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Contrasting Stakeholders' Perceptions of Pine Plantations in the *Páramo* Ecosystem of Ecuador

Carlos Quiroz Dahik [1,2,*], Patricio Crespo [1], Bernd Stimm [2], Felipe Murtinho [3], Michael Weber [2] and Patrick Hildebrandt [2,4]

1 Departamento de Recursos Hídricos y Ciencias Ambientales, Facultad de Ciencias Agropecuarias, Facultad de Ingeniería, Universidad de Cuenca, Av.12 de abril s/n, Cuenca 0101168, Ecuador; patricio.crespo@ucuenca.edu.ec

2 Institute of Silviculture, Center of Life and Food Sciences Weihenstephan, Technische Universität München, Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany; stimm@mytum.de (B.S.); m.weber@tum.de (M.W.); hildebrandt@tum.de (P.H.)

3 International Studies and Institute of Public Service, Seattle University, 901 12th Avenue, Seattle, WA 98122-1090, USA; murtinhf@seattleu.edu

4 Institute of Forest Management, Center of Life and Food Sciences Weihenstephan, Technische Universität München, Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany

* Correspondence: caquirozd@hotmail.com; Tel.: +49-08161-71-4690

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Abstract: The *páramo*, a collection of Neotropical alpine ecosystems, plays a prominent role in ecosystem services (ESs), providing water supply and regulation, conservation of biodiversity, and carbon storage in soil. The establishment of pine plantations for carbon sequestration and wood production has recently raised questions concerning the possible impact on the *páramo's* ES. This study identifies the main stakeholders in this field and compares and contrasts their perceptions of the impact of pine plantations on the *páramo's* ES, because the disparity among stakeholders' perceptions must be addressed to achieve sustainable management. The data were gathered using 56 semi-structured interviews and were qualitatively analyzed. The results show that the main stakeholder groups (landowners, local government officials, foresters, and nature conservationists) acknowledge the important ES of the plantations. The perception of plantation impact varies among and within stakeholder groups, however, on specific functions, such as water provision, carbon storage, erosion prevention, and habitat function for wildlife and natural vegetation. Consideration and integration of these perceptions can help policy makers and organizations develop sustainable policies for the future management of the *páramo* ecosystem.

Keywords: Andes; ecosystem services; exotic plantations; *Pinus patula*

1. Introduction

Tropical alpine ecosystems, of which the *páramo* is one of the most important and widespread, provide ecosystem services (ESs) to more than 100 million people [1]. The most prominent ESs the *páramo* provides are water supply and regulation, biodiversity conservation, and carbon storage [2]. The majority of the main cities in the northern Andes benefit from these services for domestic and industrial water supply, irrigation, and the generation of hydroelectric power [3]. In addition to providing these ESs, the *páramo* is important for the establishment of economic activities. The *páramo* has long been used for grazing llamas and alpacas, and in the last few centuries, sheep, cattle, and horses [4,5]. In the last century, the *páramo* has also seen use for plantations, predominantly of pine. These plantations have varied purposes, including wood production, restoration of degraded land, and in the last few decades, generation of carbon credits as part of the Climate Change Kyoto Protocol, which has caused an increase in the rate of plantation establishment [6,7].

Given the potential positive impact of wood production both for local communities and for carbon sequestration, pine plantations have been broadly recognized as a valuable use of land in the high altitudes of the Andes [6,8]. Several recent studies have, however, raised critical views on *páramo* pine afforestation, taking into consideration their potential negative effects on water regulation and carbon storage [9–13]. More recently, some environmental non-governmental organizations (NGOs) and public media adhering to these views have criticized plantations of pine trees on *páramo* sites. For example, an Ecuadorian newspaper [14] published an article entitled "*Pinos destructores*" (destructive pines), in which pine plantations on *páramo* sites were blamed for the loss of native forests and biodiversity. Several environmental NGOs have also condemned the plantations for diminishing the water supply, drying the soil, and producing a negative economic impact on landowners [15,16].

Opinions on the benefits and risks of pine afforestation on *páramo* sites are both inconsistent and divergent, which presents a challenge to policy makers. The current high level of uncertainty about the future establishment and management of pine plantations is a direct consequence of these divergent opinions. Urgenson [17] emphasizes that the comprehension of stakeholder perceptions is an important means of understanding the opportunities and constraints of ecosystem conservation. Future management of the *páramo* therefore depends largely on reconciling the different stakeholder perceptions. In Ecuador, for example, Gonzales [18] describes how the country's new constitution (approved in 2008) created regulations that guarantee the active and ongoing participation of indigenous nationalities, local communities, forest stakeholders, and the general public in the planning, execution, and control of all forestry activities.

The objectives of this study were (i) to identify the main groups of stakeholders related to the establishment of pine plantations in the *páramo* ecosystem of Ecuador; (ii) using qualitative analysis, to explore and contrast stakeholder perceptions of both the negative and positive impacts of pine plantations on *páramo* ESs in Ecuador. This analysis contributes to the environmental management literature by illustrating the main differences in stakeholder perceptions and current scientific knowledge, ultimately emphasizing the need for additional knowledge. The results of this study are intended to improve public discussions of better management practices for future and already established plantations in *páramo* ecosystems.

2. Materials and Methods

2.1. Study Area

The Neotropical alpine ecosystem *(páramo)* is a high mountain ecosystem situated between the upper limit of the continuous closed forest and the upper limit of plant life, mostly distributed in the northern Andes; the traditional natural vegetation consists of tussock grasses, large rosette plants, shrubs with evergreen, coriaceous and sclerophyllous leaves, and cushion plants [19]. The *páramos* of northern and central Ecuador are found generally from 3500 masl, and in the south they can be found from 2800 masl and higher [20]. In the *páramos* of Ecuador, the annual precipitation varies widely (between 500 and 2000 mm) [19,21] even within rather short ranges, due to the complex topography of the mountains system [22]. In most of the territory, precipitation presents a bimodal pattern with rainy seasons from February to May and from October to December. *Páramos* have a generally cold and humid climate with sudden changes in weather and diurnal fluctuation in temperature oscillating from below freezing to 25 °C, with an annual average that varies between 2 and 10 °C [19,21,23,24]. Soil is one of the most important characteristics of the *páramo*; *páramo* soils act as huge carbon pools, storing and accumulating organic carbon, due to the formation of organometallic complexes that physically protect the humus against decomposition [25].

Interaction between humans and the *páramo* goes back 10,000 years, when parts of the *páramo* were used for hunting and gathering. The most important human impact on the Ecuadorian *páramo* began with the arrival of the Incas, who began to use the lower parts of the *páramo* for agriculture, as well as for grazing llamas and alpacas [4]. Later, Spanish invaders took the most productive

lands in the valleys and displaced the native inhabitants to the highlands, some of them into the *páramo*. The Spanish also replaced the south American camelids with sheep, cattle, and horses and began burning large tracts of *páramo* to encourage the growth of tender forage [5]. Although the *páramo's* primary production is not high, as a whole it produces enough plant material to be partially usable for livestock grazing and supplies part of the population's demand for meat and milk [26]. More than 500,000 people, most of them from indigenous communities, live near the *páramo* and use it for productive agriculture [27]. As in other areas in the Ecuadorian Andes, people living inside or close to the *páramo* ecosystem tend to be relatively marginalized. Their main livelihood is agriculture, including cattle grazing, although in some cases they have off-farm income [28].

Pines were introduced to Ecuador in the 1920s as part of governmental forestation programs. At the beginning, these forestation programs focused mainly on meeting the need for fuel, restoring degraded landscapes and, in the case of some large plantations, contributing to economic development [6]. In recent decades, the establishment rate of plantations increased, mainly to generate carbon credits in the context of the clean development mechanism (CDM) [7]. This program promoted the plantation of pines in the *páramo*, based on the belief that they were effective at sequestering carbon from the atmosphere [29]. In Ecuador, the private company PROFAFOR Latinoamérica S.A. (Programa FACE de Forestación del Ecuador S.A.) created and funded by the Face Foundation (Forest Absorbing Carbon Dioxide Emissions), a foundation founded by a consortium of Dutch electricity companies (SEP), is the largest company currently compensating for CO_2 emissions through forestry. Since 1993, PROFAFOR has signed 152 forestation contracts with private and community landowners for carbon sequestration through reforestation and afforestation, 95% of which are located in the Andean highlands [29]. Up to 2003, 22,000 ha of plantations were established in the Ecuadorian highlands, of which 94% are pine plantations [30]. Most of the contracts were signed for 20 years, the expected rotation period for these pines. Landowners are compensated for the costs of the seedlings and their planting and are given an annual visit by a technician. Landowners are obliged to protect their plantations with a firewall and to manage them by pruning and thinning. At harvest time, the landowners receive 70% of the revenue and in the event they want to reforest the area, the full revenue [29].

The interviews given to pine plantation owners and local government authorities were carried out in the Azuay province, situated in southern Ecuador (Figure 1). *Páramo* landowners in the Azuay province include indigenous communities and mestizo farmers (of mixed Spanish and indigenous descent) [31]. This area was chosen because of the establishment of extensive pine plantations in the *páramo* and the society's dependence on the *páramo's* ESs. One of the most critical ESs this region provides is the water for the Paute hydroelectric complex, the oldest and largest in the country [32]. The local University of Cuenca, in collaboration with Belgian and German universities, developed a water resources program that became the main point of reference for ecohydrological research in the *páramo* [4].

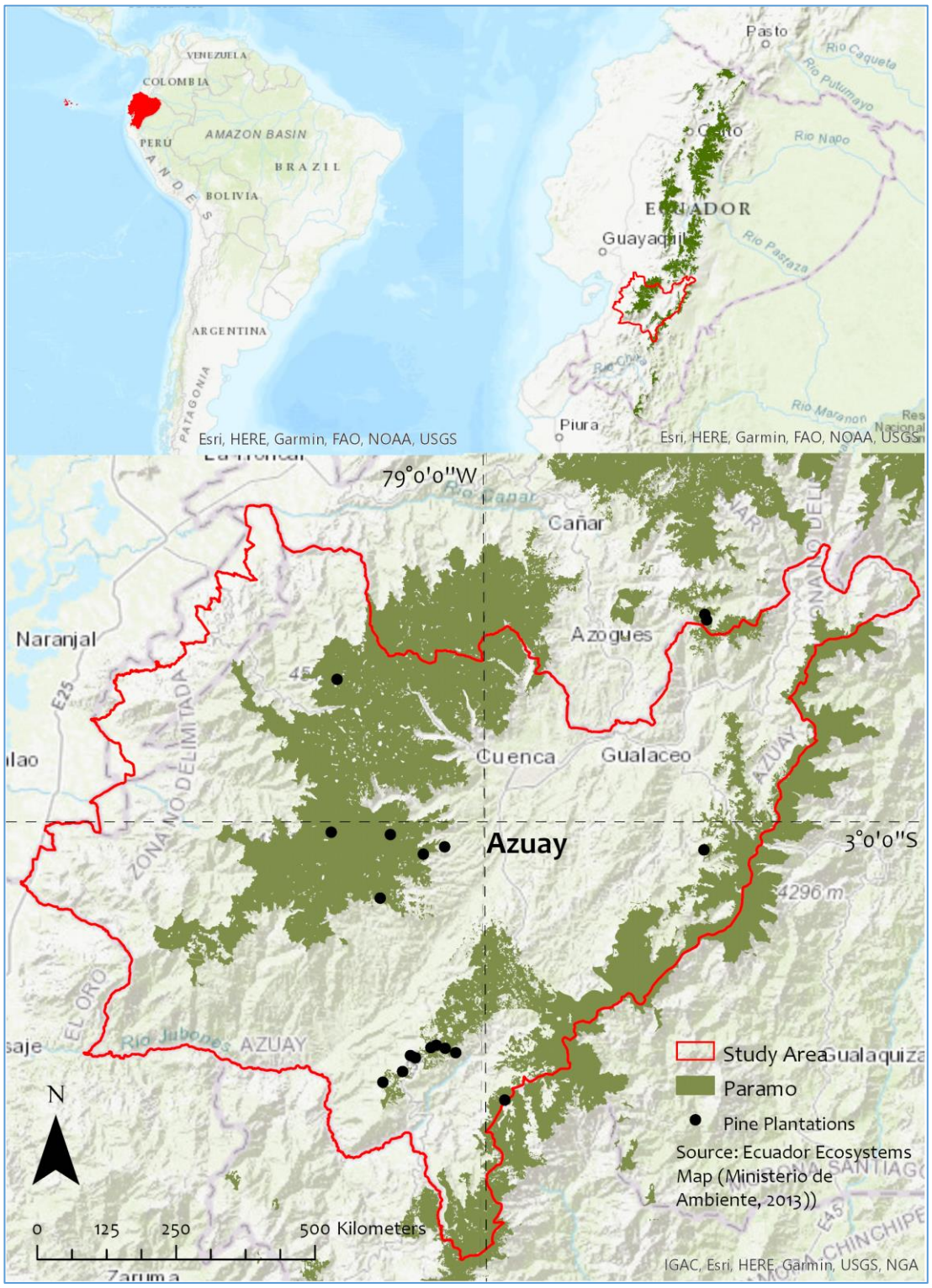

Figure 1. Map of Ecuador indicating the extent of the *páramo* ecosystem and the location of pine plantations corresponding to the group of landowners.

2.2. Methodology

To assess stakeholder perceptions, we followed the definition of Grimble and Chan [33], in which stakeholders are individuals within a system "who affect, and/or are affected by, the policies, decisions

and actions of the system; they can be individuals, communities, social groups or institutions of any size, aggregation or level in society. The term thus includes policy makers, planners and administrators in government and other organizations, as well as commercial and subsistence user groups". We identified and contacted public and private organizations that either deal with forestry in the *páramo* and/or are involved in the conservation and sustainable management of the *páramo.* We created a map of stakeholders to identify the main actors in relation to pine plantations in the *páramo*. After the mapping, we identified four main groups of stakeholders: landowners, local governments, foresters, and nature conservationists. We made a list of potential interview subjects from each group of stakeholders. This list was verified and streamlined [33], as each interviewee was also asked to recommend other interviewees, using a snowball sampling technique [34], so that only those who were essential to the analysis were included. Availability also determined the final sample of interview subjects. Following standard practice, a substantial number of key informants from each group were interviewed [35], including: 19 landowners, 15 foresters, 12 nature conservationists, and 10 interviewees from local governments.

The interviews were semi-structured and used open-ended questions to guide the interview. We developed two interview formats: Appendix A.1, which was applied to the owners of the plantations and Appendix A.2 for the rest of the interviewees (Appendixes A.1 and A.2). The difference between the formats was that A1 collected more detailed information about the owners' plantations while A2 collected information about the plantations in the *páramos* in general. With the exception of certain specific information in A1, the rest of the questions were similar in such a way that the information could be compared. The interviews included an introduction to the research project and also assured confidentiality. We conducted 56 interviews in Spanish between June 2013 and June 2015, and collected information on: (1) the characteristics of the plantations (date and place of establishment, extension, type of agreement if it is the case, etc.) and the applied management activities (this information was collected only from landowners); (2) the motivation for establishing pine plantations; (3) the land conditions before planting (the response from landowners related to their own plantations, the replies of the other stakeholders were related to their own experience with pine plantations); (4) the perceptions of the plantations' positive and negative impacts (these perceptions were coded following the categories of ESs used by The Economics of Ecosystems and Biodiversity [36]; provisioning, regulating, supporting, and cultural ES); and (5) future plantations. Interviews were conducted in person by one or two members of our team. One interview was conducted via Skype. The interviews lasted between 26 and 90 min, depending on the availability of the interview subject. Where consent was granted, interviews were recorded (32 interviews) and transcribed (all 56 interviews).

3. Results

Results were grouped in two main categories: (i) stakeholder classification; and (ii) information collected in the interviews.

3.1. Stakeholder Classification

We classified the stakeholders in four groups: landowners, local governments, foresters, and nature conservationists. Stakeholders from the groups of landowners and local governments were located in the *páramos* of Southern Ecuador, while stakeholders from the groups of foresters and nature conservationists were represented by local, regional, national, and international organizations (Table 1).

- Landowners; this group was represented by property owners or land managers with primary decision-making authority for the property. The properties included pine plantations located in the highlands of South Ecuador.
- Local governments; this group was represented by representatives from the Juntas Parroquiales Rurales, the autonomous local governments decentralized from the central government; they are in charge of the protection and sustainable use of the environment and the biodiversity of their jurisdiction. For this reason, they have to promote plans and programs of conservation, afforestation, reforestation, and other actions tending towards the fulfillment of this objective. Additionally, local

governments have to coordinate environmental management with other entities (public and/or private) and prevent the generation of conflicts derived from inadequate management of natural resources. For this study, we considered only local governments from territories with pine plantations (established in private properties) in the *páramos* of southern Ecuador.

- Foresters; this group was represented by forestry professionals and forestry researchers working for public institutions, private organizations or companies, and universities. Of the public institutions, we selected the national and regional forestry departments, which are the entities in charge of promoting and regulating commercial forestation activities. The private companies consisted of timber companies and others that specialized in the establishment of plantations for climate change mitigation and the sustainable management of plantations. The universities included were involved in research and education. All of them were involved in activities in the *páramos*.
- Nature conservationists; this group was represented by researchers and professionals engaged in the conservation of natural resources from both the public and private sectors or universities. From the public institutions we included the national department that is in charge of forest restoration. The private institutions considered were specialized in research, managements and conservation of the *páramo* ecosystem. Some of them were international NGOs that had local representation.

Table 1. Stakeholders classification in relation to pine plantations in the *páramo* ecosystem of Ecuador.

Stakeholder Classification	Stakeholder	Institutional Level	Environmental Interest
Landowners	Pine plantation owners	Local on-site	Timber production, conservation
Local governments	Local authorities	Local	Biodiversity conservation, timber production, and conflict avoidance
Foresters	Companies	Local, regional, national	Climate change mitigation, sustainable forestry, advice on the creation and implementation of sustainable forest management policies
	Forest departments	Local, regional, national	Plantation productivity, sustainable management of commercial plantations
	Universities	Local, regional, national	Research, sustainable management of plantations
	Wood industry	Regional, national	Plantation productivity
Nature conservationists	Consortium	Regional, national, international	Applied research, information exchange and policy development
	Corporation	Regional, national, international	Research, training, and technical support of the sustainable management of the *páramo*
	Environmental departments	Local, national	Forestry regulation on protected areas
	NGOs	Regional, national, international	Preservation and restauration of ecosystems in the highlands
	Private mercantile trust	Local, regional	Research, monitoring, forest restoration, and planting in the highlands
	Universities	Regional, national	Research, sustainable management of the *páramo*

3.2. Information Collected in the Interviews

3.2.1. Characteristics and Management of the Plantations

The plantations of the 19 interviewed landowners cover a total area of 4886 ha. Excluding a single plantation of 2400 ha, the 18 remaining plantations varied in size between 19 and 350 ha with an average size of 138 ha. Of the plantation area, 70% is located above 3500 masl. The average size of the plantations increased with altitude, from 90 ha (2800–3200 masl), over 152 ha (3200–3500 masl) to 172 ha above 3500 masl. In all, 4 landowners manage their plantations autonomously, 14 have management contracts with PROFAFOR, and 1 has a contract with a local governmental institution.

The contracts with PROFAFOR were signed between 1994 and 2000 for an assumed rotation time of 20 years. One of the four autonomously managed plantations has been completely harvested and two of the plantations with PROFAFOR contracts harvested a minimum percentage of their area (one 7% and the other 0.7%). Although the contracts obligate the owners to thin and prune the plantations, 80% of the plantations had not received any thinning and 20% only received thinning in limited areas. Similarly, only 33% of the plantations had received a complete pruning, while 54% had been pruned only in selected parts of the plantation and 13% had not been pruned at all. Two plantations, both located above 3500 masl, received neither thinning nor pruning.

3.2.2. Motivation for the Establishment of Plantations

Although multiple answers were possible, the results show that the majority of landowners (89%) established their plantations for the purpose of wood production, nearly a third for carbon sequestration (as part of the PROFAFOR program), while a quarter mentioned both reasons, and just one (5%) mentioned erosion prevention. These results correspond with the perception of the other stakeholders (local governments, foresters, and nature conservationists), 70% of whom perceived wood production and 11% carbon sequestration as the main motivation for establishment. They also included other purposes such as erosion prevention (14%) and water regulation and supply (8%) (Figure 2).

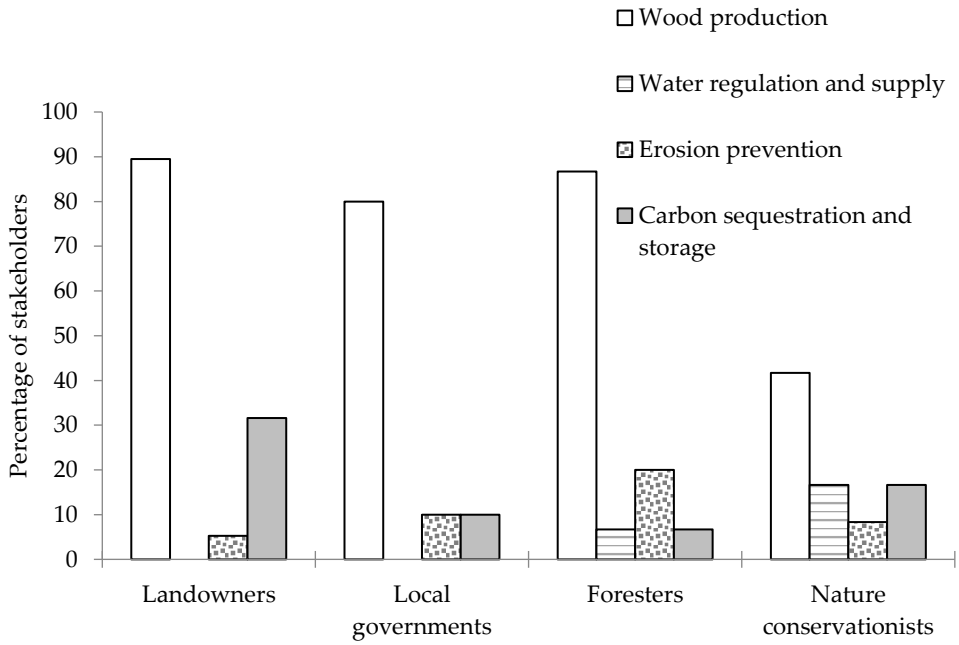

Figure 2. Stakeholder motivations (landowners) and perceptions (local governments, foresters, and nature conservationists) for the establishment of pine plantations in the highlands of Ecuador (multiple answers possible).

3.2.3. Stakeholder Perceptions of the Land Condition Previous to Afforestation

To characterize the land conditions before afforestation, we referred to the categories established by Hofstede et al. [21] in their study of the Ecuadorian *páramo.* Nature conservationists (75%) and landowners (74%) agreed in their perception that the category of the land used for the afforestation was "grazed *páramo*," characterized by tussock grass with signs of frequent burning and the presence of cattle. Only a few landowners (21%) and foresters (7%) perceived that the plantations were established in conserved *páramo*, characterized by tall tussock grasses, without any signs of burning, without cattle, and with the presence of native vegetation. More than half of the foresters (60%) and half of the local government (50%) perceived that most plantations were established on both types of *páramo* (Figure 3).

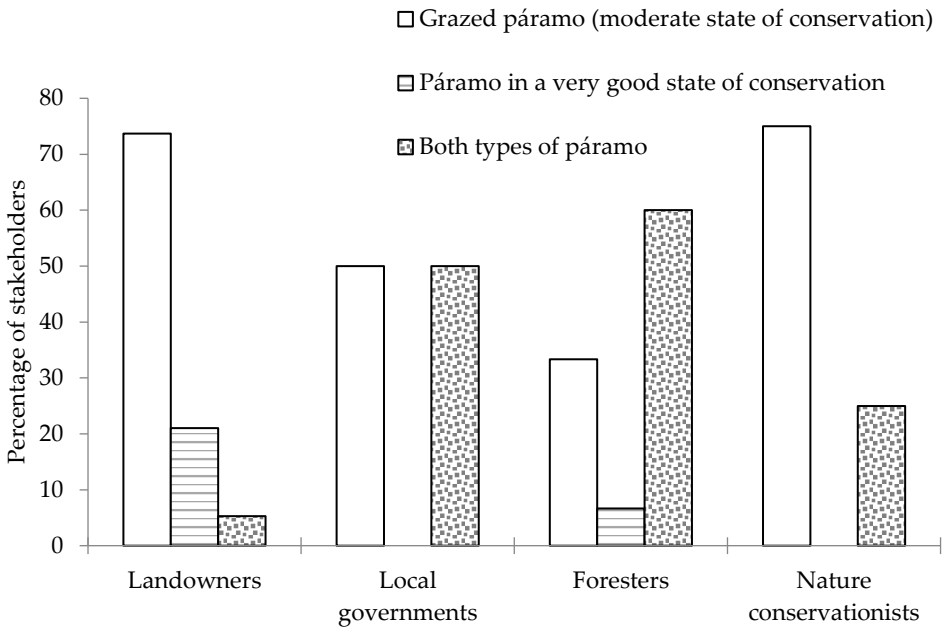

Figure 3. Stakeholder observations (landowners) and perceptions (local governments, foresters, and nature conservationists) about the prior condition of the land before the establishment of pine plantations in the highlands of Ecuador.

3.2.4. Stakeholder Perceptions of the Impacts Caused by Pine Plantations

In interviews, the stakeholders noted four categories of ESs: provisioning, regulating, supporting, and cultural services. Among the ESs mentioned by at least 25% of the interview subjects, the most important subcategories were: providing wood, regulating carbon sequestration and storage, regulating water flows, regulating erosion prevention or maintenance of soil fertility, and supporting habitat for species (Table 2).

Table 2. Summary of categories, subcategories, and brief description of the ESs mentioned by the interviewees. The table includes the percentage of respondents that mentioned each ES in the context of the research. Adapted from [36] and interviews with stakeholders.

Category	Subcategory	Brief Description	Respondents (%)
Provisioning	Raw materiales (wood)	Ecosystems provide a great diversity of materials including wood.	91
	Freshwater	Ecosystems regulate the flow and purification of water. Vegetation and forests influence the quantity of water available locally.	2
Regulating	Carbon sequestration and storage	Ecosystems regulate the global climate by storing and sequestering greenhouse gases. Forest ecosystems are carbon stores.	27
	Water flows	Ecosystems and living organisms create buffers against natural disasters, thereby preventing possible damage. For example, wetlands can soak up flood water. Regulation of natural drainage, irrigation and drought prevention.	45
	Erosion prevention and maintenance of soil fertility	Soil erosion is a key factor in the process of land degradation and desertification. Vegetation cover prevents soil erosion. Soil fertility is essential for plant growth.	57

Table 2. *Cont.*

Category	Subcategory	Brief Description	Respondents (%)
Supporting	Habitat for species (refugium)	Habitats provide everything that an individual plant or animal needs to survive: food, water, and shelter. Each ecosystem provides different habitats that can be essential for a species' lifecycle.	70
Cultural	Ecotourism	Ecosystems and biodiversity play an important role for many kinds of tourism, which in turn provides considerable economic benefits. Cultural and eco-tourism can also educate people about the importance of biological diversity.	4

- Provisioning wood

While 70% of local governments, foresters, and nature conservationists perceived provisioning wood to be a profitable service of pine plantations in the Ecuadorian *páramo*, 79% of landowners were dissatisfied with the profitability of the wood produced by their plantations (Figure 4). Some landowners were dissatisfied with the current level of development of their trees, especially in the higher altitudes. As one landowner stated, "in the upper part of the plantation the pines are small, in these places the pines have not grown". The same group of landowners complained about the high cost of managing their plantations. As one landowner expressed it, "according to the contract we had to carry out three prunings and one thinning, but we do not have enough economic resources, we just did one pruning in the entire plantation. It is clear that there will be no profits, so we are just protecting the plantation". Regarding the management of plantations, one local government representative stated, "it is not profitable, because the income produced does not cover the cost of management", and one nature conservationist argued "it was a great deception practiced on many communities, they all had subsidies for the establishment of the plantations, but nobody had financing for the management". A landowner noted that some other landowners have encountered problems with the environmental authorities, "to extract the wood we need to make some roads, but the authorities do not allow this and they do not allow us to make roads because it will damage the environment, so the trees will remain where they are". Only three landowners with plantations in lower altitudes (2800–3200 masl), who enjoyed better growth conditions, assessed provisioning wood as positive, because they had already obtained revenue from harvesting or thinning their stands.

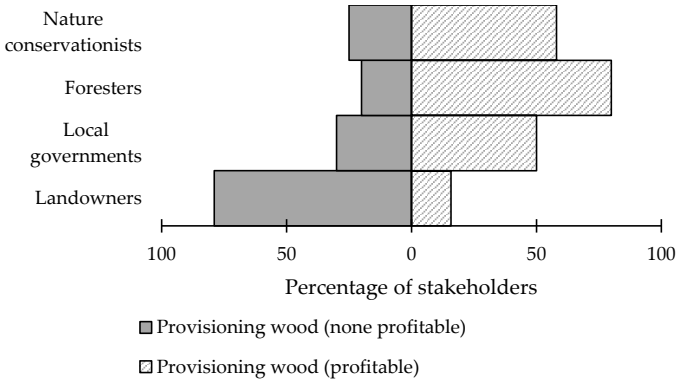

Figure 4. Stakeholder perceptions of the impact of pine plantations on provisioning wood.

- Regulating water flows

Nature conservationists (50%) and local government (60%) interview subjects had only negative perceptions of the impact of the plantations on regulating water flows (Figure 5). Of the foresters, 27% also had negative perceptions, with just 7% expressing positive assessments. Landowners, on the other hand, had more positive (37%) than negative perceptions (5%; Figure 5). Foresters and nature conservationists

referred specifically to the negative impact. As one of them commented: "the generally rapid growth of exotic plantations is having a negative effect on the hydrological balance due to the greater use of water". One landowner and some representatives of local governments also mentioned that "water sources near pine plantations have dried up"; "now there is drought around the plantations". However, one of the foresters claimed that "plantations regulate the watershed water balance". The perceptions of most of the landowners referred to their impact on springs. They explained, for example, "previously the springs were drying up; now, they are not dry, and the water flows permanently"; some of them stated that "with the establishment of the plantations the springs have recovered".

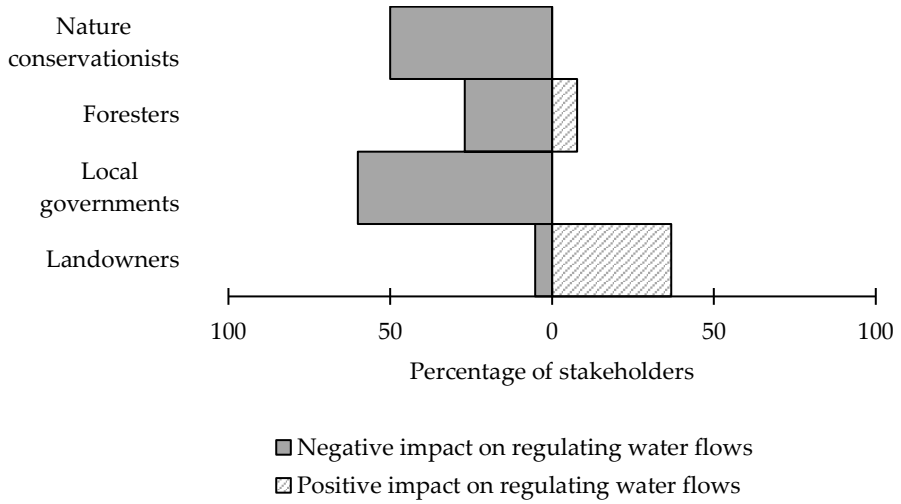

Figure 5. Stakeholder perceptions of the impact of pine plantations on regulating water.

- Regulating carbon sequestration and storage

Although 32% of the landowners said that carbon sequestration was a motivating factor for establishing a plantation, plantation impact on carbon sequestration was positively perceived by only 23% of the interviewees from among all the groups of stakeholders; 8% of the nature conservationists even expressed negative views (Figure 6). One of them explained that "in the *páramo,* approximately 90% of the carbon is stocked in the soil, and some studies showed that the capture of carbon in the biomass of the pines is causing a change in the soil carbon dynamics, causing a loss of soil carbon that could be large enough to offset the gains in biomass carbon". The interview subject emphasized, "this may lead to the failure of this type of project".

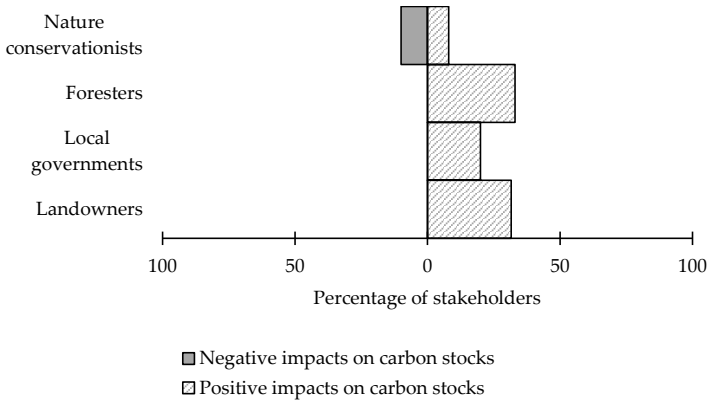

Figure 6. Stakeholder perceptions of the impact of pine plantations on regulating carbon sequestration and storage.

- Regulating erosion prevention and maintenance of soil fertility

Only the representatives of local governments were limited to negative perceptions of erosion prevention and maintenance of soil fertility; the other stakeholders had diverse perceptions (Figure 7). Positive perceptions were related to the recovery of degraded land. A landowner commented, "the plantations caused soil recovery, the pine needles help generate humus and shelter a diversity of insects"; one forester mentioned a case in which the control of desertification was attributed to the planting of pines, stating, "the process of desertification that comes from the Jubones river would have continued to advance if we would not have built a natural barrier using pines". The negative perceptions focused on the alteration of the soil properties, specifically its acidity (pH). A nature conservationist mentioned, "there is an acidification of the soil and a reduction of the water retention of the soil". On this matter, foresters and nature conservationists both observed that the impact depends on what is compared. The plantations may have a positive impact on degraded soils and a negative impact on well-preserved *páramo*.

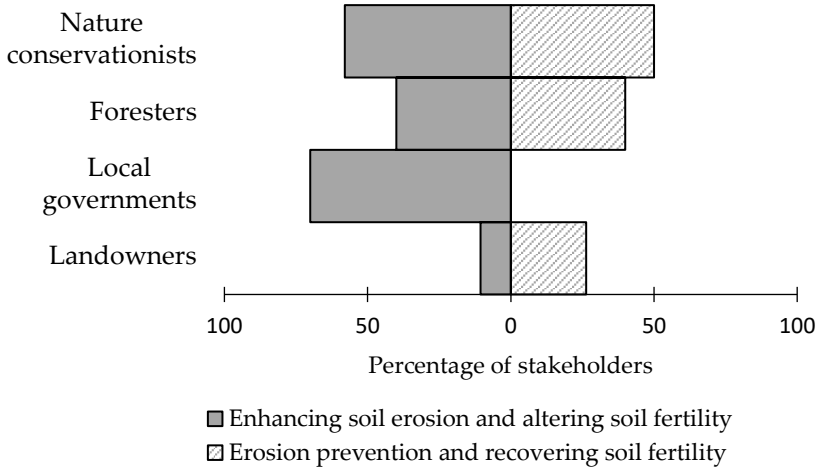

Figure 7. Stakeholder perceptions of the impact of pine plantations on regulating erosion and maintenance of soil fertility.

- Supporting habitat

Regarding this ES, two main perceptions were reported: one regarding fauna and the other one regarding flora. In relation to fauna, all stakeholders perceived that the plantations serve as a refuge for animals. Notably, almost all landowners (89%) had this perception and only 16% of local government representatives, foresters, and nature conservationists shared this perception. All landowners mentioned the presence of deer, rabbits, or guinea pigs on their plantations, and some even mentioned seeing rare mammals, such as the mountain tapir and cougar (Figure 8a). Concerning flora, all the interviewees perceived that the plantations are causing the disappearance of native plants. For example, one stated, "studies have shown alterations in the structure and composition of vegetation and a reduction of its biodiversity," and another said that "on plantations, the understory will not develop" (Figure 8b).

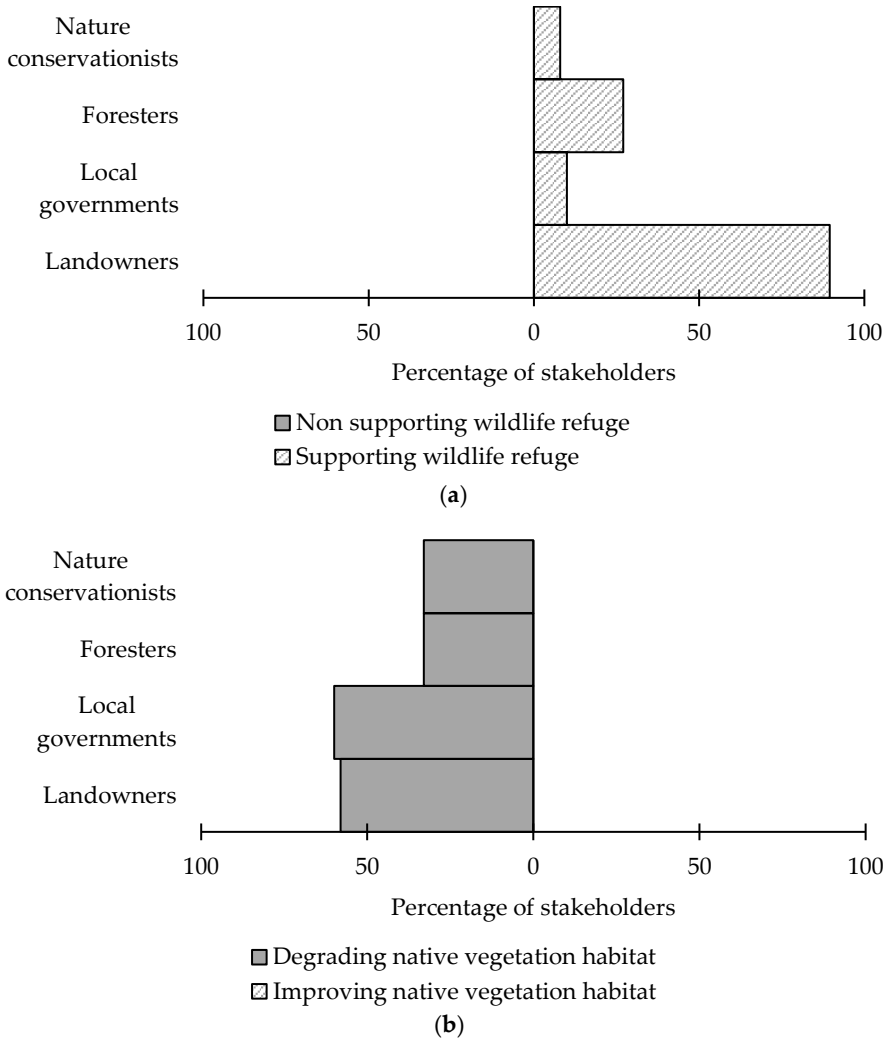

Figure 8. Stakeholder perceptions of the impact of pine plantations on supporting habitat. (**a**) Perceptions related to wildlife refuge, and (**b**) perceptions related to native vegetation.

3.2.5. Future Plantations

In this part, we collected technical information related to the future management of plantations by asking questions to local governments, foresters, and nature conservationists. The majority (67%) of representatives of local governments, foresters, and nature conservationists agree that future plantations should be established only in designated areas. A technical study by the Ministry of Agriculture (MAGAP) and the Ministry of Environment found that there was an area of 2.6 million ha available for the forest plantations to be established for commercial purposes [37]. This evaluation also specified the areas where commercial plantations cannot be established, namely, native forests or *páramo* located above 3500 masl (north of 3° latitude) and above 3000 masl (south of 3° latitude); as well as protected areas or places with slopes greater than 50°. The stakeholders interviewed further considered areas with degraded soils for plantation establishment (60% of local government representatives, 13% of foresters, and 33% of nature conservationists). However, they agreed with the MAGAP that *páramo* ecosystems (30% of local government representatives, 53% of foresters, 66% of nature conservationists), protected areas (30% of representatives of local governments, 47% of foresters, 42% of nature conservationists), and places with existing water sources (20% of representatives of local governments, 13% of foresters, 17% of nature conservationists) should not be afforested using plantations. Concerning the potential for improvement of the plantations, the interviewees

highlighted four topics: the proper management of the plantations (38%), establishing plantations only in appropriate places for forestry (35%), the improvement of the genetics of the forest reproductive material (19%), and encouragement of research in the public sector (19%).

This section contains the information related to the interest of the stakeholders in future research. The different stakeholders clearly differentiated topics for further research. Most landowners (68%) were interested in practical aspects related to the management of the plantations, such as the silviculture and commercialization of the wood, and 26% on the impact of the plantations on the soil. The representatives of local governments were mainly interested in the impact of plantations on hydrology (50%), while the foresters had a special interest in the impact of plantations on carbon sequestration and storage (26%), in silviculture (20%), and the generation of work. Of the foresters, 13% were also interested in the impact on hydrology, soil, natural regeneration, and reforestation with native species. The nature conservationists prioritized the impact on hydrology (33%), natural regeneration (33%), and carbon capture (17%). Finally, all landowners expressed their willingness to provide their own plantations for any type of study to support the development of any kind of future research. All stakeholders were willing to collaborate and interact with researchers.

4. Discussion

In recent years the benefits of pine plantations in the *páramo* have been increasingly questioned [4,12], mainly due to the awareness of the importance of the *páramo*'s ESs [2,4]. Most stakeholders we interviewed agreed that the triggering factor for the establishment of pine plantations in the *páramo* is wood production. Pines were introduced to Ecuador in the 1920s, primarily to provide fuel and timber or to restore degraded soils, generally in the highlands, including the *páramo*. Throughout the 1970s and 1980s, the government also promoted the establishment of planations for the same objectives [7]. Since 1993, plantations were established under contract with PROFAFOR, which are mostly located in the highlands (95%) [29], with the purpose of sequestering CO_2 from the atmosphere to generate emissions-reduction credits that could be sold to industrialized countries. However, the amount of carbon credits generated depends on the amount of biomass produced and soil organic carbon stocked, which makes this aspect very important if this type of project is to be successful.

There was a discrepancy between landowners and other stakeholders in their perception of the condition of the land before afforestation. Hofstede et al. [9] and Chacon et al. [38] found in their studies that the plantations in the *páramo* were generally established on extensively grazed areas, which supports the landowners' perceptions and downplays the idea that most plantations damaged *páramo* sites that had good conservation status.

The ES of provisioning wood was mentioned by almost all interviewees. Our study revealed an astonishing discrepancy between the landowners and the other stakeholders in their perceptions of provisioning wood. In contrast with the latter, all landowners with plantations located between 3100 and 3800 masl (79% of the plantations) were dissatisfied with the profitability of their plantations, which could be due to the unexpectedly slow growth of trees at higher elevations. This led to the fact that today, afforestation above 3500 masl is no longer recommended, as previously mentioned [39,40]. Another reason that could have affected the productivity of the plantations is deficient management practices due to the high cost of thinning and pruning. 68% of the plantations did not undertake any thinning and just 32% of the landowners have pruned their entire plantation. Other important points that should be considered and mentioned by the stakeholders are the necessity of improving the genetics of the seeds and the establishment of plantations on land suitable for wood production, rather than degraded land. On the other hand, the positive perceptions in relation to this ES could be that the interviewees associate wood productivity with the levels of production of the wood company Aglomerados Cotopaxi S.A. This company was established in 1978 in the highlands of the north-central area of Ecuador. Currently, the company has approximately 10,000 ha of pine plantations and is one of the biggest manufacturer of medium-density fiberboard (MDF) panels in the Andean region [41]. But in this case, the management of these plantations meets high standards of quality. They produce

3.6 million seedlings per year, they prepare the soil with its own substrate and apply pruning and thinning, and have forest roads to facilitate timber extraction [42]. Moreover, the company saves production costs by locating the plantations next to the production plant and has guaranteed the sale of its wood. On the contrary, all the plantations from this research located from 3460 to 3800 masl had very precarious roads that did not meet the minimum standards of forest roads [43]), which makes the commercialization of their timber even more complicated.

Concerning the regulation of water flows, in contrast to the other stakeholders and most studies, most landowners had a positive perception of this ES. Bosch et al. [44] reviewed 94 catchment experiments worldwide and found that afforestation decreases water yield. In a global synthesis of the effects of afforestation, Farley et al. [11] found reductions of annual runoff when grasslands and shrublands became afforested. The few studies done in the *páramo* ecosystem revealed similar results. Buytaert et al. [12] and Crespo et al. [3] studied the impact of afforestation with *Pinus patula* on the water yield in a *páramo* site in the south of Ecuador. They compared the water yield of a cultivated and a natural catchment and their results indicated an approximately 50% reduction in the water yield of the catchment covered with pines. In the scientific community, it is accepted that the total water consumption of forests is larger than that of short vegetation such as grasslands [12]. Furthermore, as trees have larger leaf area indexes and roughness, they produce higher evapotranspiration; trees' deeper and better-developed root systems also allow them to access deeper water levels, reducing the water yield. Nevertheless, other studies support the perception of some landowners that the afforestation of degraded land can lead to improvements in the properties of the soil and therefore to the recovery of hydrological functions [45,46]. A possible reason why most of landowners perceived a positive effect of the plantations on this ES could be linked to an increase of precipitation in the area after the establishment of the plantations. In a similar study, Farley and Bremer [5] obtained a similar response from an interviewee who mentioned that on his property, pines had caused more rain than before. In a study in the Colombian Andes, Murtinho et al. [47] found that local people related changes of water scarcity with rainfall. We compared rainfall averages from 5 hydrological stations in the area [48], within the period of 1960–1994 (years of the establishment of the plantations) with the period of 1995–2013 (years of the interviews). The comparison of the averages resulted in an increase in precipitation. From 1960 to 1994 the average was 714 mm year^{-1}, while from 1995 to 2013 it was of 1036 mm year^{-1}. To determine the factors that caused the increase in precipitation, more research would be needed, but this fact could justify the positive perception of landowners.

The ES of regulating carbon-sequestration and -storage was the less mentioned by the interviewees. It was positively perceived by 25% of the interviewees, most of them landowners (43%), probably because the landowners assume that their plantations are contributing positively to carbon sequestration and storage, since all of these landowners have a contract with PROPAFOR and surely are familiar with the company's program. The only negative perception came from the group of nature conservationists. The majority of positive perceptions were probably influenced by the promotion of carbon sequestration; in general, conifer forests are considered major terrestrial carbon reservoirs [49]. Nevertheless, studies worldwide have shown that the afforestation of grasslands can have differing outcomes depending on the previous condition or use of the land [50]. For instance, Berthrong et al. [51] found in a meta-analysis that afforestation with pines decreased stocks of soil organic carbon (SOC). Most studies in the Ecuadorian *páramo* [9,52–54] found a decrease in SOC, although Chacon et al. [38] found no change. Local studies are therefore recommended, as SOC may also be affected by climate and parental material, which may vary among regions [55]. The reduced number of interviewees that mentioned this ES could be explained because there is not much information concerning this topic, as more studies are still needed to better understand the effects of land use change on SOC stocks [54,56].

The foresters and nature conservationists had diverging perceptions of the impact of plantations on erosion prevention and maintenance of soil fertility of the *páramo*. Both groups stated that the impact depends on the characteristics of the soil when the plantation is established: if the soil is degraded, the impact of a plantation could be positive, but if the soil is in good state of conservation, then its impact is more likely to be negative. As an example of a positive impact, some foresters and nature conservationists

mentioned the plantation of pines established in the dry *páramo* of Palmira (Chimborazo province in central Ecuador). It is believed that this plantation halted the advance of sand dunes. This argument was stated in a technical report [57]. Hofstede [58] mentioned that it is obvious that pine plantations have prevented soil erosion in some *páramo* areas. For the moment, these perceptions are not based on sound scientific studies; we therefore recommend a conclusive study to assess the impact of pine plantations on erosion in one of these sites. On the other hand, the perception that erosion is enhanced or soil fertility is altered by changes in soil properties is supported by most Ecuadorian studies [9,24,59], which have shown that, for different *páramo* study sites throughout the country, the soil is considerably drier in pine plantations. Farley and Kelly [52] found more acid soils at plantations. Nevertheless, most landowners felt that the pines had led to an improvement in soil fertility. Another important factor that affects this ES is the frequency of burning commonly associated with grazed *páramo*. The perceptions of the stakeholders vary depending on what type of burning management is compared. A grassland that has been burned frequently and had intensive grazing will present few remnants of original vegetation and will have big patches of bare ground. In this type of management, erosion will be enhanced [60]. A different management with sporadic burning and extensive grazing would have less impact on this ES.

The concern of many stakeholders that the plantations may have negative effects on supporting habitats for native vegetation thanks to a degradation of such habitats has been supported by some studies in the *páramo* of Venezuela [61] and Colombia [62]; which have found that as pine coverage increases, species diversity of native vegetation decreases. In Ecuador, Hofstede et al. [9] found different results; in some plantations, the vegetation was similar to *páramo* grassland, and in others the understory was completely lacking. Farley and Bremer [5] found that in pine plantation sites plant species richness vary from lower to higher and plant species composition had large changes. Other studies [63] have also found that the type and quantity of solar radiation available in a forest influences numerous physiological, morphogenetic, and reproductive processes of plants. This effect depends on the density of the plantation, the age (the taller the pines, the less light they allow to fall on the soil), and the management of the plantation (without pruning and/or thinning, less light passes through). Concerning the function of the plantations in supporting habitat for wildlife (animals), landowners differed considerably from the other stakeholders. Almost all the landowners expressed this perception, but there is very limited research to support this belief. Molina [64] studied the biology of the white-tailed deer in the *páramo* of Venezuela, finding that the largest number of deer sightings occurs in the plantations and 70% of the inhabitants interviewed said that pine plantations benefit deer by providing refuge. According to Molina [64], these plantations are playing a positive ecological role for the preservation of the deer and the presence of this animal will depend on the renovation of these plantations. In our research, it was the landowners who highlighted the same function that the plantations are possibly providing to the animals.

Related to the future management of the plantations, the stakeholders believed that the productivity of the plantations could improve by: enhancing their management, establishing them in sites suitable for forestation, improving the genetic quality of the seeds, and supporting more research. All of these aspects corroborate the information already collected. In relation to the stakeholders' interest in future research, the results showed, as indicated Hein et al. [65], that stakeholders at different spatial scales have different interests in ESs. The landowners were mainly interested in the productivity of their plantations (management and commercialization) which also corroborates the intention for which most of them established their plantations. The local governments were interested in studies on the impact of the plantations on water resources, as water is one of the most valuable resources in rural areas. Foresters and nature conservationists were more interested in topics related to their areas of expertise such as the impact on carbon stocks and natural regeneration.

5. Conclusions

This study is one of the first to classify stakeholders in relation to pine plantations in the *páramos* of Ecuador and to report and contrast stakeholder perceptions of the impact of these plantations on the *páramo* ecosystem services. There are five main findings:

- Scientific evidence should be the starting point to reconcile the different perceptions between the stakeholders. Therefore, foresters and nature conservationists should communicate the results and nature of their research with the other stakeholders [66].
- The local knowledge provided by the perceptions of the landowners was fundamental [67] to identify gaps of knowledge related to the ES of provisioning wood and supporting habitat (wildlife refuge for animals).
- Perceptions among stakeholders differ on several aspects, such as: wood production, water regulation and supply, and support of habitat. Even within stakeholder groups, perceptions were not uniform on topics such as the regulation of erosion prevention and the maintenance of soil fertility. This disparate views should be reconciled by more interaction between stakeholders, which will facilitate linkage and information flow [68].
- Because wood production has been the main objective for the establishment of pine plantations in the *páramo*, their management must be improved; for example by establishing the plantations in lands designated for forestation, providing financial plans and silvicultural treatment, ensuring adequate road access to plantations and the fair commercialization of wood.
- It is quite unlikely that the emission-reduction objectives intended in the contracts can be achieved, especially for the plantations located in higher altitudes. Furthermore, it must be noted that the plantations may have negative effects on the provision of other ESs, such as supporting habitats for native species and regulating water flows. Consequently, the establishment of new plantations should take into account these possible trade-offs [5,69].

Identifying these perceptions may help avoid future conflicts in the management of the natural resources of the *páramo* and the design of effective conservation policies. In an Andean country like Ecuador, where awareness of the importance of *páramo* ESs has rapidly increased and is expected to continue doing so, the validation of such perceptions in future studies is important and could ultimately result in sustainable management and improved conservation of the *páramo*.

Author Contributions: C.Q.D., P.C. and P.H. developed the study design; C.Q.D. collected the data; C.Q.D., M.W. and P.H. analyzed the data; C.Q.D. wrote the paper; all authors contributed to the paper's structure and provided extensive revision. All authors read and approved the final manuscript.

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Appendix A

Appendix A.1. Interviews Applied to Landowners

Fecha:
Entrevistador:

1. Información general

A pesar de la importancia que tienen los páramos para el desarrollo socio-económico y ambiental de la zona Austral. Desde hace varios años estos ecosistemas están siendo alterados, donde la forestación con especies exóticas como el pino han sido comúnmente usadas para diversos objetivos que van desde el secuestro de carbono hasta la conservación de agua. Sin embargo, estas prácticas no han sido evaluadas y su manejo ha sido muy deficiente. Por esta razón, esta investigación tiene como objetivo evaluar las diferentes prácticas de manejo forestal sobre la producción de madera, biodiversidad vegetal, secuestro de carbono y regulación de agua. Para ellos varias parcelas de monitoreo serán instaladas en la zona de Yanuncay al sur del Ecuador. Al final del proyecto se espera poder dar sugerencias sobre las prácticas de manejo forestal evaluadas para que se pueda realizar un manejo sostenible en las zonas de páramo

(La información obtenida en esta entrevista servirá para investigación científica y será anónima).

1.1. Nombre del propietario:
1.2. Lugar de la plantación:
1.3. Coordenadas y altitud:
1.4. Extensión de la propiedad: de la plantación:
1.5. ¿Existe algún tipo de convenio?
No___ Si ___
Tipo: Socio Bosque___ Créditos de carbón___ Otro:___
Institución:
Fecha: De _____a_____ Área:
1.6. Otras actividades que se realicen en la propiedad (ganadería, agricultura . . .)

2. Plantación

2.1. Motivo por el cual se realizó la plantación
2.2. Fecha del establecimiento de la plantación (Si hay varias plantaciones en diferentes épocas, especificar):
2.3. Especies de plantas utilizadas en la plantación:
2.4. ¿Cuáles fueron los criterios para seleccionar a esta especie? ¿Se consideraron otras especies, si es así cuales? ¿Por qué no se tomaron en cuenta otras especies?
2.5. Número de árboles por hectárea (distancia entre plantas):
2.6. ¿Cuál es la procedencia genética de los plantines? (en donde se cosecharon las semillas)
2.7. ¿En dónde se adquirieron los plantines?
2.8. Antes de la plantación, ¿Qué tipo de manejo tenía el terreno? (bosque, páramo, agricultura, ganadería, etc.)
2.9. Antes de plantar, ¿se preparó de alguna manera el terreno? (macheteo, desyerbar, abonar, herbicidas, etc.)
2.10. ¿Cuál fue el tamaño de los plantines en el momento de sembrarlos?
2.11. ¿Quién fue el responsable de realizar la plantación, y quién está a cargo ahora?
2.12. ¿Quién realizó la plantación? (mano de obra local capacitada, etc.)
2.13. Costos
Plantines:
De cada plantin_____
plantines/ha____

costo por ha____
de ha ____
costo total____
Trabajadores:
Pago diario por trabajador____
#de trabajadores diarios____
Salarios diarios____
de días contratados____
Costo total por trabajadores____
Gastos por contratación de técnicos:
Pago por cada asistencia____
(#)_____asistencias en ____ años
Costo total por contratación de técnicos____
Otros gastos:
Inversión total:
Existió algún tipo de subvención, o crédito

3. Manejo

3.1. ¿Existen algún tipo de regulación en cuanto al manejo?
No___ Si___
¿Cuáles son las regulaciones de manejo, o las condiciones legales que se deben cumplir?

3.2. ¿Cuenta con asesoría técnica?
No___ Si___
¿Quién?
¿Frecuencia de la asesoría?
¿Costos?

3.3. ¿Qué tipo de manejo ha tenido la plantación? (raleo, poda, tala, ninguno):
¿En qué área se hizo el manejo (en una sección o en toda la plantación)?
¿Cuál fue la intensidad?
¿Cuál fue el rendimiento?
¿Hubo algún ingreso?

3.4. Si ha tenido manejo, ¿con qué frecuencia se lo ha realizado?

3.5. Costo aproximado del manejo:

3.6. ¿Se han presentado algún tipo de plagas?
No___ Si___
¿Cuándo?
¿En qué extensión?
¿Se aplico algún tipo de tratamiento?
¿Cuál fue el resultado?
¿Fue reembolsado este gasto, por quién, en cuánto tiempo y qué porcentaje?

3.7. ¿Han ocurrido incendios?
No___ Si___
¿Cuándo?
¿En qué extensión?
¿Quién se encargó de controlarlo?
¿Tuvo algún costo por parte de la entidad que lo controló?

3.8. ¿Ha observado algún tipo de impacto generado por la plantación sobre la flora o fauna del lugar?
¿Si es así, se han tomado algún tipo de medidas para regular estos efectos?

4. Manejo futuro

4.1. ¿Cuál es el objetivo de manejo en su plantación?

Producción de madera ___
Protección del suelo (erosión) ___
Conservación del ciclo del agua ___
Secuestrar carbono ___
Producción de otros productos no maderables (¿cuáles, con qué frecuencia y cuáles serían las ganancias?)

4.2. ¿Qué actividad realizará en los próximos 10 años?
Ninguna ___
Poda ___
Raleo ___
Tala ___
No se sabe todavía ___

4.3. ¿Qué actividad realizará en los próximos 20 años?
Ninguna ___
Poda ___
Raleo ___
Tala ___
No se sabe todavía ___

4.4. ¿Existe algún interesado en comprar la madera? (¿Quién y con qué fines, a qué precio por metro cúbico?)

4.5. ¿Existe algún tipo de convenio para conservar la plantación? (¿con qué organismo y por qué?)

4.6. Otro tipo de manejo:

5. Estudio

Para realizar este estudio posiblemente se van a requerir realizar diferentes tipos de manejo (poda, raleo, enriquecimiento con especies nativas) en determinadas parcelas de las plantaciones. La superficie de las parcelas será de 24 m $\times$ 24 m aproximadamente, se estima que para todo el estudio se requerirán 50 parcelas aproximadamente.

5.1. ¿Cuál ha sido la mayor dificultad que ha tenido con la plantación?

5.2. ¿Le parece importante que se realice este tipo de investigación?
No___ Si___
¿Por qué?

5.3. ¿Estaría dispuesto a que se realice estos tipos de manejo en parcelas que se seleccionen en su propiedad?
No___ Si___
¿En cuántas parcelas de la plantación se podría realizar el estudio?
¿Cuáles actividades sería posible hacer?

5.2. Observaciones y/o comentarios.

Appendix A.2. Interviews Applied to Local Governments, Foresters and Nature Conservationists

Fecha:
Entrevistador:
Entrevistado:

A pesar de la importancia que tienen los páramos para el desarrollo socio-económico y ambiental de la zona Austral. Desde hace varios años estos ecosistemas están siendo alterados, donde la forestación con especies exóticas como el pino han sido comúnmente usadas para diversos objetivos que van desde el secuestro de carbono hasta la conservación de agua. Sin embargo, estas prácticas no han sido evaluadas y su manejo ha sido muy deficiente. Por esta razón, esta investigación tiene como objetivo evaluar las diferentes prácticas de manejo forestal sobre la producción de madera, biodiversidad vegetal, secuestro de carbono y regulación de agua. Para ellos varias parcelas de

monitoreo serán instaladas en la zona de Yanuncay al sur del Ecuador. Al final del proyecto se espera poder dar sugerencias sobre las prácticas de manejo forestal evaluadas para que se pueda realizar un manejo sostenible en las zonas de páramo.

(La información obtenida en esta entrevista servirá para investigación científica y será anónima).

1. ¿Conoce cuándo se realizaron las primeras plantaciones de plantas exóticas (pino), y cuál fue el motivo (reforestación, producción de madera, protección del suelo, etc.)?
2. ¿Cuáles fueron los criterios para seleccionar a esta especie? ¿Por qué no se tomaron en cuenta otras especies?
3. ¿Se consideraron otras especies? ¿Cuáles?
4. ¿Cuál es la procedencia de los plantines, por qué se escogió esta procedencia?
5. ¿Qué tipo de terrenos se seleccionaron para las plantaciones, hubo algún tipo de preparación del terreno antes de la plantación?
6. ¿Bajo qué marco legal se están manejando las plantaciones, qué tipo de convenios existen, quienes son los responsables, qué tipo de regulaciones existen?
7. En la actualidad, ¿cuáles serían los impactos positivos que se han generado gracias a las plantaciones? (ambientales, económicos, sociales)
8. ¿Cuáles serían los principales impactos negativos, y qué medidas se han tomado o se están tomando? (ambientales, económicos y sociales)
9. ¿Cuál es el objetivo de manejo de las plantaciones forestales (protección, producción, secuestro CO_2, etc.)?
10. ¿Qué actividades se planifica realizar en los próximos años? (tipo de manejo, estudios, etc . . .)
11. A la institución a la cual usted representa, ¿cuáles son los aspectos que más le interesan, respecto a las plantaciones (pino)? (estudios, ventajas/desventajas, protección, producción, captura carbono, reintroducción especies nativas, etc.)
12. ¿Cuáles son las desventajas que se presentan a futuro para las plantaciones (de pino)?
13. ¿Cómo cree que las plantaciones se podrían mejorar y/o acelerar?
14. ¿Cree que las plantaciones forestales podrían mejorar la situación económica de los propietarios, industrias forestales?
15. ¿Cómo su institución podría mejorar esta situación, esta la institución activamente participando en este proceso o planea hacerlo?
16. ¿Qué áreas deberían designarse para plantaciones forestales, y cuáles no? (especificar pino)
17. ¿Apoya su institución el establecimiento de plantaciones forestales, con qué especies? (económicamente, asesoría técnica, pago por servicios ambientales, etc.)

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