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Impacts of forestation on water and soils in the Andes: What do we know?

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Key messages

- This brief summarizes the findings of a systematic review on the impacts of forestation on water and soils in the Andes (detailed in Bonnesoeur et al., 2018).
- Exotic tree plantations and, to a lesser extent, native forests consume water and therefore often reduce the total water supply to downstream users in most Andean regions.
- Only in areas immersed in clouds, such as in the eastern slope of the Andes, might native forests increase downstream water availability compared to other land covers.
- Decreased total water supply could be acceptable to many users if it confers other benefits, such as increased water availability during the dry season or a reduction in water turbidity.
- When trees, including exotic species, are planted on degraded soils (bare and/or compacted soils), they can improve soil infiltration, reduce peak flows and control erosion.
- Exotic tree plantations on well-conserved grasslands (*páramos*, *jalcas*, *punas*) have detrimental impacts on total water supply and hydrological regulation.
- Existing native forests provide excellent water regulation and erosion control, more than mature tree plantations.
- As restoring degraded native forests does not necessarily recover original hydrological services, the conservation of existing forests must be a priority for watershed management.
- The hydrological impacts of native species forestation, however, have largely been overlooked and require further research.
- Long-term hydrological monitoring and research are necessary to fill the multiple data and knowledge gaps identified in this review.

Context and objective

In response to international commitments (e.g., the Initiative 20x20 and the Bonn Challenge) or to local and national demands for wood and watershed protection, several Andean countries are restoring forest cover, with the expectation of improvements in ecosystem services. Water-related ecosystem services, such as water supply, hydrological regulation and erosion control, are particularly important to sustaining the lives of more than 50 million Andean people. In recent decades, rapid and extensive forest cover changes, through deforestation and forestation, have extensively modified hydrological services in the Andes [1].

Forestation is defined here as the establishment of forest cover in the form of plantations or by natural regeneration on areas that had forest in the past or not. The most common arguments that have supported forestation are to produce wood, halt and reverse land degradation, protect biodiversity and improve hydrological services [2].

It is frequently included in portfolios of nature-based solutions or green infrastructure initiatives that are recently gaining importance in watershed management and adaptation to climate change in Latin America [3].

Forestation is sometimes used on degraded soils (e.g. eroded, compacted or depleted in organic matter) as a last resort, when croplands or pastures are no longer productive. However, enhancing land productivity has become the main focus of most forestation projects, resulting in a preference for fast-growing exotic species (e.g. *Eucalyptus* or *Pinus*). The possible negative impacts on soils and water have been largely ignored. In addition, fast-growing exotic species have also been planted on natural and well-conserved high-altitude grasslands, sometimes creating conflict due to declines in water yield.

To answer the question of how forestation should be used to address water- and soil-related problems in the region, we reviewed existing scientific knowledge on the impacts of forestation on soils and water in the Andes. This brief presents the main findings of our review [4].

Our analysis

Following a rigorous and transparent methodology of systematic review (see details in [4]), we analyzed 155 scientific publications and theses that investigated the impacts of forestation on different hydrological services and parameters (Fig. 1) in the seven Andean countries (Fig. 2). We used meta-analysis techniques but also more qualitative data synthesis.

Here, we present our findings on the impacts of forestation on (1) water supply, (2 and 3) hydrological regulation and (4) soil erosion. For each finding, we report the confidence level in the evidence found in the literature reviewed (Fig.3). The results of the synthesis (summarized in Fig. 4) also helped to identify research gaps, which are described after the findings.

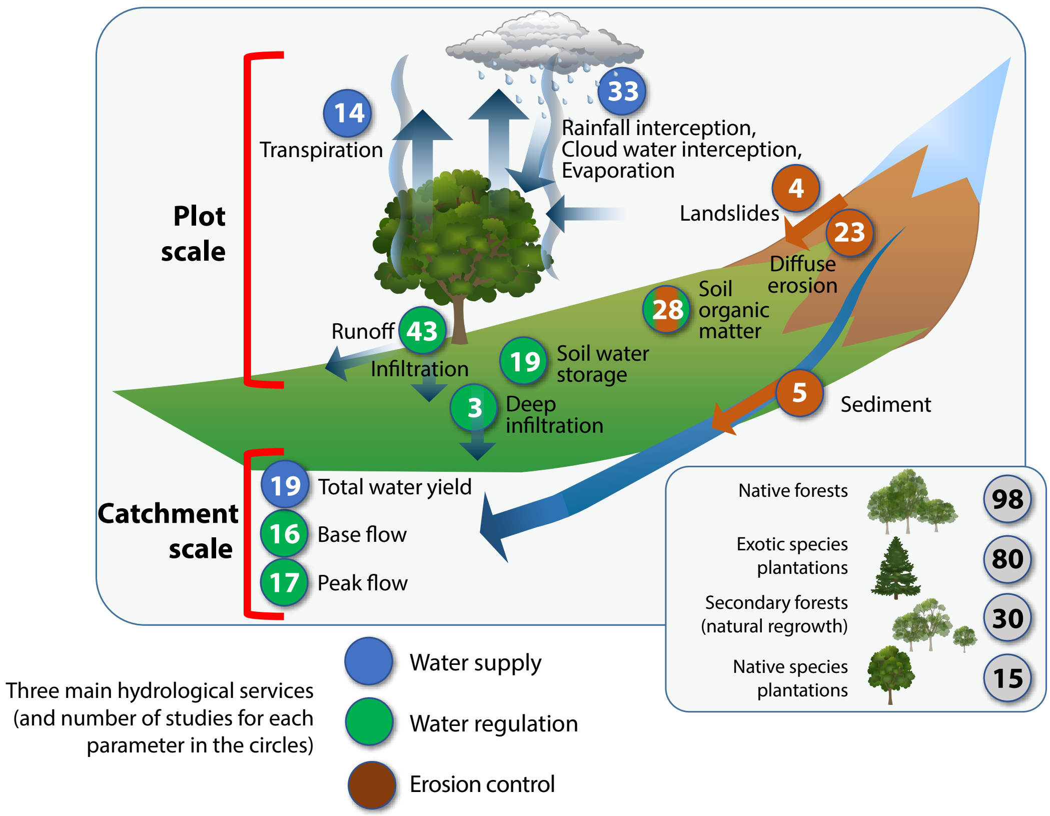

Figure 1. Hydrological services and parameters considered in this review with the number of studies (in circles) for each parameter and forest type

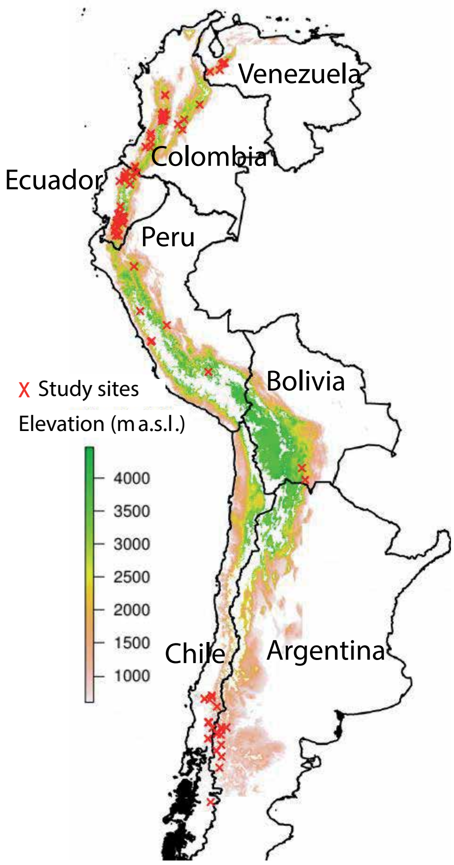

Figure 2. Location of study sites

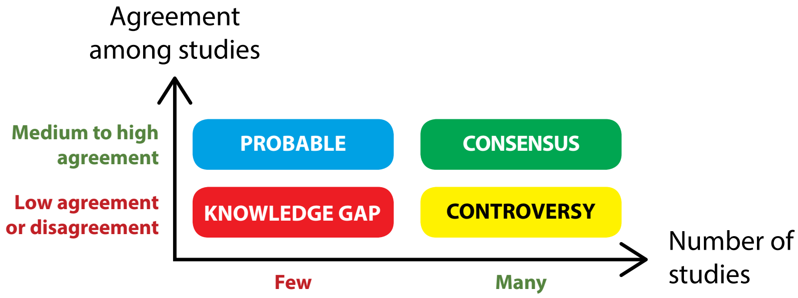

Figure 3. Classification of the level of evidence depending on the number of studies and the agreement among studies (few studies: four or fewer).

Eucalyptus trees are often found within agricultural landscapes in the Andes (photograph: rural landscape near Curahuasi, Apurímac, Peru, by Bruno Locatelli)

Findings 1: Forestation in the Andes reduces total amount of water

What ecosystem service(s)?	The total amount of water available in rivers, streams, springs or wells during the whole year, without considering regularity or seasonality.
Important for whom?	The total amount is important for water users with storage capacity (e.g. hydroelectric dams, reservoirs for agriculture, domestic or industry) that require large volumes of water.
What ecosystem functions?	The total amount of water depends on water inputs (rainfall plus some additional inputs, such as cloud interception by vegetation) minus the losses (evaporation and transpiration, which are both influenced by vegetation).

CONSENSUS Watersheds with exotic tree plantations and, to a lesser extent, natural forests, have a lower water yield (by 20-45%) than watersheds with non-forested land uses in the Andes [5].

PROBABLE Even though water transpiration from forested lands has not been studied extensively in the Andes, many studies in other regions showed that plantations and forests transpired more than grass per unit area, constituting a greater loss of water for the watershed [6].

PROBABLE Nevertheless, plantations of *Pinus* and *Eucalyptus* might be more efficient than native forests in terms of the amount of water used per ton of wood produced.

CONSENSUS Raindrops are intercepted by leaves and branches in plantations and forests; these eventually evaporate (~25% of annual rainfall). In dry regions of the Andes, interception by forest canopy is higher and probably worsens water scarcity.

KNOWLEDGE GAP The total amount of water is lost for watershed users but not for everyone, as the resulting atmospheric vapor may create rain elsewhere [7]. However, the influence of forests on rainfall has not been studied in the Andes.

CONSENSUS In less than 10% of the Andean forest area, cloud montane forests play a particular role because cloud immersion reduces their transpiration at the same time as their leaves and epiphytes capture tiny drops of cloud water, which can constitute a non-negligible water input (up to 15%) [8].

KNOWLEDGE GAP Research is lacking on whether and, if so, how forestation in mountain areas immersed in clouds might increase water availability.

Reforestation is often used in watershed management interventions (photograph: pine plantations in the Piuray lake watershed, one major source of water for the city of Cuzco, Peru, by Bruno Locatelli)

Findings 2: Forestation in degraded soils conserves base flow

What ecosystem service(s)?	Conservation of water flow in rivers, streams, springs or wells during the dry season or during droughts (called base flow).
Important for whom?	Preservation of base flow is key for all water users to cope with water scarcity due to seasonality, climate variability and climate change, especially those who lack artificial storage capacity.
What ecosystem functions?	Water flows during dry times come mostly from subsurface water slowly released in streams. Infiltration of water into soils increases the service, whereas plant transpiration decreases it.

CONSENSUS Tree plantations, including those using exotic species, strongly enhance infiltration rates (by a factor of 8) on degraded Andean soils, for example on overgrazed grasslands.

CONSENSUS Forestation of degraded agricultural soils (with low levels of organic matter) increases soil organic matter. This improves the infiltration and storage of water in the soil, although in limited proportions.

CONTROVERSY At the watershed level, the effect of forestation on base flow is less clear and depends on a delicate balance: forestation increases base flow if the positive effect of improved infiltration is higher than the negative effect of increased plant transpiration. For example, in an Ecuadorian catchment, exotic tree plantations on highly degraded soils increased base flows substantially [9]. Where land has not been degraded, water use of exotic tree plantations very often exceeds the increase in soil infiltration leading to base flow reductions (up to 10 fold) [10].

CONSENSUS Exotic tree plantations have higher transpiration than grasslands and native forests and lower infiltration than well conserved forests or grasslands. Thus, for base flow, it is generally better to conserve native forests or grasslands than to plant trees.

Findings 3: Forestation reduces peak flows during heavy (but not extreme) rain

What ecosystem service(s)?	The reduction of runoff water during rainfall events and the subsequent rapid increase in stream flow (also called peak flow).
Important for whom?	Peak flow control is important in reducing the effects of floods on people and activities located in flood-prone areas.
What ecosystem functions?	Several ecosystem functions that contribute to water losses and storage converge to reduce peak flow: interception and evaporation, transpiration and infiltration.

CONSENSUS Forestation reduces runoff during heavy but not extreme rainfall events (i.e., less than 5–10 years return period), leading to less frequent and less intense floods. Indeed, forestation on grassland increases interception and transpiration, which enhances rainfall buffering, and may increase infiltration (especially in degraded soils), which reduces surface runoff.

PROBABLE In the case of extreme or prolonged rainfall, however, canopy and soil storage become saturated and forest cover could have limited effects on catastrophic flooding [11].

CONTROVERSY Although forests might not reduce the magnitude of extreme floods, they might reduce the frequency at which floods occur. Controversy over the relationship between forests and floods has arisen because of differences in the methodologies used to quantify and predict flood occurrence [12].

Findings 4: Forestation reduces water erosion of soils

What ecosystem service(s)?	The control of soil erosion, either diffuse (laminar erosion) or mass erosion (landslides), influenced by vegetation cover and soil properties.
Important for whom?	Reducing erosion is important to preserve soils that support many ecosystem services (e.g. food production) and to reduce potential effects on downstream populations and activities; for instance, reservoir siltation or water filtration costs. In addition, it is important to reduce landslides, which are among the most destructive hazards in the Andes.
What ecosystem functions?	Diffuse erosion can be reduced by enhanced infiltration (reduction in water runoff), high soil stability (function of soil properties such as texture or organic matter), dense surface vegetation cover (protection from raindrop impacts) and dense root systems (increased soil resistance). Landslide risk also depends on mechanical reinforcement by roots and on infiltration (increasing the water pressure on unstable slopes).

CONSENSUS Exotic tree plantations on bare soils can effectively control soil erosion. Sediment production decreases exponentially with surface vegetation cover so that a small increase in surface vegetation cover on bare land results in a strong decrease in water erosion.

CONSENSUS Exotic tree plantations and natural regenerated forests have lower surface vegetation cover than native forests and grasslands, resulting in moderately higher erosion rates but much lower erosion rates than those in degraded soils [13].

CONSENSUS Deforestation increases the risk of shallow landslides.

KNOWLEDGE GAP In contrast, the impact of forestation on landslides has received very limited attention and more research is needed.

Hydrological parameters	Effects of land-cover changes on hydrological parameters: Conserved grassland → Exotic tree plantation	Degraded land → Exotic tree plantation	Native forest → Degraded land	Major links between hydrological parameters and hydrological services: Water supply	Water regulation	Erosion control
Total water yield	--	-	+	+		
Rainfall interception	+	+	-	-		
Transpiration	++	+	-	-		
Base flow	--	+/-	-		+	
Peak flow	-	-	+		-	
Infiltration	+	++	--		+	+
Soil organic matter	-	+	-		+	+
Diffuse erosion	+	--	++			-
Landslides	?	?	+			-

Erosion control

Legend: ++ Strong increase; + Increase; -- Strong decrease; - Decrease; +/- Controversy; ? Knowledge gaps; Consensus; No consensus; (+) Positive link; (-) Negative link

Figure 4. Synthesized impacts of forest cover change on hydrological parameters (left part of the table) and major links between hydrological parameters and services (right part). Some links are omitted for sake of simplicity (e.g. transpiration reduces water flows during dry seasons, which affects negatively the service of water regulation).

Knowledge Gaps

Native species. Most research has focused on exotic species, such as *Pinus* and *Eucalyptus*. The lack of research on native tree plantations presents a barrier to their use in forestation projects. Similarly, more information is needed on how natural regeneration of abandoned lands or where grazing has stopped can improve water regulation.

Forest management. Sound forest management (e.g. density or rotation length) and spatial distribution of forested areas (e.g. key areas or hydrological connectivity) can improve hydrological services; for example, an intermediate stand density can increase base flow conservation [14]. However, research is lacking for the Andes.

Short-term versus long-term impacts. We need to understand better how long hydrological functions and services take to recover. Most of the studies showed that after 20 years of forestation, an increase in soil infiltration rate and erosion control close to those found in native forests was achieved. However, other hydrological functions might take longer to recover. This highlights the importance of conserving existing native forest.

Recommendations

Recognize that forestation reduces overall water availability. Forests are often perceived as having a positive effect on water and the environment in all circumstances, which can create unrealistic expectations from local stakeholders that depend on water. The possible positive and negative hydrological impacts of forestation should be assessed and discussed with stakeholders.

Define spatial priorities for forestation. Forestation of degraded soils is beneficial for hydrological regulation and the control of water diffuse erosion, even with exotic species. In order to optimize hydrological services, forest landscape restoration initiatives across the Andes should prioritize soils without vegetation cover, with compacted soils and with soils depleted of organic matter.

Understand tradeoffs and clarify what is expected from forestation. Forestation with *Pinus* and *Eucalyptus* consumes much more water than native vegetation in the Andes, but uses it more efficiently to produce wood (efficiency is quantified here in terms of the amount of wood produced per cubic meter of water used). Decision-makers need to balance trade-offs between water and wood: if the objective is to produce wood or diversify local livelihoods with forest products, *Pinus* and *Eucalyptus* might be good choices. However, if the objective is to improve water supply or base flow preservation, other species may be better.

Research native species. Forestation with native species might be good for soils and water, but we do not know enough. Research must work on native species and their impacts in order to improve forestation practices and move them away from a focus on *Pinus* and *Eucalyptus*.

Protect native grasslands. Decision-makers sometimes assume that forestation is central to watershed conservation or restoration, whereas native Andean grasslands in good condition provide excellent hydrological services. Landscape restoration or green infrastructure initiatives must avoid exotic tree plantations of these grasslands. Conserving or restoring native grasslands in páramo and puna ecosystems should be favored, given the excellent total amount of water provided, hydrological regulation and erosion control of these ecosystems.

Protect native forests. Native Andean forests are excellent at regulating water and protecting soils. It is difficult (or impossible) and time-consuming to restore hydrological services affected after forests are degraded or destroyed. There is an urgent need to protect forests from degradation and deforestation, particularly cloud forests, not only for their rich biodiversity but also for their contribution to water and soil regulation. Substantial areas of montane cloud forests are still unprotected in the eastern range of the Andes in Colombia, Peru and Ecuador.

Build knowledge on green infrastructure and forestation. Landscape restoration and green infrastructure projects must invest in hydrological monitoring and research, such as in the iMHEA network ("Iniciativa Regional de Monitoreo Hidrológico de Ecosistemas Andinos")[15]. More research is needed to fill the multiple data and knowledge gaps identified in this review. Research outcomes need to feed decision-making processes, and to inform and support the design, implementation and evaluation of conservation and forestation projects.

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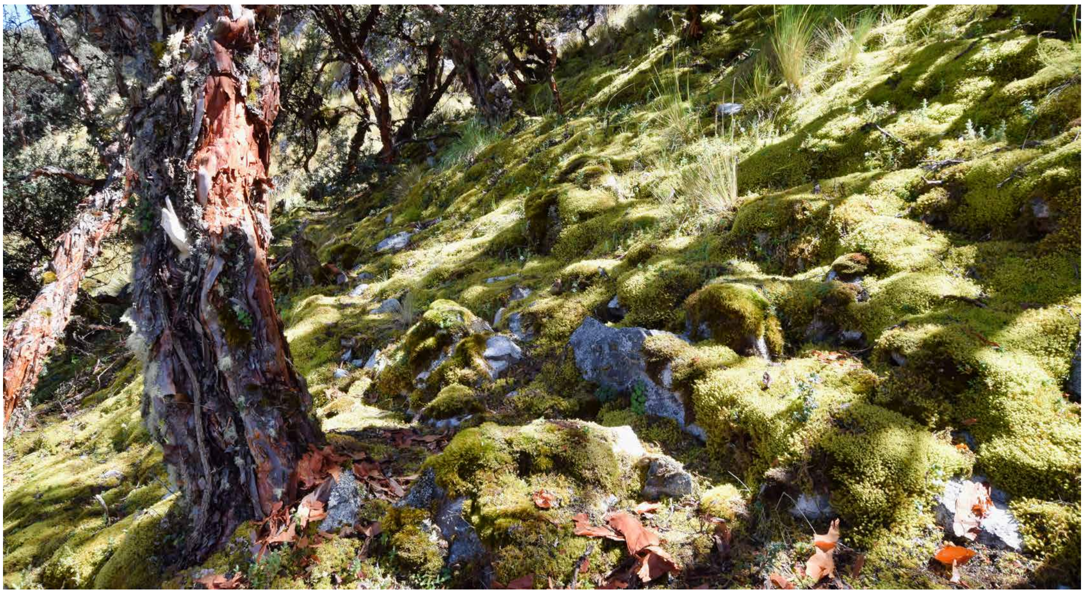

Native Andean forests are excellent at regulating water and protecting soils (photograph: Rontococcha forest in Apurímac, Peru, by Bruno Locatelli)