, and 2 volunteering. A cooperation agreement was established with the Humboldt Institute to support the monitoring of the ecological restoration process and the consolidation of the tropical dry forest research center. The process has been linked in various activities with the National Dry Forest Network, the Colombian Restoration Network Redcre, and the Ibero-American and Caribbean Society for Ecological Restoration SIACRE. The advances of the ecological restoration process have been presented in national (Colombian Congress of Restoration 2016 and 2018, Colombian Congress of Botany 2017 and 2019) Latin American (SIACRE 2015), and global (SER 2015, 2017, and 2021) congresses, among other academic activities.
Information technology-oriented	
KMP13	The ecological restoration plan has been supported by Geographic Information Systems (GIS) using software such as ArcGis, Conefor, fragstats, Linkage Mapper, spatial analyst, patch analyst, and PDF maps. For the storage of information and databases, we use Word, Excel, PDF, Dropbox, and GDB; we also have several hard disks, desktop and laptop computers. RStudio and IBM SPSS are used for data analysis. The geographic and monitoring information is used to make decisions on area prioritization, strategy design, species selection, among other activities.
KMP14	From the diagnosis, secondary information was consulted and primary information was collected in the field on all physical and biotic aspects. Based on this information, the rest of the activities were developed. With the collection of monitoring data from the ecological restoration trials for more than four years, there is a large amount of data that can guide the new activities of the ecological restoration process. It is proposed to continue generating data to guide the ecological restoration process and establish the effectiveness and impact of the actions carried out.
KMP15	Conventional communication channels such as email and WhatsApp are used, as well as informative publications (videos, web notes, social networks, etc.). Due to the pandemic that occurred in 2020, as a means of dissemination, it was decided to conduct a series of webinars with eight weekly sessions, with the participation of more than 120 people.
Strategy oriented	
KMP16	During the development of the pilot plan activities, knowledge needs were identified in the design of field experiments and statistical analysis of data, as well as in the design of monitoring strategies, for which advice was sought from experts in these areas. Carolina Murcia, from the Universidad Javeriana, and Álvaro Lema Tapia, from the Universidad Nacional, assisted in different activities of the process. In addition to the human team, we had the services of the National Herbarium of the Institute of Natural Sciences, the Wood, Forestry and Soil Laboratory of the Universidad Distrital, the Forestry Laboratory of the Universidad del Cauca, the Nutrition Laboratory of the Veterinary School of the Universidad Nacional, and the Soil Analysis Laboratory. In Phase II, an agreement was signed with the Humboldt Institute to support monitoring, data analysis, functional analysis, and other topics. Several members of the work team have been trained in different topics necessary for the proper development of the process.

Table A1. *Cont.*

Knowledge Management Practices	Description
KMP17	Throughout the ecological restoration process in the tropical dry forest, it has been possible to study, learn about and exchange experiences with other ecological restoration processes, both in Colombia (Cerrejón, Ituango Hydroelectric, Sogamoso Hydroelectric, URRA, Ecopetrol, SDA, SINA II) and in Brazil (ITAIPU, restoration of the Atlantic Forest, Embrapa) in order to understand their progress, challenges and difficulties.
KMP18	One of the principles of the ecological restoration plan in the tropical dry forest is adaptive management that allows adjustments or reorientation of activities based on the monitoring and continuous observation of changes or situations that may cause undesirable results. Throughout the ecological restoration plan, extreme climatic, ecological, social, and public health phenomena in the tropical dry forest, among others, have led to changes in the way activities are carried out in the nursery, implementation, maintenance, monitoring, and dissemination. These lessons learned are incorporated into new planning and are considered to program new activities and generate budgets.
KMP19	As a mechanism for dissemination and exchange of knowledge, guided visits are conducted to inform about the progress made throughout the ecological restoration process in the tropical dry forest. These visits have focused on all stakeholders involved in the ecological restoration process (communities, academia, public institutions, and companies). In the Pilot Plan, 130 visits were made with approximately 1800 participants, and in Phase II there is a goal of 1200 visitors. This practice has made it possible to share the knowledge and experience acquired by the work team.
Intellectual protection oriented	
KMP20	Enel-Emgesa, regarding the intellectual protection policies, established a confidentiality clause for the proper handling and safeguarding of information, which has been extended by Fundación Natura to each person who is part of the ecological restoration process in the tropical dry forest. To disclose information, prior authorization was requested from the company and Fundación Natura, and due credit was given for all material generated on the ecological restoration process. Each person is acknowledged for his or her intellectual contribution.
KMP21	A protocol has been established for managing process information in both physical and digital media; all documents and field forms are duly digitized and archived. Part of the information is stored in Dropbox and all files have backup copies. Through scientific and informative publications, new knowledge and the different advances of the process are made known, making explicit part of the knowledge generated throughout the ecological restoration process. Throughout the process, one scientific article has been published in an international journal [50], nine scientific articles in journals of the Universidad Nacional, and a book on the experience of domestication and propagation of native species in tropical dry forest.
KMP22	There are protocols, instructions, and formats designed to capture information on the different activities carried out, which facilitate the organization and processing for subsequent analysis; all the information is transferred to digital media for subsequent use. The information is duly organized in documents, databases, images, videos, audio, among others. The capture and processing of information are also supported by the GIS geographic information system.

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