Review

Revista Actualidades Biológicas

*Actual. Biol. 44(117): 1-17, 2022 | DOI:10.17533/udea.acbi.v44n117a02*

# Ecological restoration research in Colombian Andean forests: a bibliometric analysis and information gap

## Investigación de restauración ecológica en bosques Andinos Colombianos: un análisis bibliométrico y vacíos de información

Iván Camilo Rodríguez-González[1*]

**Abstract**

Research is the basis for the development of ecological restoration strategies and, therefore, bears the responsibility for the frequent failure of this practice. Experimental research is considered one of the most powerful tools to establish the causality of an ecological phenomenon and to provide relevant information in terms of ecosystem management. In this work, a review of the specific scientific knowledge on ecological restoration of Andean and high Andean forests was carried out in order to perform an analysis based on bibliometric indicators of importance (Price index, Isolation index and Collaboration index) and scientific impact (Immediacy index and Impact index of publications) to identify information gaps regarding experimental research. A total of 186 documents were analyzed, including scientific articles, technical papers, books, book sections and graduate theses. In general, experimental research in terms of ecological restoration in Andean and high Andean forests is only used in 17% of the research, with a special emphasis on the study of flora. The largest information gaps, derived from experimental research, are found in the fields of agroecology, socioeconomics and multi-thematic or multidisciplinary studies. Most of the experimental research corresponds to technical documents or degree theses with partial or unpublished results, so the potential for generating knowledge in ecological restoration is high if the investigations are completed and carried out with sufficient scientific rigor.

*Keywords:* experimental design, experiment, research methods, paramo

**Resumen**

La investigación es la base para el desarrollo de estrategias de restauración ecológica y por tanto es responsable por la frecuencia del fracaso de esta práctica. La investigación experimental se considera una de las herramientas más poderosas para establecer la causalidad de un fenómeno ecológico y proveer información relevante en términos de gestión de ecosistemas. En este trabajo se realizó una revisión del conocimiento científico específico en restauración ecológica de bosques andinos y alto andinos, con el fin de realizar un análisis a partir de indicadores bibliométricos de importancia (índice de Price, índice de aislamiento e índice de colaboración) e impacto científico (índice de inmediatez e índice de impacto de las publicaciones) y posteriormente, identificar los vacíos de información respecto a la investigación experimental. Se analizaron 186 documentos, entre artículos científicos, documentos técnicos, libros, secciones de libro y tesis de grado. En general, la investigación experimental, en términos de restauración ecológica en bosques andinos y alto andinos, solo se utiliza en el 17% de las investigaciones, con especial énfasis en estudios de flora. Los vacíos de información más grandes, derivados de la investigación experimental, se encuentran en los campos de la agroecología, la socioeconomía y los estudios multitemáticos o multidisciplinares. La mayoría de las investiga-

[1.] Line of Research in Ecological Restoration, Botanical Garden of Bogotá José Celestino Mutis, Bogotá, Colombia.

* Corresponding author: <icrodriguez@jbb.gov.co>

Received: June 2021; accepted: February 2022.

Revista Actualidades Biológicas
*Actual. Biol. 44(117): 1-17, 2022 | DOI:10.17533/udea.acbi.v44n117a02*

ciones experimentales corresponden a documentos técnicos o tesis de grado, con resultados parciales o no publicados, por lo que el potencial de generación de conocimiento en restauración ecológica es alto, siempre y cuando las investigaciones se culminen y se realicen con suficiente rigor científico.

*Palabras clave:* diseño experimental, experimento, métodos de investigación, páramo

## INTRODUCTION

Ecological restoration is increasingly gaining momentum and is considered the main strategy to combat the global problem of biodiversity loss (Hobbs and Suding, 2009; Menz et al., 2013). Compensation tools created by local governments, aimed at repairing the ecological damage generated by development projects in areas with significant biodiversity values, are often insufficient and demonstrate the need for technically precise ecosystem restoration strategies (Quétier et al., 2014). The application of these ecological restoration techniques must have very high standards in order to be truly effective as a biodiversity offset strategy or to fulfill its objective of helping to conserve communities and species of plants and animals. These standards can only be achieved with considerable scientific input (Burbidge et al., 2011; Menz et al., 2013). However, the evaluation of the effectiveness of restoration methods, according to the literature, are mostly insufficient to establish at least a methodological line (Palmer et al., 2010; Quétier et al., 2014).

Since research is the basis for the development of ecosystem restoration strategies, it bears some responsibility for the frequent failure of ecosystem restoration practices. Applied research can only lead to better restoration outcomes if it addresses practice-relevant questions (Cabin et al., 2010). Although useful research is carried out in Colombia, it occurs in the absence of an updated framework that allows for the generation of applicable results, in addition to an evident thematic bias, in terms of research, that privileges the descriptive over the experimental. According to Parrado-Roselli et al. (2016), most of the publications associated with forest and ecology studies in Colombia focus on baseline descriptions, mainly on the composition and structure of both flora and fauna. Understanding that descriptive, or non-experimental, research is fundamental to understand the current state of ecosystems, experimental research is considered one of the most powerful tools to establish the causality of an ecological phenomenon and allows generating knowledge from changing dynamics of the biophysical environment. In addition, experimental research provides cost-effective tools for the resolution of some ecological problems, which can be used as input for planning ecological restoration strategies.

Although most of the information on forest ecology is concentrated in the Andean region (Arbeláez-Cortés, 2013), with approximately 50% of the publications on the topic of ecological restoration (Garibello et al., 2021), it is possible that research in the Andean and high Andean forests presents a similar pattern with respect to the descriptive nature of scientific production. For this reason, this paper aims to review the scientific knowledge related to the ecological restoration of Andean and high Andean forests, in order to perform an analysis based on bibliometric indicators of scientific importance and impact, as well as to identify information gaps with respect to experimental research.

## MATERIALS AND METHODS

The research was based on a bibliometric analysis of the scientific production related to ecological restoration in Andean and high Andean forests, specifically in Colombia, for which a systematic search of the information generated between 2000 and 2020 was carried out, including all the academic production published in reliable sources at the national and international level. Specific search criteria were defined as key words and possible synonyms used alternatively within the scope of study, which was used as a search equation:

(*ecological restoration* OR *ecological reclamation* OR *ecological rehabilitation* OR *restoration ecology*) AND (*Andean* OR *high Andean* OR *paramo* OR *humid montane forest*) AND (*Colombia*).

### Metadata

From the bibliography found, basic metadata were obtained corresponding to: the type of reference, the name of the document, the number of authors, the name of the author(s), the year of publication, the author's institution, the methodology, the main ideas, the area of study, the city, the type of research (experimental or non-experimental) and the journal of publication. On the other hand, the number of references and citations retrieved from websites such as Web of Science, Scopus and Google Scholar were extracted. In addition, individual searches were evaluated for each combination of words in order to analyze which compositions yielded more results about the topic of study.

### Metadata analysis

The data collected were subjected to descriptive analysis through the application of bibliometric indicators of scientific importance and impact (Escorcia, 2008). Regarding the indicators of scientific importance, the Price index was calculated to find the percentage of references not less than five years old, where year zero is the year of publication; the isolation index associated with the number of references belonging to the country of origin, determined by the number of references from the country versus the total number of references; and the collaboration index measured as a percentage by the number of authors per article.

In the case of scientific impact indicators based on citation analysis, we considered the publication impact indicator, measured by the number of citations received by subsequent publications, proposed as an indicator of article visibility rather than scientific quality, and the immediacy index, used to measure the speed with which an article is cited during the year in which it was published.

### Identification of information gaps

Once the documents were classified into Experimental and Non-Experimental, and the information was catalogued in large areas of knowledge (fauna, flora, soil, landscape, socioeconomic, hydrology, agroecology, fire ecology and multi-thematic), those topics in which less experimental research was carried out were identified. Subsequently, specific methodologies were analyzed in order to generate research questions to fill these information gaps.

## RESULTS

### Metadata

From the search equation in the specialized engines, a total of 4206 results were obtained. However, only 92 documents met the exact parameters, which indicates an acceptance rate of 2.3% (table 1). In the same sense, when testing the different word combinations, a greater number of results were found for *Ecological restoration + Paramo*, followed by *Ecological restoration + High Andean forest* (table 2).

### Metadata analysis

From the exploration in search engines and direct inquiry in different entities related to research on Andean forests in Colombia, it was possible to access 186 documents focused on research on Andean and high Andean forests, including moorlands, within the national territory. The main information was extracted from the previously classified documents, in addition to the variables for the bibliometric indicators. An initial result of the classification, it was found that only 17% of the research related to Andean and high Andean forests carried out in Colombia is of the experimental type (figure 1).

Of the research analyzed, 55% are technical documents. According to the review, this proportion corresponds to unpublished works and/or documents with preliminary research results. It is important to note that most of the technical documents analyzed came from the Botanical Garden of Bogotá José Celestino Mutis; it was not possible to access projects

of this type in other entities related to Andean and high Andean forests. On the other hand, 24% of the information corresponds to scientific papers published in indexed journals: 10% to book sections, 9% to graduate and undergraduate theses and 2% to books. In the same vein, within each type of document, the general trend is maintained, most are non-experimental research with the exception of the book sections, which had an equal number of experimental and non-experimental research (figure 2).

With regard to the entities that generate knowledge or scientific information related to Andean and high Andean forests, three large groups were classified. The first corresponds to research institutes, which contributed 65.05% of the documentary production, with the most representative being the José Celestino Mutis Botanical Garden of Bogotá and the Alexander von Humboldt Institute for Research on Biological Resources. Universities contributed 33.87% of the documentation consulted, followed by NGOs with 1.08%. In relation to the above, the entities related to the study ecosystems, such as the Ministry of Environment and Sustainable Development, the District Secretariat of Environment and the Regional Autonomous Corporations, no open information was found, or it was not possible to access specific research on ecological restoration of Andean and high

**Table 1. Number of documents found vs. accepted, by each search engine**

| Search engines | Results founds | Accepted documents |
|---|---|---|
| Google Scholar | 3820 | 56 |
| Scielo | 8 | 8 |
| Science Direct | 189 | 17 |
| Scopus | 189 | 17 |

**Table 2. Number of results found by search combination**

| Combinations | Andean forest | High Andean forest |
|---|---|---|
| Ecological restoration | 2040 | 714 |
| Ecological rehabilitation | 229 | 93 |
| Ecological reclamation | 215 | 77 |
| Restoration ecology | 113 | 52 |

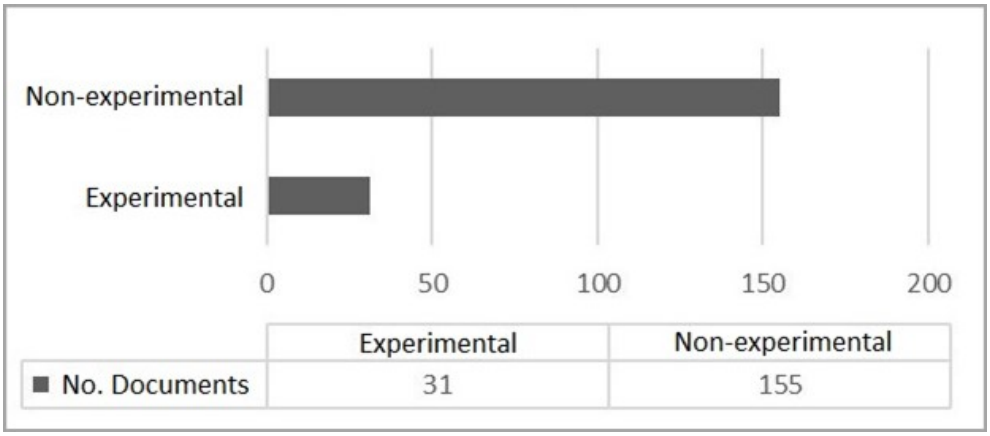


**Figure 1.** Type of research conducted in Andean and high Andean forests in Colombia.

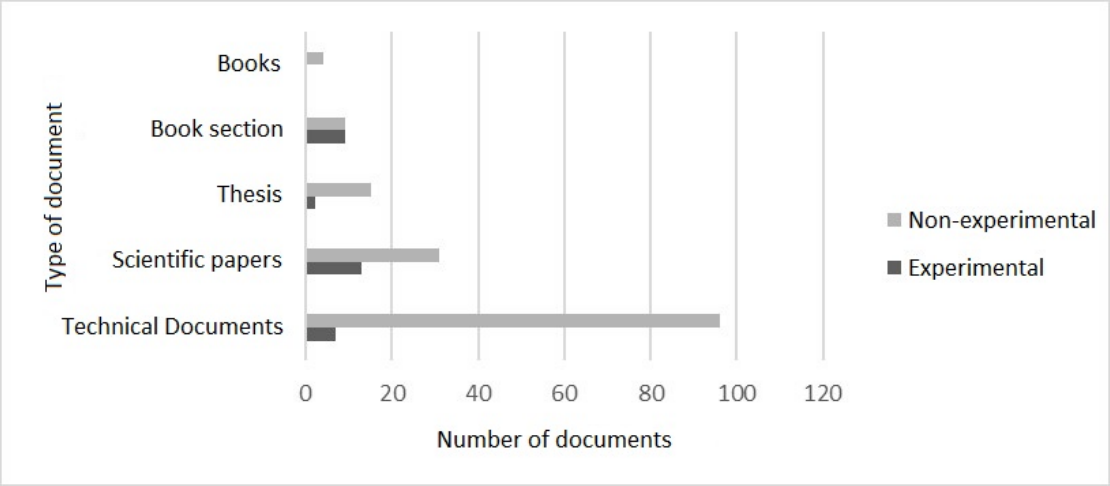


**Figure 2.** Type of research present in the different document types.

Andean forests.

It is worth noting that although research institutes have the largest number of studies, 85.12% correspond to technical or working documents which have limited access, while universities provide more freely accessible and published information.

A total of 46.77% of the research related to ecological restoration in Andean and high Andean forests is focused on the study of flora, while 19.35% corresponds to multi-thematic studies covering different disciplines. The topics with a lower percentage of research are associated with socioeconomic studies (9.68%), followed by soil restoration (8.06%), while the fauna and landscape restoration studies have 6.45% of the documents each. Finally, restoration studies based on fire ecology and agroecological processes represent 2.15% and 1.08% of the analyzed documents, respectively (figure 3).

In terms of research type, flora studies comprise 67.74% of the experimental research, an area of knowledge that most applies to this type of approach. However, in terms of the proportion of experimental research compared to the total amount studied, 33.33% of the research related to soil restoration is of the experimental type. Contrary to this, in multithematic, socio-cultural and agroecological studies, no research was found where a design based on manipulation of variables was applied.

Although research institutes generated most of the projects aimed at studying Andean and high Andean forests, universities are the entities that generate the greatest amount of information from experimental research, with 33.33% of their scientific production focused mainly on flora. 91.74% of the research projects carried out by the institutes, specifically the Botanical Garden of Bogotá, are concentrated in non-experimental research, mainly focused on floristic characterization, conceptual models and evaluation of the physical-biotic potential (table 3).

For the spatial analysis of the studies, the technical documents were omitted since they are concentrated in institutions of the capital district, with results were based on documents freely available on the Internet. Consequently, 70% of the research contained in the technical documents is concentrated in Bogotá and Cundinamarca, both experimental and non-experimental, the latter being dominant in most of the regions, with the exception of Boyacá, where four of the five investigations found a contemplated design based on manipulation of variables, so it is categorized as experimental (figure 4).

The general direction of research in the Colombian Andean and high Andean ecosystems shows an annual growth trend, whose X coefficient of the equation of the straight line is 0.89. In principle, there is evidence of a substantial increase in scientific production from 2005, with a strong periodic decrease

Revista Actualidades Biológicas
*Actual. Biol. 44(117): 1-17, 2022 | DOI:10.17533/udea.acbi.v44n117a02*

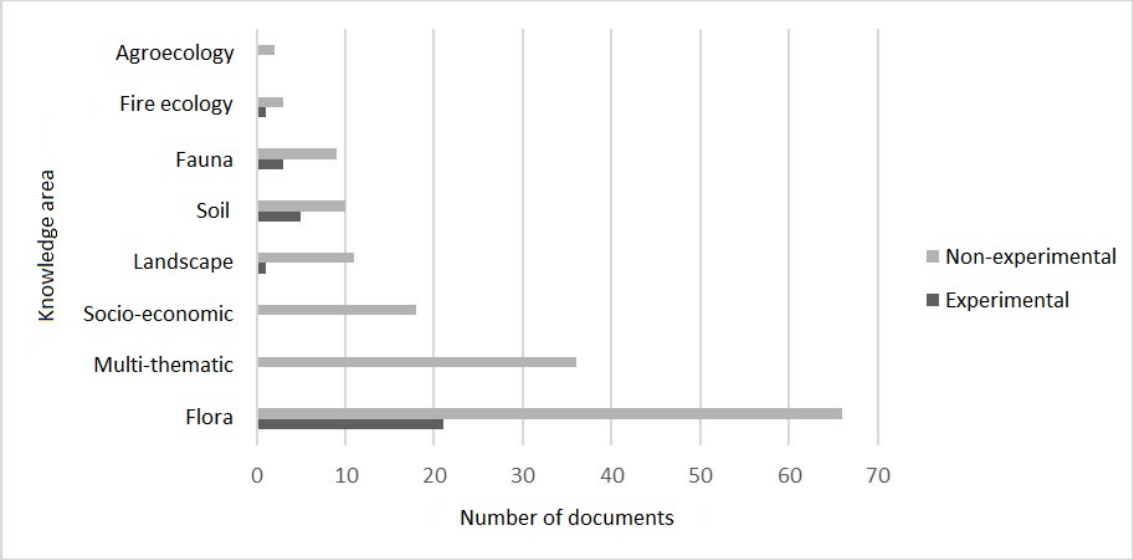


**Figure 3.** The type of research by area of knowledge found in the documents.

**Table 3. Type of research produced by the different entities in each area of knowledge**

| Knowledge area | Research Institute | | NGO | | University | |
|---|---|---|---|---|---|---|
| | Experimental | Non-experimental | Experimental | Non-experimental | Experimental | Non-experimentall |
| Agroecology | - | 2 | - | - | - | - |
| Fire ecology | 1 | 3 | - | - | - | - |
| Fauna | 1 | 5 | - | - | 2 | 4 |
| Flora | 6 | 43 | - | 2 | 15 | 21 |
| Multi-thematic | - | 28 | - | - | - | 8 |
| Landscape | - | 6 | - | - | 1 | 5 |
| Socio-economic | - | 15 | - | - | - | 3 |
| Soil | 2 | 9 | - | - | 3 | 1 |
| **Total** | **10** | **111** | **0** | **2** | **21** | **42** |

from 2017 to 2020 (figure 5). Regarding the temporal dynamics of knowledge generation related to the type of research, non-experimental studies present an increase very similar to the general increase in documental production, with a coefficient of X = 0.81. In contrast, experimental research has remained stable, with a slight downward trend, as evidenced by the X coefficient of the line with a value of -6.06 (figure 6).

Bibliometric indicators were found only for scientific articles published in indexed journals, since in this type of documents it is possible to better understand the specific trend for the different areas of knowledge. Regarding the indexes of scientific importance, both the Price index and the isolation index are higher for non-experimental research. Within the areas of knowledge, the articles related to fauna with an experimental approach display the highest values in the Price index, while, in the non-experimental ones for this index, the highest values are presented in Landscape Ecology and Flora. Regarding the isolation index, within the experimental articles, studies related to soil restoration show the highest percentage, which differs from non-experimental research, where multithematic and socioeconomic studies show the highest

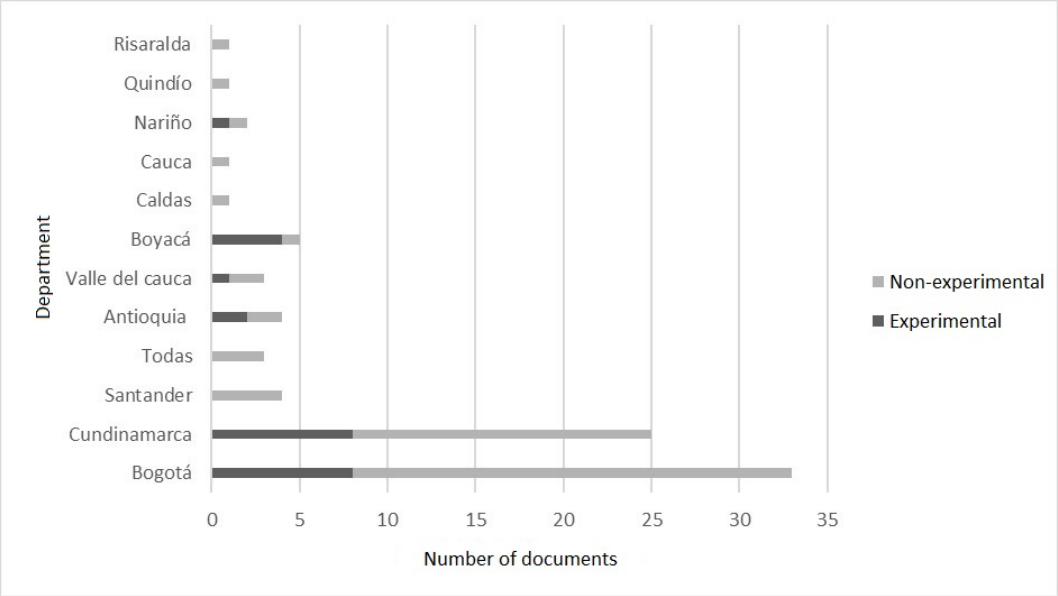


**Figure 4.** Research conducted in the different departments of Colombia.

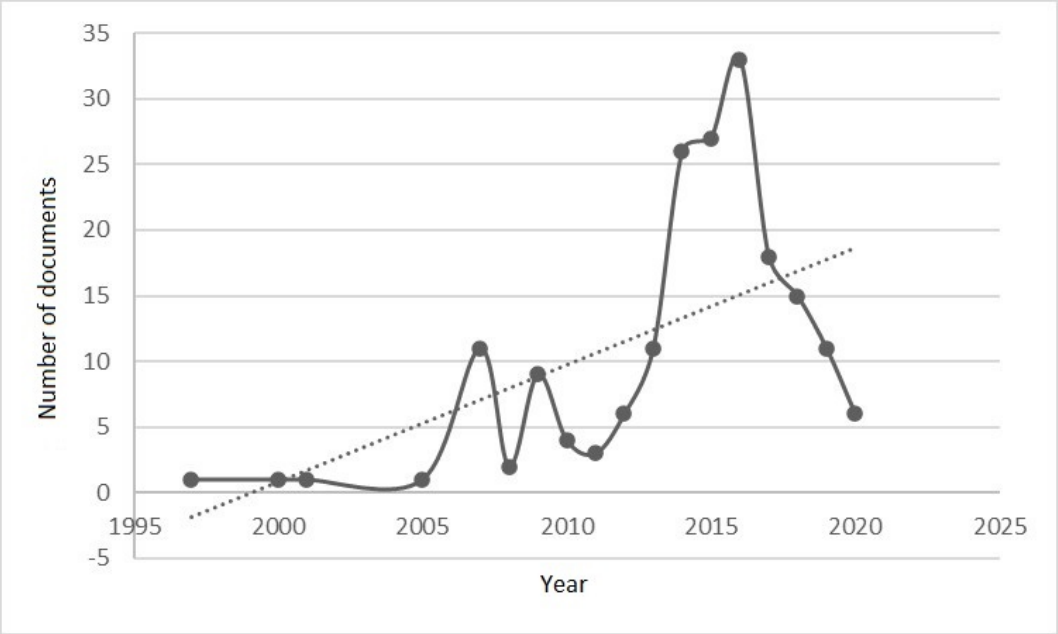


**Figure 5.** Temporal production of research from 1997 to 2020.

indexes (table 4).

The collaboration index for the total number of articles consulted shows that 68.18% were written by two to three researchers. In the case of experimental research, 53.85% have two authors, while 38.71% of the non-experimental articles have three authors, 51.61% have between one and two authors (table 5). Regarding the collaboration index for the different areas of knowledge, there are between one to three authors. However, the greatest collaboration is observed in the landscape-scale restoration studies with four authors in all the articles. This is contrary to the socioeconomic studies, with a single author in

Revista Actualidades Biológicas
*Actual. Biol. 44(117): 1-17, 2022 | DOI:10.17533/udea.acbi.v44n117a02*

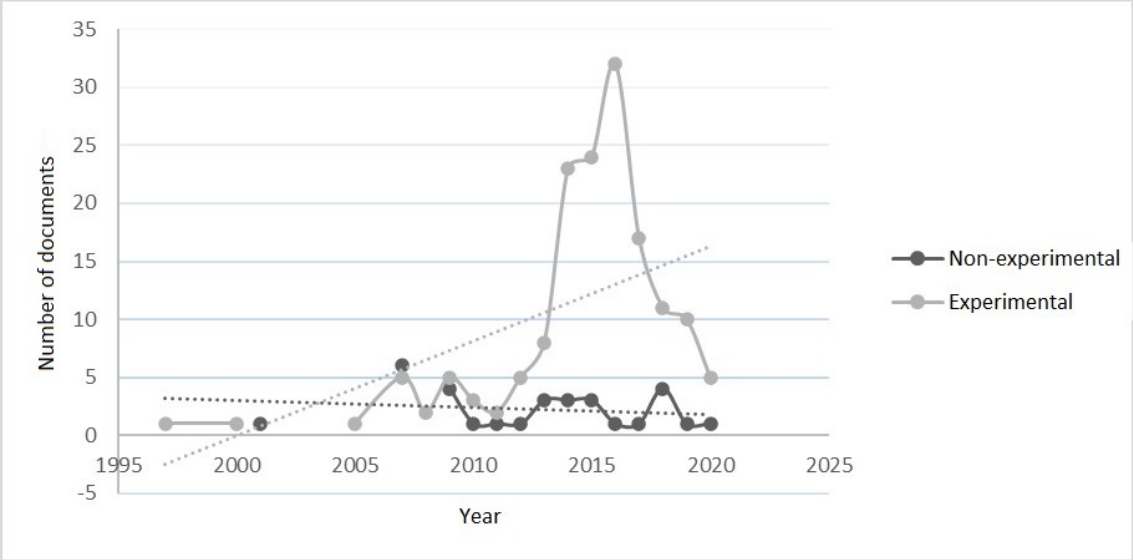


**Figure 6.** Temporal production by type of research from 1997 to 2020.

66.67% of the publications (table 6).

Regarding scientific impact indices, specifically the number of citations received by the article, observational or non-experimental research documents received, on average, twice as many citations as experimental articles. In the same sense, articles related to flora and fauna restoration received the highest number of citations. On the other hand, the immediacy index values, despite being low for all publications, are higher for non-experimental research, mostly represented by the topics of fire ecology, flora and fauna (table 7).

## Identification of information gaps

In general, research related to ecological restoration in Andean and high Andean forests has been little studied from an agroecological and/or fire ecology approach. However, since this work concentrates on experimental research, there is a lack of information derived from studies based on manipulation of variables in the fields of agroecology, socioeconomics and multi-thematic approaches where restoration is analyzed holistically. Additionally, fire ecology and landscape scale studies have only a single study focused on restoration (figure 3).

**Table 4. Price index for types of research and areas of knowledge**

| Knowledge area | Experimental | | Non-experimental | |
|---|---|---|---|---|
| | Price Index | Insulation index | Price Index | Insulation index |
| Fire ecology | - | - | 20.61% | 18.98% |
| Fauna | 30.77% | 23.08% | 18.98% | 24.38% |
| Flora | 15.74% | 28.87% | 25.48% | 31.33% |
| Multi-thematic | - | - | 0.00% | 62.50% |
| Landscape | - | - | 25.95% | 15.27% |
| Socio-economic | - | - | 24.90% | 60.30% |
| Soil | 12.16% | 55.87% | - | - |
| **Total** | **16.35%** | **32.58%** | **23.67%** | **33.15%** |

**Table 5. Overall collaboration index and by research type**

| No. Authors | General | | Experimental | | Non-experimental | |
|---|---|---|---|---|---|---|
| | Number of items | Collaboration index | Number of items | Collaboration index | Number of items | Collaboration index |
| 1 | 9 | 20.45% | 1 | 7.69% | 8 | 25.81% |
| 2 | 15 | 34.09% | 7 | 53.85% | 8 | 25.81% |
| 3 | 15 | 34.09% | 3 | 23.08% | 12 | 38.71% |
| 4 | 3 | 6.82% | 1 | 7.69% | 2 | 6.45% |
| 5 | 2 | 4.55% | 1 | 7.69% | 1 | 3.23% |

**Table 6. Collaboration index by area of knowledge**

| No. Authors | Knowledge area | | | | | | |
|---|---|---|---|---|---|---|---|
| | Ecology Fire | Fauna | Flora | Multi-thematic | Landscape | Socio-economic | Soil |
| 1 | 50.00% | 0.00% | 16.13% | 100.00% | 0.00% | 66.67% | 0.00% |
| 2 | 50.00% | 25.00% | 38.71% | 0.00% | 0.00% | 0.00% | 50.00% |
| 3 | 0.00% | 75.00% | 32.26% | 0.00% | 0.00% | 33.33% | 50.00% |
| 4 | 0.00% | 0.00% | 6.45% | 0.00% | 100.00% | 0.00% | 0.00% |
| 5 | 0.00% | 0.00% | 6.45% | 0.00% | 0.00% | 0.00% | 0.00% |

Although there are three experimental studies focused on fauna, all are oriented on avifauna evaluated through perches, so there is a lack of information related to other faunal groups and their habitat preferences. Additionally, although the five studies related to soil focus on the performance of vegetation in different soil types or the application or elaboration of substrate, there are no studies related to the recovery or rehabilitation of the biota and/or physicochemical characteristics of the soil. Even though the flora component is the one with the most associated research, there are some thematic approaches that are not used in the research that can answer relevant questions for ecological restoration, such as an analysis from the genetic and functional point of view.

Based on the above, and on the research carried out by Miller et al. in 2017 in which the different areas of ecological restoration and under-investigated topics are evaluated, table 8 shows the research questions relevant to all areas of knowledge related to the restoration of the Andean and high Andean ecosystems which cannot be answered with the research developed to date in the country for these ecosystems and can be approached mostly from an experimental point of view (table 8).

## DISCUSSION

Although search engines are a fundamental tool for the exploration of scientific information, when too specific search formulas are applied, a thorough review is required in order to obtain documents that meet a strict set of criteria, given that search engines suppress some terms to achieve broader results. In this same sense, the search for "Ecological Restoration" was the term that yielded the greatest number of results, since it is a term that groups approaches, such as Recovery and Rehabilitation. Although the "Paramo is immersed within the high Andean ecosystems, it was necessary to include it as an independent criterion, since it is the term that presents the greatest amount of research.

Revista Actualidades Biológicas
*Actual. Biol. 44(117): 1-17, 2022 | DOI:10.17533/udea.acbi.v44n117a02*

**Table 7. Scientific impact indexes for types of research and areas of knowledge**

| Area of knowledge | Number of citations | | Immediacy index | |
|---|---|---|---|---|
| | Experimental | Non-experimentall | Experimental | Non-experimental |
| Ecology Fire | - | 2.5 | - | 0.043 |
| Fauna | 2 | 9 | 0 | 0.026 |
| Flora | 8.4 | 18 | 0.006 | 0.032 |
| General | - | 7 | - | 0 |
| Landscape | - | 3 | - | 0.002 |
| Socio-economic | - | 5.3 | - | 0.009 |
| Soil | 2.5 | - | 0 | - |
| **Total** | **7** | **14** | **0.005** | **0.028** |

## Metadata analysis

The number of documents obtained for the analysis of this research (186 documents) is relatively high compared to other studies of the state of knowledge in Colombia with lower search restrictions. For example, Garibello et al. (2021) evaluated the state of knowledge on ecological restoration in the country. However, it is noteworthy that in this research, unlike other studies, both research and technical documents were analyzed, a fact that broadened the spectrum of data. However, this generated a challenge in terms of obtaining information, considering that technical documents are not freely accessible by those outside of the entities that generate them. In this sense, 55% of the studies analyzed in this research corresponded to technical documents generated mainly by entities in the city of Bogotá, as these were the entities that allowed moderate access such information. It is evident that there is a large amount of research related to restoration of Andean and high Andean forests, whose results do not contribute to the knowledge or management of these ecosystems due to the lack of dissemination and/or publication of these results. This difficulty in terms of access to information reaffirms the fact that scientific knowledge is only available to a few groups and the majority of the population does not have access to this information (Fuller et al., 2014).

Regarding the type of research conducted, the low percentage of studies based on experimental parameters (17%) may be associated with the type of entity where the information is generated. Much of the knowledge generated, despite not being published, is developed in research institutes that are mostly funded by governmental contributions (Murcia and Guariguata, 2014). Since experimental research is based on responses to the manipulation of one or several factors, a minimum time is required to demonstrate these responses. This fact makes experimental research take longer than observational research, which is not convenient when research goals are mixed with governmental restoration objectives based on the number of hectares or number of trees planted.

Despite the fact that the vast majority of research on ecological restoration issues is based on flora studies, 76% is focused on characterizations and baselines. In this sense, flora research from an experimental point of view could generate information that allows for the adaptive management of ecosystems and active ecological restoration processes (Ramirez et al., 2016). This fact is also related to what was mentioned above, where much of the research is associated with regional or district goals, where tree planting is the indicator of success. This limits experimental research in areas such as fauna and soil restoration and studies at the socioeconomic and landscape levels. These results are consistent with other research on the state of ecological knowledge in Colombia, where flora accounts for the majority of studies (Arbeláez-Cortés, 2013; Garibello et al., 2021; Murcia and Guariguata, 2014; Parrado-Roselli et al., 2016).

**Table 8. Research questions associated with information gaps**

| Areas of knowledge | Research questions |
|---|---|
| Socioeconomic | • How to evaluate the social impact of ecological restoration processes?<br>• What are the appropriate strategies to generate community ownership of the territory or of the restoration processes?<br>• What metrics and/or survey techniques are required to adequately characterize communities associated with areas undergoing ecological restoration? |
| Agroecology | • What is the influence of different agricultural crops on the physicochemical characteristics of the soil necessary to initiate ecological recovery or rehabilitation processes?<br>• How to improve agricultural productivity in areas adjacent to ecological restoration zones, as a way to reduce anthropogenic pressure?<br>• What type of agricultural crops can improve soil conditions prior to the initiation of restoration processes? |
| Multi-thematic | • What monitoring, design and testing techniques are required to adequately evaluate the restoration process to allow unambiguous assessment of progress and success at different stages?<br>• Are the physical, hydrological, climatic and biological attributes of the environment limiting and can they be manipulated to optimize plant growth and survival in restoration? |
| Fire ecology | • Can fire be manipulated as a disturbance for the development of natural regeneration?<br>• What is the reaction of different plant species or functional groups to different fire intensities? |
| Landscape | • Can the density, planting patterns or sequences of ecological corridors be varied to optimize connectivity and/or energy flow between forest patches?<br>• How do social, physical, climatic, socioeconomic, infrastructure, etc. characteristics influence the connectivity and restoration potential of a forest relict?<br>• For Andean and high Andean forests, what is the minimum size and distance of forest patches that guarantee ecological viability? |
| Fauna | • Which faunal groups are ideal for enhancing passive regeneration and dispersal?<br>• What type of plant species are suitable for attracting pollinators or dispersers?<br>• Can habitat and resource requirements of wildlife species be increased to enhance biodiversity values and ecosystem function? |
| Soil | • Do environmental conditions on the soil affect the development of microbiota and can artificial or natural structures or treatments be constructed to enhance their effects?<br>• Can topsoil germination be maximized by changes in harvesting, storage, re-storage and treatment techniques?<br>• How can soil microbiota enhance seed production in natural populations?<br>• How does the soil biota and seed bank react to intensities or types of disturbances?<br>• Is soil biota necessary for plant growth and survival and what treatments can be employed to optimize its return in restoration? |
| Flora | • For seed supply, is it better to mix genotypes (thus increasing evolutionary potential) or to match genotypes to local conditions (maximizing local adaptation)?<br>• For seed supply, is it better to mix genotypes (thus increasing evolutionary potential) or to match genotypes to local conditions (maximizing local adaptation)?<br>• Can functional groups be introduced or managed to improve the sustainability or regeneration of a population? |

When ranking the studies by region, Bogotá and Cundinamarca are the dominant departments in terms of scientific production, which is evident in studies such as that of Murcia and Guariguata (2014). This is explained by the fact that Bogotá concentrates most of the research institutes and universities. Thus, from a logistical and economic point of view, it is easier to conduct research, either in the city or in the adjoining municipalities.

The trend in terms of scientific production focused on ecological restoration in Andean and high Andean forests over time shows a considerable increase in both experimental and non-experimental research as of 2005, coinciding with that reported by Garibello et al. (2021) and by Murcia and Guariguata (2014). This trend may be due to the fact that in the second five years of the 21st century, several research projects on ecological resources were generated by the Mayor's Office of Bogotá and the Corporación Autónoma Regional de Cundinamarca (CAR) within the framework of the government program Bogotá Without Indifference 2004-2007. In contrast, experimental research has shown a downward trend, despite the increase in environmental challenges that require this type of information for the generation of knowledge for management, such as the management of invasive species (Miller et al., 2017).

The indicators of scientific importance place the non-experimental articles with a high Price index, this means that the authors of this type of research used a greater amount of recent references to generate new information. This makes sense if we consider the amount of information generated from an experimental approach, since less scientific production makes it more complicated to find recent supporting documents. As for the isolation index, the higher the value obtained for this indicator, the less influence external knowledge will have on research or other types of activities being carried out in the country. This is contrary to what happened with research carried out in the Andean and high Andean forests of Colombia, whose index is low in comparison with research on different ecosystems in more developed countries (Grindle, 2017). Therefore, as a country, we are forced to rely on foreign information, even though we are talking about very specific ecosystems of the northern Andes.

These indicators of scientific importance can also shed light on the state of research by the area of knowledge. Regarding Price's index, experimental research on fauna is the one that presents the highest number of updated references, despite having a high influence of foreign information, given its isolation index value. On the other hand, restoration research from a socioeconomic and multi-thematic component presents a low influence of foreign information, which is understandable, since social and economic behaviors are very particular at the local and/or regional level.

The scientific impact indexes show, in terms of number of citations, that descriptive studies of flora are the most consulted and cited, since they are important comparative and supporting documents for characterization studies and baselines for ecological restoration projects. Regarding the immediacy index, which measures the level of dissemination of a research study in the first year of publication, the subject with the greatest dissemination is fire ecology, which was to be expected due to the little information that exists on the subject, which implies a high demand for studies of this type. In terms of type of research, non-experimental studies not only have a higher number of citations, but also a higher rate of immediacy, which leads us to conclude that the quality of the information and/or the relevance of the research questions in experimental projects in the country is not adequate, which means that these studies are not a reference for subsequent research.

## Identification of information gaps

The results obtained identify the aspects that have been addressed more or less frequently at the local level and identify those that have not yet been explored. They also suggest that research associated with ecological restoration in Andean and high Andean forests is insufficient considering the extent of degradation and the diversity involved (Etter et al., 2008).

Although there are areas of knowledge with clear information gaps, such as restoration studies with a multi-thematic, socioeconomic or agroecological ap-

proach, when reviewing in detail the methodologies and research questions, significant biases are evident in all areas of knowledge, so there are issues that are not addressed and are fundamental for restoration ecology in Andean and high Andean ecosystems (Garibello et al., 2021, Miller et al., 2017). In this context, the flora component has the largest number of studies addressed from different approaches. However, in the case of functional traits, the studies are extremely descriptive and there is no guidance on the usefulness or application of this information in ecological restoration projects or integrated forest management. On the other hand, studies of genetic diversity or population genetics have not been studied, despite the importance of this information at both local and regional levels (El Enshasy et al., 2015).

Although sustainable harvesting and mixed sustainable forest management projects have been part of the agenda of different governments, research in agroecology and socioeconomics related to ecosystem restoration has not been significant or conclusive (MADS, 2014). In this sense, knowledge in this area can provide tools for integrated ecosystem management and achieve a relative balance between conservation and resource use by communities.

Based on the research questions, some conceptual approaches can be made to partially fill the information gaps. In the area of socioeconomic research, no information was found on the impact of ecological restoration projects on communities and the techniques applied to specifically quantify this impact in Andean ecosystems. However, Aguilar-Garavito and Ramirez (2015) proposed some general parameters for community involvement in ecological restoration projects, which may be applicable to the ecosystems under study. The indicators to measure impact are: employment generation, number of people involved, generation of business opportunities, community participation in monitoring, and youth participation.

Regarding appropriation techniques, Castañeda Rincón (2019) makes a description of techniques used by the Educational Subdirectorate of the Botanical Garden of Bogotá, which are mainly based on ecological tours, outreach days and participation in plantations. However, no reference is made to whether these strategies were adequate or achieved the expected objective Aguilar-Garavito and Ramirez (2015) affirm that participation strategies based on economic appropriation are the most effective in the long term, based on experiences carried out in Amazonian forests or Middle Magdalena forests, where the relationship between the community and the ecosystem is different from that of Andean and high Andean forests. Nevertheless, it is necessary to implement this economic approach in the ecosystems of Bogotá and the region, with productive projects such as community nurseries, seed production and sale, etc.

Agroforestry is a productive approach with the capacity to promote the recovery of degraded agroecosystems, particularly because of its adaptive characteristics to climate change (Chepstow-Lusty, 2011). In this sense, the evaluation of the impact of productive systems, especially on the soil, provides fundamental tools to address ecological restoration processes in areas altered by agricultural disturbances. Arce-Alvarez and Azero-Alcocer (2020) evaluated different types of crops and their influence on soil characteristics in a study conducted in the Andean forests in Bolivia. They concluded that crops with forest plantations, either as living fences or internal shading, had better physical and chemical characteristics that facilitated the development of all types of vegetation.

On the other hand, Zamora et al. (2017), experimented different types of crop associations in relation to soil and productivity. The results showed that the coffee-guamo-orange association increased the contribution of organic matter and improved soil fertility conditions, presenting the highest values of available phosphorus and potassium. These results can be applicable to transition processes in agricultural areas adjacent to restoration zones.

For the specific case of the Andean forests of Bogotá and the region, research should focus on experimenting with different native species desirable in restoration processes as opposed to traditional crops in the region, using soil characteristics, seed bank and groups of indicator fauna as main indicators. On the

other hand, it would be possible to experiment, at the plot level, with mixtures of traditional crops of the Cundinamarca-Boyacá highlands to identify the best productive cycles and the best associations.

The investigation of fire ecology takes relevance, since it is a disturbance that modifies the composition and structure of plant communities through the responses and functional characteristics of the species present at the site. In addition, fire interacts with other types of disturbances, such as changes in the hydroperiod or the introduction of exotic species (López-Rosas & Moreno-Casasola, 2012). Páramo Pérez et al. (2018) found, under an experimental design with controlled fires, that the intensity and recurrence of fire influence natural regeneration in Mexican forests. On the other hand, Carbone et al. (2017) found similar results for Chaco forests in Argentina.

Understanding that many of the non-tropical forests are related to recurrent episodes of fire due to seasonality, unlike the Andean and high Andean forests, the behavior of seed banks and the response of native and non-native species to different intensities and frequency of fires could be evaluated experimentally by carrying out experimental designs with controlled burns or fires. Experimentation with fire events can show prospective scenarios and based on these, manage or develop strategies for the management of areas with increased fire regimes, either due to anthropogenic causes derived from population increase or due to the effect of radiation and temperature associated with climate change.

In terms of wildlife research, ecological integrity includes an enriched biodiversity, a flourishing interaction between plants and animals, and a dynamic nutrient cycle. In this sense, it is necessary that restoration projects not only focus on the recovery of forest composition and structure, but also generate attributes for fauna, especially those in charge of dispersal or pollination. Juwarkar and Singh (2016) found a close relationship of pollinators with specific plant species or configurations in different restoration scenarios. On the other hand, Alonso-F. et al. (2017) manipulated characteristics of the habitat to determine the desired quality to attract species with contrasting ecological requirements, such as *Tapirus pinchaque*, *Sturnira erythromos* and *Cebus albifrons*. Knowing the preferences of native fauna, especially dispersers and pollinators, whether in terms of habitat or simply food tastes, makes it easier for ecological restoration processes to be comprehensive and, therefore, more efficient and grounded in the natural processes of an ecosystem.

Regarding the study of soil in relation to ecological restoration, Wang et al. (2019) conclude that the late reestablishment of a diverse microbiome in soil may be critical for the restoration of functional characteristics of plant diversity after anthropogenic disturbance, so soil restoration should be a priority within ecological ecosystem restoration models. Perkins and Hatfield (2016) tested different commercial microbial compounds for soil improvement, finding, that compounds that decrease fungal activity reduced vegetation growth in general, but the effects on invasive species were much more severe. Pizarro-Tobías et al. (2015) explored the use of bioremediation and rhizoremediation techniques for the restoration of soils vulnerable to erosion and concluded that, in burned forests, the application of bioremediation techniques increased the speed of recovery of pre-fire characteristics. Koziol and Bever (2017) found that the inoculation of mycorrhizae at a specific concentration accelerated the vegetative succession of the native forest in an area historically used for grazing. Stavi et al. (2018) found that soil turning or plowing processes favored the recovery of some soil characteristics ideal for the establishment of native cover. Finally, Wagner et al. (2014), through plantations on soils with different characteristics, discovered that the microbiota has a close relationship with the phenological cycles of the vegetation that develops there.

Experimental research on soil restoration techniques, such as those mentioned above, does not involve large investments of resources or time, but it does have a great impact on the formulation of restoration projects, especially in Andean and high Andean ecosystems whose soils have been gradually degraded by anthropic pressure.

Although there is a wealth of information regarding

the flora, there are still several information gaps that are important to fill. In this regard, genetic diversity and structure have long been recognized as critical for the maintenance of viable and resilient populations and as raw material that determines the ability of populations to respond to change and represents an important buffer against extinction (Rato et al., 2015). In this sense, research on the genetics of vegetation used in ecological restoration processes provides tools for decision making to ensure better performance of plantations and their coupling with the forest matrix.

Deacon and Cavender-Bares (2015) analyzed the response of the same species under different environmental conditions within an altitudinal gradient in order to identify possible adaptations at the local level. They found that no such adaptations developed, indicating that there is the possibility of using seed sources of species that grew under different environmental conditions, without compromising seedling survival. Despite this, not all species have the same phenological plasticity, so this type of studies should be applied in a particular way by species and type of ecosystem. These results are reaffirmed by Van Rossum et al. (2020) and Zavodna et al. (2015), who found benefits from genetic mixing of taxa from areas with different physical and environmental conditions.

On the other hand, Kimball et al. (2014) tested plantations with different functional groupings in order to test their behavior in the face of plant species invasion. As a result, they obtained a better performance of plantations with greater functional diversity, associated with resource utilization and/or consumption strategies. However, it was not evaluated in areas with soils degraded by invasive species and/or previous agricultural processes, as is the case of areas with invasion of *Ulex europaeus* in Andean and high Andean ecosystems.

Finally, in terms of restoration studies at the landscape level, it is important to understand that research should include as many of the components or areas of knowledge described above as possible. On the other hand, studies carried out can obtain results in the short, medium and long term. However, experimental research necessary to obtain efficient management tools requires long periods of time and continuity in the lines of research to achieve effective results that can be applied to restoration projects at the landscape scale.

## CONCLUSIONS

It is evident that most of the research is focused on flora studies, leaving aside fundamental areas for ecosystem restoration such as soil, fauna and the socioeconomic component. The information gaps in these areas of knowledge can be filled by experimental research. However, it is necessary to allocate more resources to research, implementation and monitoring strategies to measure the impact of ecological restoration projects. In addition, the fact that information is not publicly available limits the availability of a broader spectrum of information to facilitate the success of restoration processes.

In general terms, there are many gaps in knowledge that are relevant to the success of ecological restoration projects. In this sense, this lack of information is not only due to the scarce experimental research, but also to a low rate of publication of the results of studies related to ecological restoration, which is why it should be a policy of the different entities and institutes that research should start from relevant research questions and be carried out with sufficient scientific rigor to qualify for publication in scientific journals.

## ACKNOWLEDGMENTS

The author is grateful to the Botanical Garden of Bogotá José Celestino Mutis, not only for funding the research, but also for providing key documents for the development of the research. The English version was translated by Actualidades Biológicas Journal and approved by the author.

## CONFLICT OF INTEREST

The author has no conflicts of interest, so his judgment, independence and impartiality remained in-

tact in the preparation of this research.

## REFERENCES

Aguilar-Garavito, M., & Ramirez, W. (Eds.). (2015) *Monitoreo a procesos de restauración ecológica aplicado a ecosistemas terrestres.* Instituto de Investigación de Recursos Biológicos Alexander von Humboldt (IAvH). https://bit.ly/3FzBX2A

Alonso-F., A. M., Finegan, B., Brenes, C., Günter, S., & Palomeque, X. (2017). Evaluación de la conectividad estructural y funcional en el corredor de conservación Podocarpus-Yacuambi, Ecuador. *Caldasia, 39*(1), 143. https://doi.org/10.15446/caldasia.v39n1.64324

Arbeláez-Cortés, E. (2013). Knowledge of Colombian biodiversity: published and indexed. *Biodiversity and Conservation, 22*(12), 2875−2906. https://doi.org/10.1007/s10531-013-0560-y

Arce-Alvarez, A., & Azero-Alcocer, M. (2020). Evaluación comparativa de la calidad de suelos en sistemas agroforestales dinámicos versus sistemas convencionales en el semiárido de Cochabamba−Bolivia. In M. Azero-Alcocer (Ed.), *Evaluación de sistemas agroforestales dinámicos en el semiárido de Cochabamba,* (pp. 105−132). Universidad Católica Boliviana de San Pablo. https://chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fcba.ucb.edu.bo%2Fwp-content%2Fuploads%2F2019%2F02%2FEvaluaci%25C3%25B3n-de-sistemas-agroforestales.pdf&clen=18088678&chunk=true

Arbeláez-Cortés, E. (2013). Knowledge of Colombian biodiversity: published and indexed. *Biodiversity and Conservation, 22*(12), 2875−2906. https://doi.org/10.1007/s10531-013-0560-y

Burbidge, A. H., Maron, M., Clarke, M. F., Baker, J., Oliver, D. L., & Ford, G. (2011). Linking science and practice in ecological research and management: How can we do it better? *Ecological Management & Restoration, 12*(1), 54−60. https://doi.org/https://doi.org/10.1111/j.1442-8903.2011.00569.x

Cabin, R. J., Clewell, A., Ingram, M., McDonald, T., & Temperton, V. (2010). Bridging Restoration Science and Practice: Results and Analysis of a Survey from the 2009 Society for Ecological Restoration International Meeting. *Restoration Ecology, 18*(6), 783−788. https://doi.org/https://doi.org/10.1111/j.1526-100X.2010.00743.x

Carbone, L. M., Aguirre Acosta, N., Tavella, J. R., & Aguilar, R. (2017). Cambios florísticos inducidos por la frecuencia de fuego en el Chaco Serrano. *Bol. Soc. Argent. Bot, 52*(4), 753 − 778. https://doi.org/52.10.31055/1851.2372.v52.n4.18861

Castañeda Rincón, J. A. (2019). *Elaboración e implementación del programa de Educación Ambiental y Estrategias Metodológicas para la apropiación social en el componente forestal de las localidades de Antonio Nariño, San Cristóbal y Teusaquillo.* [trabajo de grado]. http://hdl.handle.net/11349/24456

Chepstow-Lusty, A. (2011). Agro-pastoralism and social change in the Cuzco heartland of Peru: a brief history using environmental proxies. *Antiquity, 85*(328), 570−582. https://doi.org/85.570-582.10.1017/S0003598X0006796X.

Deacon, N. J., & Cavender-Bares, J. (2015). Limited Pollen Dispersal Contributes to Population Genetic Structure but Not Local Adaptation in *Quercus oleoides* Forests of Costa Rica. *PLOS ONE, 10*(9), e0138783. https://doi.org/10.1371/journal.pone.0138783

El Enshasy, H., Maftoun, P., Johari, H., Soltani, M., Malek, R. A., & Othman, N. (2015). The Edible Mushroom Pleurotus spp.: I. Biodiversity and Nutritional Values. *International Journal of Biotechnology for Wellness Industries, 4*, 67−83. https://doi.org/10.6000/1927-3037.2015.04.02.4

Escorcia-Otàlora, T. A. (2008). *El análisis bibliométrico como herramienta para el seguimiento de publicaciones científicas, tesis y trabajos de grado* [trabajo de grado]. Pontificia Universidad Javeriana. https://repository.javeriana.edu.co/handle/10554/8212

Etter, A., McAlpine, C., & Possingham, H. (2008). Historical Patterns and Drivers of Landscape Change in Colombia Since 1500: A Regionalized Spatial Approach. *Annals of the Association of American Geographers, 98*(1), 2−23. https://doi.org/10.1080/00045600701733911

Fuller, R. A., Lee, J. R., & Watson, J. E. M. (2014). Achieving open access to conservation science. *Conservation Biology: The Journal of the Society for Conservation Biology, 28*(6), 1550−1557. https://doi.org/10.1111/cobi.12346

Garibello, J., Riaño, L., Cuellar, J., Barrera-Cataño, J. I., & Ramírez, W. (2021). Identificación de vacíos de investigación aplicada para restaurar ecosistemas terrestres en Colombia. *Colombia Forestal, 24* (1 SE-Artículos de investigación científica y tecnológica), 88−107. https://doi.org/10.14483/2256201X.15679

Grindle, M. S. (2017). *Politics and Policy Implementation in the Third World.* Princeton University Press. https://doi.org/doi:10.1515/9781400886081

Hobbs, R., & Suding, K. (2009). *New Models for Ecosystem Dynamics and Restoration.* Society for Ecological Restoration International. https://books.google.cg/books/about/New_Models_for_Ecosystem_Dynamics_and_Re.html?hl=fr&id=TxwKQG_7HlgC&output=html_text

Juwarkar, A.A., & Singh, L. (2016). Biodiversity Promotion in Restored Mine Land through Plant-Animal Interaction. *Journal of Ecosystem Ecography, 06*(01), 2. https://doi.org/10.4172/2157-7625.1000176

Kimball, S., Lulow, M. E., Mooney, K. A., & Sorenson, Q. M. (2014). Establishment and Management of Native Functional Groups in Restoration. *Restoration Ecology, 22*(1), 81−88. https://doi.org/https://doi.org/10.1111/rec.12022

Koziol, L., & Bever, J. D. (2017). The missing link in grassland restoration: Arbuscular mycorrhizal fungi inoculation increases plant diversity and accelerates succession. *Journal of Applied Ecology, 54*(5), 1301−1309. https://doi.org/https://doi.org/10.1111/1365-2664.12843

López-Rosas, H., & Moreno-Casasola, P. (2012). Invader versus natives: Effects of hydroperiod on competition between hydrophytes in a tropical freshwater marsh. *Basic and*

*Applied Ecology, 13*(1), 40−49. https://doi.org/https://doi.org/10.1016/j.baae.2011.10.004

MADS. (2014). *Informe de Gestión 2014.* Ministerio de Ambiente. https://www.minambiente.gov.co/images/planeacion-y-seguimiento/pdf/Informes_de_Gestión/Informe_de_Gestión_MADS/INFORME_GESTION_MADS_2014.pdf

Menz, M. H. M., Dixon, K. W., & Hobbs, R. J. (2013). Hurdles and opportunities for landscape-scale restoration. *Science, 339*(6119), 526−527. https://doi.org/10.1126/science.1228334

Miller, B. P., Sinclair, E. A., Menz, M. H. M., Elliott, C. P., Bunn, E., Commander, L. E., Dalziell, E., David, E., Davis, B., Erickson, T. E., Golos, P. J., Krauss, S. L., Lewandrowski, W., Mayence, C. E., Merino-Martín, L., Merritt, D. J., Nevill, P. G., Phillips, R. D., Ritchie, A. L., Ruoss, S., & Stevens, J. C. (2017). A framework for the practical science necessary to restore sustainable, resilient, and biodiverse ecosystems. *Restoration Ecology, 25*(4), 605−617. https://doi.org/https://doi.org/10.1111/rec.12475

Murcia & Guariguata. (2014). La restauración ecológica en Colombia: Tendencias, necesidades y oportunidades. Center for International Forest and Research (CIFOR) Ocassional Paper, *107.* http://www.cifor.org/publications/pdf_files/occpapers/OP-107.pdf

Palmer, M. A., Menninger, H. L., & Bernherdt, E. (2010). River restoration, habitat heterogeneity and biodiversity: a failure of theory or practice? *Freshwater Biology, 55*(s1), 205−222. https://doi.org/https://doi.org/10.1111/j.1365-2427.2009.02372.x

Páramo Pérez, M. E., Lindig-Cisneros, R., & Moreno-Casasola, P. (2018). Potencial de invasión de *Phragmites australis* en comunidades dominadas por especies nativas ante disturbios por fuego en condiciones controladas. In *Hidrobiológica , 28*, 201−207. https://doi.org/https://doi.org/10.24275/uam/izt/dcbs/hidro/2018v28n2/lindig

Parrado-Roselli, A., Gonzalez-M., R., & Garcia, H. (2016). Estado actual de la investigacion científica publicada sobre los bosques colombianos. *Biodiversidad en la Practica 1*(1), 177−197. https://bit.ly/3A2AfWx

Perkins, L. B., & Hatfield, G. (2016). Can commercial soil microbial treatments remediate plantsoil feedbacks to improve restoration seedling performance? *Restoration Ecology, 24*(2), 194−201. https://doi.org/https://doi.org/10.1111/rec.12302

Pizarro-Tobías, P., Fernández, M., Niqui, J. L., Solano, J., Duque, E., Ramos, J.-L., & Roca, A. (2015). Restoration of a Mediterranean forest after a fire: bioremediation and rhizoremediation field-scale trial. *Microbial Biotechnology, 8*(1), 77−92. https://doi.org/https://doi.org/10.1111/1751-7915.12138

Quétier, F., Regnery, B., & Levrel, H. (2014). No net loss of biodiversity or paper offsets? A critical review of the French no net loss policy. *Environmental Science & Policy*, 38, 120−131. https://doi.org/https://doi.org/10.1016/j.envsci.2013.11.009

Ramirez, W., Murcia, C., Guariguata, M. R., Thomas, E., Aguilar, M., & Isaacs, P. (2016). Restauración ecológica: los retos para Colombia. In *Biodiversidad 2015. Estado y tendencias de la biodiversidad continental de Colombia* (p. 150). http://reporte.humboldt.org.co/biodiversidad/2015/cap3/308/#seccion1

Rato, C., Harris, D. J., Perera, A., Carvalho, S. B., Carretero, M. A., & Rödder, D. (2015). A Combination of Divergence and Conservatism in the Niche Evolution of the Moorish Gecko, *Tarentola mauritanica* (Gekkota: Phyllodactylidae). *PLoS ONE, 10*(5), e0127980. https://doi.org/10.1371/journal.pone.0127980

Stavi, I., Siegal, Z., Drori, B., Hyams, E., Shafir, A., Kamiski, Y., Al-Ashhab, A., Dorman, M., & Tsoar, A. (2018). Single Session of Chiseling Tillage for Soil and Vegetation Restoration in Severely Degraded Shrublands. *Water 10*(6), 755. https://doi.org/10.3390/w10060755

Van Rossum, F., Hardy, O. J., Le Pajolec, S., & Raspé, O. (2020). Genetic monitoring of translocated plant populations in practice. *Molecular Ecology, 29*(21), 4040−4058. https://doi.org/https://doi.org/10.1111/mec.15550

Wagner, M. R., Lundberg, D. S., Coleman-Derr, D., Tringe, S. G., Dangl, J. L., & Mitchell-Olds, T. (2014). Natural soil microbes alter flowering phenology and the intensity of selection on flowering time in a wild *Arabidopsis relative. Ecology Letters, 17*(6), 717−726. https://doi.org/https://doi.org/10.1111/ele.12276

Wang, G., Schultz, P., Tipton, A., Zhang, J., Zhang, F., & Bever, J. D. (2019). Soil microbiome mediates positive plant diversity-productivity relationships in late successional grassland species. *Ecology Letters, 22*(8), 1221−1232. https://doi.org/https://doi.org/10.1111/ele.13273

Zamora, F., Torres, D., Medina, M., & Labarca, R. (2017). Efecto de los sistemas agroforestales sobre La fertilidad de suelos de ladera de la sierra Falconiana (Venezuela). *Revista Academia, 16*(37), 71−82. https://bit.ly/3fy2Fhw

Zavodna, M., Abdelkrim, J., Pellissier, V., & Machon, N. (2015). A long-term genetic study reveals complex population dynamics of multiple-source plant reintroductions. *Biological Conservation, 192*, 1−9. https://doi.org/https://doi.org/10.1016/j.biocon.2015.08.025