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A prototype decision support tool for native woody species selection for seasonally dry tropical forest restoration in northern Peru and southern Ecuador

Een prototype decision support tool voor de selectie van inheemse houtige species voor de restauratie van tropisch droogbos in noord-Peru en zuid-Ecuador

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Dissertation presented in
Fulfillment of the requirements
for the degree of Master of Science in
Agro- and Ecosystems Engineering

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June 2018

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Acknowledgements

First, I would like to thank my promotors prof. Bart Muys and dr. Evert Thomas for the chances they gave me and the support during the thesis project. Your feedback, remarks and suggestions have been very useful.

Next, I would like to thank my daily supervisor Tobias Fremout. You have supported me a lot during whole the project, from the fieldwork till the final stage of developing the prototype decision support tool and handing in the thesis. I could contact you at every moment and you were always open to hear my opinion and ideas. It has been a pleasant collaboration!

I would also like to thank Tania Villegas, Janette Chang, Claudia Gutiérrez and Arantza Acosta for the nice times we had during the fieldwork and for the collaboration in collecting the data. Further, I would like to thank the scientific experts we interviewed. Dr. José Luis Marcelo-Peña, dr. Eduardo Cueva and dr. Reynaldo Linares-Palomino, the information you gave during the interviews was very useful to me. In addition, I would like to thank the NGO's Naturaleza y Cultura Internacional (especially Darwin Martínez and dr. Eduardo Cueva) and Bioversity International (especially dr. Evert Thomas) for their aid. Moreover, a lot of local people supported us during the fieldwork, from answering the interviews to offering us a place to sleep. Thank you very much.

Last, I want to thank my family and friends for always supporting me, taking care of me and experiencing good times together.

Abstract

Seasonally dry tropical forests deliver a wide range of ecosystem services and often harbour a high number of endemic species. As they are mostly situated on relatively fertile soils, these forests are often situated in relatively densely populated areas, which causes their degradation. Overgrazing, selective logging, fire, erosion and desertification are the main degrading agents. In addition, they are easier to clear than tropical rainforests because of their lower stature. Because of the degradation and deforestation, seasonally dry tropical forests are one of the world's most threatened ecosystems. Although the scientific attention for this ecosystem is increasing, they remain vastly understudied, and the available information is highly fragmented.

Restoration projects in seasonally dry tropical forests often involved the active planting of a few well-known and easily available species. These species are not necessarily adapted to the local environmental stress factors and do not always provide the locally preferred ecosystem services, which is likely to affect the success of restoration projects.

In the first research question, local ecological knowledge expert interviews and household interviews were used to determine which woody species are the most useful in the studied rural communities. Species' usefulness was evaluated with the Cultural Importance Index and an adjusted Cultural Importance Index. The local ecological knowledge expert interviews provided information on potential uses, whereas the household interviews yielded insights on actual uses. *Vachellia macracantha, Prosopis pallida* and *Cordia lutea* were among the five most useful species for both interview types and both index types. Further, it was found that potential uses strongly exceeded actual uses. The number of use reports for the different use categories was analysed and compared between the interview types. During the household interviews, construction and fuel were mentioned the most, followed by medicine, animal food and environmental use. Whereas, the local ecological knowledge experts mentioned animal food and construction the most, followed by medicine, materials and fuel almost equally. The adjusted Cultural Importance index was later used in the prototype decision support tool to select species that provide the desired provisioning ecosystem services.

The second research question was aimed at evaluating if local ecological knowledge (LEK) can be used for species recommendations for seasonally dry tropical forest restoration. Local ecological knowledge experts were asked to recommend species for a number of information categories, which include environmental stress factors and restoration objectives. The internal consistency of the species recommendations was analysed by calculating the mean Jaccard dissimilarities within the information categories. Subsequently, the species recommendations from local ecological knowledge expert interviews were compared to the species

recommendations from literature and scientific expert interviews. When the species that were recommended only once for an information category were excluded, the internal consistency increased and the number of inconsistent recommendations, when compared to literature and scientific experts, decreased sharply. The results indicate that local ecological knowledge can be used for species recommendations for seasonally dry tropical forest restoration but that the species that were recommended only once for an information category had to be excluded in the prototype decision support tool to eliminate potential erroneous information.

The main aim of this thesis research project was to develop a prototype decision support tool to provide species recommendations given a number of user-defined local environmental stress factors and priority restoration objectives. The fragmented knowledge of 111 native woody species of the study region was bundled into an extensive database containing species traits that were collected from literature, local ecological knowledge expert interviews, household interviews, scientific expert interviews and estimations based on functional traits. The developed decision support tool is based on this database and provides a number of recommended species to be planted under the local environmental stress conditions at the planting site, ranked according to the user-defined restoration objectives. The prototype decision support tool can be found at https://siebe.shinyapps.io/PrototypeDST/.

Samenvatting

Tropische droogbossen leveren een wijd gamma aan ecosysteemdiensten en herbergen vaak een groot aantal endemische soorten. Aangezien deze bossen meestal gelegen zijn op vruchtbare gronden, zijn deze bossen vaak gelegen in relatief dichtbevolkte gebieden, dit veroorzaakt hun degradatie. Overbegrazing, selectieve kapping, brand, erosie en woestijnvorming zijn de hoofdoorzaken van degradatie. Bovendien worden ze makkelijker vernietigd dan tropische regenwouden omwille van hun lagere gestalte. Door de degradatie en ontbossing zijn tropische droogbossen nu een van de meest bedreigde ecosystemen op aarde. Ondanks de toenemende wetenschappelijke aandacht voor dit ecosysteem blijven ze sterk onder-bestudeerd en is de beschikbare informatie sterk gefragmenteerd.

In restauratieprojecten in tropische droogbossen werden meestal slechts een aantal bekende en eenvoudig verkrijgbare soorten geplant. Deze soorten zijn niet persé geschikt zijn om te planten onder de lokale omgevingsstressfactoren en ze voorzien niet altijd de lokaal verkozen ecosysteemdiensten, dit is hoogstwaarschijnlijk van invloed op het succes van de restauratieprojecten.

In de eerste onderzoeksvraag werden interviews met lokale ecologische kennis experts en interviews met huishoudens gebruikt om te bepalen welke houtige soorten het nuttigst zijn in de bestudeerde landelijke gemeenschappen. Het nut van de soorten werd bepaald aan de hand van de Culturele Belang index en een aangepaste Culturele Belang index. De interviews met lokale ecologische kennis experts leverden informatie omtrent de lokale kennis van mogelijke gebruiken, terwijl de interviews met huishoudens informatie opleverden omtrent de werkelijke gebruiken. *Vachellia macracantha, Prosopis pallida* en *Cordia lutea* behoorden tot de vijf nuttigste soorten voor beide types interviews en beide index types. Bovendien werd er bepaald dat de mogelijke gebruiken, de werkelijke gebruiken sterk overschreden. Het aantal gebruiksvermeldingen voor de verschillende gebruikscategorieën werd geanalyseerd en vergeleken tussen de interview types. Gedurende de interviews met huishoudens, werden bouw en brandstof het vaakst vermeld, gevolgd door medicinale planten, diervoeding en omgevingsgebruiken. De lokale ecologische kennis experts vermelden diervoeding en bouw het meest, gevolgd door medicinale planten, materialen en brandstof. De aangepaste Culturele Belang index werd gebruikt in het prototype beslissingsondersteunend systeem om soorten te selecteren voor de levering van de gewenste productverstrekkende ecosysteemdiensten.

De tweede onderzoeksvraag was erop gericht om te analyseren of lokale ecologische kennis gebruikt kan worden voor het aanbevelen van houtige soorten voor het herstel van tropische droogbossen. Er werd aan de lokale ecologische kennis experts gevraagd om soorten aan te

bevelen voor een aantal informatiecategorieën, deze bevatten zowel omgevingsstressfactoren als restauratiedoelstellingen. De aanbeveling van soorten door lokale ecologische kennis experts werd getest op interne consistentie door het berekenen van de Jaccard ongelijkheden binnen de verschillende informatiecategorieën. Vervolgens werden de aanbevelingen van soorten door lokale ecologische kennis experts vergeleken met de aanbevelingen van soorten door literatuur en wetenschappelijke experts. Wanneer de soorten die slechts één keer aanbevolen werden door lokale ecologische kennis experts voor een informatiecategorie uitgesloten werden, nam de interne consistentie toe en het aantal inconsistente aanbevelingen van soorten, vergeleken met literatuur en wetenschappelijke experts, daalde sterk. De resultaten geven aan dat lokale ecologische kennis gebruikt kan worden voor het aanbevelen van soorten voor het herstel van tropische droogbossen maar dat de soorten die slechts één keer vermeld werden voor een informatiecategorie, uitgesloten moesten worden in het prototype beslissingsondersteunend systeem, om mogelijke foutieve informatie te verwijderen.

De hoofddoelstelling van dit thesisonderzoeksproject was om een prototype beslissingsondersteunend systeem te ontwikkelen voor de aanbeveling van soorten onder een aantal door de gebruiker geselecteerde lokale omgevingsstressfactoren en prioritaire restauratiedoelstellingen. De gefragmenteerde kennis over 111 inheemse houtige soorten uit het studiegebied werd samengebracht in een uitgebreide database, waarin informatie omtrent de karakteristieken van deze soorten werd verzameld van interviews met lokale ecologische kennis experts, interviews met huishoudens, interviews met wetenschappelijke experts, literatuur en schattingen gebaseerd op functionele planteigenschappen. Het ontwikkeld beslissingsondersteunend systeem is gebaseerd op deze database en beveelt soorten aan om te planten onder de lokale omgevingsstresscondities van de plantplaats, gerangschikt volgens de restauratiedoelstellingen geselecteerd door de gebruiker van het systeem. Het prototype beslissingsondersteunend systeem is beschikbaar op https://siebe.shinyapps.io/PrototypeDST/.

Abbreviation list

CI: Cultural importance

DST: Decision support tool

FLR: Forest landscape restoration

JD: Jaccard dissimilarity

LEK: Local ecological knowledge

masl: Meter above sea level

NWFP: Non-wood forest products

SDTF: Seasonally dry tropical forest

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1 Introduction

1.1 Context

Seasonally dry tropical forests (SDTFs) are tropical forests with a marked rainfall seasonality with at least five months of drought (Linares-Palomino, 2006; FAO, 2012). Generally, SDTFs are situated in relatively densely populated areas, often with soils and climates appropriate for agriculture. Further, this ecosystem is easily cleared through deforestation and fire (Linares-Palomino, 2006). Consequently, this type of forest has been destroyed to a greater extent than tropical rain forests. Globally, 48.5% of the original SDTF area has been converted to other land use types (Hoekstra et al., 2005). The neotropical dry forests are recognized as one of the world's most threatened ecosystems (Castro & Espinosa, 2015).

The study region consists of the coastal SDTFs in northern Peru and southern Ecuador and the inter-Andean SDTFs of the Marañón valley in northern Peru. The population in the study region depends directly and indirectly on the ecosystem services provided by the SDTFs for its livelihood and economic activities (Orihuela & Contreras , 2012; Escribano-Avila et al., 2017). The most important ecosystem services received by the surrounding SDTFs are provisioning ecosystem services such as forage, fuel, wood for construction, honey, materials and medicine, as well as regulating services such as erosion control and watershed protection (Aguirre et al. 2006a; Raymundo Viera 2011; Aguirre & Aguirre 2015). The provision of ecosystem services for local human populations is threatened by the degradation and forest cover loss of the SDTFs. Prominent causes of forest degradation in the study region are selective logging, fire, overgrazing, erosion and desertification (Rodríguez & Álvarez, 2005).

Maintaining and restoring ecosystem services is not the only reason why it is important to conserve and restore the SDTFs of the study region. The ecosystem harbours a high number of endemic and threatened species, both fauna and flora (Aguirre et al. 2006b; Escribano-Avila et al. 2017) . The species richness of SDTFs is not represented by one specific area because of a high beta-diversity, leading to the high biodiversity in the study region (Portillo-Quintero et al., 2015; Escribano-Avila et al., 2017).

In the past, the ecological and floristic value of SDTFs in the neotropics has been underestimated. Consequently, SDTFs have been poorly investigated (Aguirre et al., 2006b). Nowadays, scientific attention on SDTFs is increasing and a crescent number of scientific publications on SDTFs becomes available, recognizing the importance of SDTFs (e.g. Banda et al. (2016) and Escribano-Avila et al. (2017)). Despite the increasing sense of the value of SDTFs, still only 10% of the investigations in the tropics is about dry ecosystems (Cayuela et al. unpublished results cited by Escribano-Avila et al. (2017)).

In summary, it will be a major and essential challenge to successfully restore the degraded SDTFs in northern Peru and southern Ecuador.

1.2 Problem statement

In general, restoration projects in SDTFs are challenging and often fail (Ceccon 2008; Darwin Martínez (NCI Zapotillo), pers. comm. 1 october 2017). Current restoration practices in SDTFs in the study region frequently involve the active planting of tree species. For this practice, the species choices are often largely opportunistic (Cerrón et al., 2017; Jalonen et al., 2017). A few well-known, readily available species are used in most cases. This can affect the resilience of the restored areas and regularly leads to a suboptimal generation of ecosystem services. It is important to adjust species choices to different situations of environmental stress in designing resistant and resilient ecosystems (Jacobs et al., 2015). Further, involving local communities in the conservation and restoration of SDTFs is a key factor for the success of the conservation or restoration project. Species choices should be aligned with the provisioning services desired by local communities (Higgs 2005; Uprety et al. 2012; Suárez et al. 2012; Brooks et al. 2012; Escribano-Avila et al. 2017).

Another problem is the fragmentation of the current knowledge about species in SDTFs. There is no database that integrates plant characteristics, such as functional traits and ecosystem services, for the woody species in the study region. The existing knowledge is scattered over several books, scientific articles and online databases. In addition, the local communities hold knowledge on woody species that can be valuable for the restoration of SDTFs in the study region, some of which never has been documented.

1.3 Objectives and research questions

The main aim of this thesis research project is to support the decision-making regarding the selection of appropriate woody species to contribute to the successful restoration of SDTFs in northern Peru and southern Ecuador with an optimized provision of ecosystem services and resilience towards local environmental stress factors. In order to provide woody species recommendations for specific combinations of restoration objectives and environmental stresses, a prototype decision support tool was created, incorporating fragmented knowledge on woody species' local uses, traits and ecology.

In this thesis, the following research questions are answered:

1) Which woody species are the most useful for the studied rural communities?
2) Can local ecological knowledge (LEK) be used for species recommendations for SDTF restoration?

3) Which woody species are suitable for SDTF restoration given different restoration objectives and local environmental (stress) factors?

1.4 Academic context of the thesis research project

The field work was carried out between 20 Augustus 2017 and 23 October 2017 with a research team of six persons. Namely, Tania Libertad Villegas Gomez (Universidad Nacional de Piura), Janette Cristina Chang Ruiz (Universidad Nacional Agraria La Molina), Claudia Elena Gutiérrez Miralda (Universidad Nacional Agraria La Molina), Arantza Helen Acosta Flota (KU Leuven) and myself (KU Leuven) under supervision of PhD-student Tobias Fremout (KU Leuven). Tania Villegas and Arantza Acosta, doing their bachelor and master thesis respectively, investigated mainly the socioeconomic relation of the local population with the surrounding SDTFs. Janette Chang, bachelor student, has studied ecosystem services delivered by the SDTFs in the study region. Claudia Gutiérrez, bachelor student, has focused on ethnobotany and local ecological knowledge (LEK) for forest landscape restoration (FLR) in the study region. There was mainly a collaboration with Claudia Gutiérrez to develop the database to be used in the prototype DST. Tobias Fremout has supported all of us and the prototype DST was made in close collaboration with him.

Tobias' PhD-project aims at developing a decision support tool (DST) for woody species selection and seed sourcing to contribute to the long-term restoration success of SDTFs in northern Peru and southern Ecuador. The tool will require the user to define a planting site, priority restoration objectives and local environmental stress factors. In turn, it will present recommendations on woody species combinations and seed sources that most effectively contribute to the user-defined restoration objectives, show the highest resilience towards local environmental stress factors and enhance adaptive capacity to climate change.

The other work packages of Tobias' PhD research project involve measuring functional traits, species suitability modelling, compiling propagation and management protocols and modelling seed transfer zone maps. The integration of this information is expected to lead to better decisions on woody species and seed sources selection, contributing to the long-term restoration success of SDTFs in the study region.

2 Literature study

2.1 Seasonally dry tropical forests (SDTFs)

The definition of SDTFs by Linares-Palomino (2006), based on the definition from Pennington et al. (2000) with some modifications, is as follows:

"… seasonally dry tropical forests receive less than 1600 mm of annual rainfall. However, the amount of rainfall is not evenly distributed throughout the year. A very marked dry season of more than five months is usually present, in which total rainfall is below 100 mm. With a few exceptions, these forests are of lower stature and basal area when compared to rainforests (Linares-Palomino & Ponce-Alvarez, 2005). They are best represented at elevations below 1000 masl but can occur as high as 2500–2800 masl (Linares-Palomino, 2004)...".

The drought leads to a lower net primary production than tropical rain forests and results in an ecosystem with a lower basal area and smaller trees (Espinosa et al., 2012). Further, the drought causes a marked seasonality of the ecological and physiological processes such as flowering and fruiting (Pennington et al., 2000). Besides, it is an ecosystem dominated by a deciduous vegetation, with many woody species losing their leaves during the dry season (Pennington et al., 2000). Most well-conserved SDTFs have a more or less continuous canopy. The strong seasonality of the coastal Tumbesian SDTFs of the study region is determined by two ocean currents, namely the cold and dry Humboldt current and the warm and wet El Niño current (Escribano-Avila et al., 2017).

The restoration of SDTFs is often more difficult than the restoration of tropical rainforests, because of the risk of extreme droughts and forest fires (Rodríguez & Álvarez, 2005). SDTFs are easily accessible, have a favourable climate and are often found on fertile soils with an intermediate to high nutrient status and pH (Pennington et al., 2000; Escribano-Avila et al., 2017). This led to a relatively high population density in SDTFs and the expansion of human settlements and activities has caused extensive degradation of the study region (Miles et al., 2006; Escribano-Avila et al., 2017).

54.2% of the SDTFs worldwide are situated in the neotropics (Miles et al., 2006), of which a minor part is situated in the study region from this project. The neotropical dry forests are one of the world's most threatened ecosystems (Espinosa et al., 2012) and this also applies to the SDTFs of the study region. Morales et al. (2013) reported that 76% of the area of the department of Piura, a central and important part of the study region, has been deforested.

The effect of the El Niño climate phenomenon is very pronounced in the study region. In El Niño years, the amount of rainfall is 8-14 times as high as the normal annual average precipitation (Rodríguez & Álvarez, 2005). The high amounts of rainfall that occur in El Niño years, lead to catastrophic consequences. Deforested areas have a low water retention capacity, leading to exacerbated impacts of El Niño rains (Fernández Barrena et al., 2007). Moreover, the study region is highly vulnerable to climate change. It was estimated that the frequency of El Niño events will double in the future (Cai et al., 2014).

The climatic and floristic characteristics of the SDTFs in the study region will be described in the methodology section.

2.2 Forest restoration and forest landscape restoration (FLR)

Over the past decennia, the world's forest cover has diminished considerably, the ecosystem services provided by forests have been reduced and biodiversity has declined. Thus, there is an urgent need to conserve the remaining forests and restore the forest cover in degraded areas (Mansourian et al., 2005; Chazdon & Guariguata, 2018).

In the narrow sense of the word, forest restoration is a type of ecological restoration. The Society for Ecological Restoration (SER) defines ecological restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" (SERI, 2004). The aim of ecological restoration is to regain ecological integrity, self-sustainability and resilience (Palmer et al., 2006; Benayas et al,. 2009; Uprety et al., 2012). This is necessary given that the regenerating capacity is altered as a direct or indirect result of humans, preventing it from recovering its pre-disturbance state. Before, historical ecosystem conditions were used as targets of restoration (Benayas et al., 2009). However, this target is sometimes unlikely to be achieved because of the implications of climate change, among other factors. Restoring the site's functionality might be preferable (Harris et al., 2006; Ostertag et al., 2015; Laughlin et al., 2016). Forest restoration is a more complex process than only recovering forest area, it is about recovering a resistant and resilient ecosystem (Newton & Tejedor, 2011).

Forest landscape restoration (FLR) is a broader concept and is more complex than returning the environment to a prior state. It also considers human wellbeing and is defined by Mansourian et al. (2005) as "a planned process that aims to regain ecological integrity and enhance human wellbeing in deforested or degraded landscapes." The aim is to restore a whole landscape to provide benefits in the present and the future. This includes biodiversity conservation and restoration of ecosystem services and processes (Newton & Tejedor, 2011; FAO, 2015). Forest landscape restoration aims to restore all elements that characterize a healthy forest landscape, including the ecosystem functions (FAO, 2015). Rather than seeing forest areas in isolation, they are restored along with other parts of the landscape to secure the connectivity between the forest areas, in this way contributing more effectively to biodiversity conservation. Forest landscape restoration aims to balance restoring the functionality within landscapes and meeting the needs of the people (Mansourian et al., 2005; Chazdon & Guariguata, 2018).

The main focus of the prototype DST developed in this thesis research project is on forest restoration, but other land uses like agri-silvicultural systems and silvopastoral systems are included as well. Thus, it is a DST for forest landscape restoration (FLR). Moreover, Chazdon & Guariguata (2018) claim that most opportunities for restoration in forest biomes lies within the mixed-use landscapes.

The restoration of SDTF landscapes is a difficult but highly necessary process (Ceccon, 2008; Newton & Tejedor, 2011; Banda et al., 2016). As mentioned in paragraph 1.1, SDTFs are an ecologically rich and unique ecosystem, providing many ecosystem services (Linares-Palomino, 2006; Portillo-Quintero et al., 2015). Moreover, SDTFs have considerable economic opportunities, like eco-tourism and multi-purpose forestry (Mansourian et al., 2005). Passive restoration has been used effectively in the past and involves the cessation of a degrading action (Mansourian et al., 2005; Benayas et al., 2009). Active restoration can involve planting tree species appropriate to be planted under local environmental stress conditions and is a more expensive possibility (Mansourian et al., 2005). When planting trees in SDTFs, the unpredictable rainfall should be taken into consideration. Other possible active restoration methods include sowing seeds, extirpation of damaging species, nutrient removal/addition, reinstatement of burning, reintroduction of animals and soil amendments (Mansourian et al., 2005; Benayas et al., 2009). The quality of the site for restoration is very important. Alvarez-Aquino & Williams-Linera (2012) stress the importance of the presence of other woody species to improve the success of restoration (Alvarez-Aquino & Williams-Linera, 2012).

Once ecological restoration has been performed, ecosystem management is necessary to guarantee the continued health of the ecosystem. “A degraded ecosystem can be considered to have been restored when it regains sufficient biotic and abiotic resources to sustain its structure, ecological processes and functions with minimal external assistance or subsidy” (Gann & Lamb, 2006). Consequently, it can tolerate normal ranges of environmental stress and disturbance, expected for the given type of land use. Further, Gann & Lamb (2006) state that important environmental and social benefits can already be realized before the ecosystem can be considered restored, even in the earliest stages of restoration.

2.3 Forest restoration and ecosystem services

Humans benefit from ecosystems. These direct and indirect contributions of ecosystems to human well-being are called ecosystem services. They support the survival and quality of life of humankind. Local governments and NGO's are often motivated to invest in FLR because they want to regain ecosystem services by restoring the integrity of the forests (Palmer et al., 2016).

Ecosystem services are subdivided in 4 types by *The Economics of Ecosystems & Biodiversity* (TEEB). They distinguish "habitat or supporting services" which support all other types of ecosystem services and include habitat for species and maintenance of genetic diversity (TEEB, 2010). Further, ecosystem services are divided in "provisioning services", "regulating services" and "cultural services". Provisioning services are the material or energy outputs from ecosystems and include food, raw materials, fresh water and medicinal resources (TEEB, 2010). Regulating services are delivered when ecosystems act as regulators. These include local climate and air quality regulation, carbon sequestration and storage, moderation of extreme events, waste-water treatment, erosion prevention, maintenance of soil fertility, pollination and biological control (TEEB, 2010). Last, cultural services are nonmaterial benefits such as recreation, mental and physical health, tourism, etc. (TEEB, 2010).

Ecosystem functions' magnitude and stability are commonly underpinned by biodiversity (TEEB, 2010). The same linkage between biodiversity and ecosystem services seems logical but hard evidence is often lacking (Palmer et al., 2016). However, it was found by Benayas et al. (2009) that at common restoration scales, biodiversity and provision of ecosystem services are positively correlated after the ecological restoration. Restoration focusing on increasing biodiversity is expected to increase ecosystem service provision (Benayas et al., 2009). This is particularly important since biodiversity is the most common measure of restoration success used for many types of ecosystems (Palmer et al., 2016).

2.4 Forest restoration and functional traits

Functional traits are characteristics that determine species' ecological roles (Díaz et al., 2013). These ecological roles are both their responses to the environment (response traits) and their effects on ecosystem properties and services (effect traits). Response traits include the capacity of species to colonize or thrive in a habitat and to persist environmental changes and thus climate change, for example bark thickness is related with fire tolerance. Effect traits influence a species' impact on ecosystem properties and services, for example nitrogen fixation influences the soil fertility (Díaz et al., 2013). The traits can be morphological, biochemical, physiological, structural, phenological or behavioural and are expressed in the phenotypes (Díaz et al., 2013).

Functional trait-based restoration is one of the latest trends in the field of ecological restoration. This approach is promising because it has the potential to increase the provision of ecosystem services because functional traits affect the ecosystem processes underlying these ecosystem services (Palmer et al., 2016). Consequently, it is advised to accomplish FLR by using species with functional traits that favour the capacity to withstand local environmental stresses and deliver the desired restoration objectives. Moreover, to create resilient ecosystems, species with favourable trait combinations can be selected to reduce mortality risks under climate change (Laughlin et al., 2016; Palmer et al., 2016). For example, in areas where aridity is expected to increase, species with traits contributing to drought resistance can be selected. With functional trait-based restoration, species with traits such as dense wood and a thick bark can be selected for restoration in the driest areas.

Giannini et al. (2017) used functional traits to select plant species for restoration of degraded lands. They also state the importance of the relation between plant functional traits and the suitability to be planted under different environmental stress conditions. Moreover, species with varying ecological functions are recommended to be planted together (Giannini et al., 2017). Thus, species recommendations are based on the maximization of functional diversity, local adaptation and use value.

2.5 Forest restoration and local ecological knowledge

Local communities are often not involved in species selection for FLR. Planting a few timber species, for which technical knowledge is available, is a common technique (Suárez et al., 2012). The risk exists that the local population is not interested in the FLR when the needs of local communities are not included, which often leads to failure of the FLR. So, including local interests and knowledge can strongly improve the success of FLR projects (Suárez et al., 2012). Restoration must create environmental conditions that are ecologically, economically and socially viable (Uprety et al., 2012).

Local communities possess considerable knowledge of the natural resources they use and can be an important source of information to use in FLR and conservation projects (Uprety et al., 2012; He et al., 2015). The local population’s knowledge can be used for species selection in restoration projects. Moreover, the monitoring of restoration projects is effectively done by local people and they can help to sustain restoration projects over the long run. Higgs (2005) and Brooks et al. (2012) emphasize the importance of the support of local communities to restore an ecosystem successfully. An increasing number of papers recognizes that successful ecological restoration depends on a combination of science and LEK and they should be seen as complementary (Uprety et al., 2012).

For example in the SDTFs of central Veracruz, Mexico, LEK has been used for species selection for the restoration of the SDTFs (Suárez et al., 2012). The authors stress that the woody species have to cover a number of uses, desired by the local communities. In order to select species, Suárez et al. (2012) calculated an ethnobotanical index based on the usefulness, scarcity and importance of wildlife of woody species.

2.6 Decision support tools for species selection in FLR

A common goal of decision support tools (DSTs) is to "interactively support decision makers in compiling useful information in order to identify problems and opportunities, and to take decisions" (Reubens et al., 2011). These tools can vary widely in complexity, from as simple as a flowchart to as complex as a packaged system of computer models (Chazdon & Guariguata, 2018).

This thesis research project was realised in collaboration with Bioversity International. This research institution developed a spatially-explicit DST, named ResTool (www.restool.org), for FLR in SDTFs in Colombia. The user-defined inputs for this DST are the location for restoration, the number and characteristics of species one wishes to plant, the characteristics of the restoration site, the restoration objectives and final details about seed transfer zones and the time horizon for restoration (Thomas et al., 2017). A beta version of this tool can be found at www.restool.org. The information that is processed by ResTool was obtained from literature and a workshop with scientific experts (Thomas et al., 2017).

ResTool integrates suitability modelling, functional trait-based restoration and the genetic quality of forest reproductive material in its decision making (Thomas et al., 2017). Suitability modelling is used to assess species' suitability at the planting site and adaptive potential under climate change. Moreover, the origin of genetic material is included in ResTool. This is important because the origin and genetic quality and diversity of forest reproductive material is positively related to survival, growth, productivity and adaptive capacity (Reed & Frankham, 2003; Thomas et al., 2014, 2017).

Another DST similar to the prototype DST of this thesis research project was developed by Reubens et al. (2011) for species selection for land rehabilitation in African semi-arid areas, based on multiple criteria. Multiple types of data-sources (literature, local knowledge and functional traits) are used and different criteria are integrated to recommend a number of species. The tool is based on an extensive database, integrating fragmented knowledge (Reubens et al., 2011).

Van der Wolf et al. (2016) created a DST for tree species selection in coffee and cocoa agroforestry systems in Uganda and Ghana. First, the user has to define the country, region, sub-zone (based on altitude) and crop. Then, the preferred ecosystem services must be defined with their corresponding weights. The information integrated in the tool is primarily based on local agroforestry knowledge (Van der Wolf et al., 2016).

The U.S. Forest Service, Oregon State University, and the Conservation Biology Institute collaborated to create a DST for matching seedlots (seed collections from a known origin) with planting sites based on climatic information. The user-defined inputs are the objective (find seedlots for your planting sites or planting sites for your seedlots), the location, the climate scenario, and the climate variables, among others. As a result, the user obtains a map with the locations where you can find the appropriate seedlots or planting sites. The tool can be found at https://seedlotselectiontool.org/sst/.

3 Materials and methods

3.1 Study region

The study region consists of the coastal SDTFs of north-western Peru and southern Ecuador and the inter-Andean SDTFs of the Marañón valley. The majority of the remaining Peruvian and Ecuadorian SDTFs are located in a global biodiversity hotspot, namely the Tumbes-Chocó-Magdalena biodiversity hotspot, further extending north along the Pacific coast up to Panama (Mittermeier et al., 2005). More specifically, the target region for the prototype DST comprises the coastal and inter-Andean valley forests of the regions of Piura, Tumbes, Lambayeque, Cajamarca, Amazonas and La Libertad in Peru and the province of Loja in Ecuador. The SDTF cover of the target region is indicated in Figure 1.

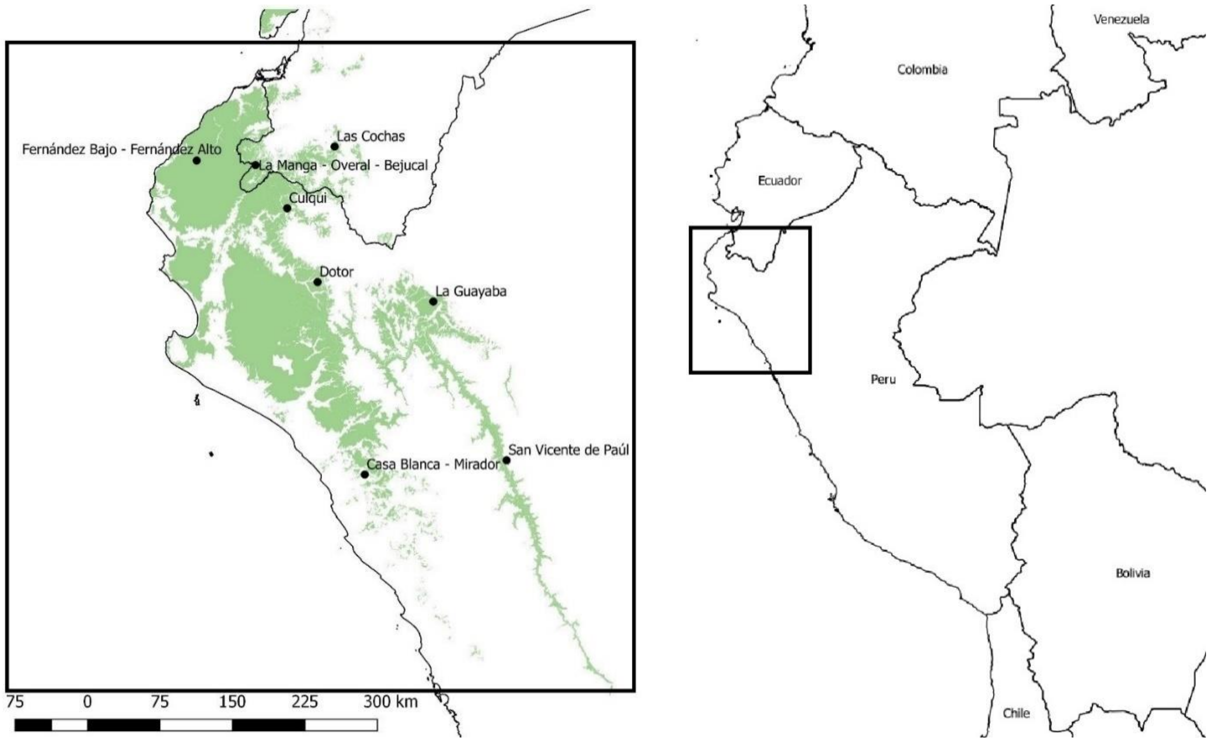

Figure 1: Study region. Target area for seasonally dry tropical forest restoration with the prototype decision support tool. Figure adapted from a figure made by Tobias Fremout, 2017. SDTF cover (in green) is based on Josse et al. 2009; MINAM 2015; Ministerio del Ambiente del Ecuador 2012.

3.1.1 Research sites

Suitable communities for the investigation were selected based on different criteria. First, it was deemed necessary to have a contact person or NGO present in the community. This facilitated the contact with the community, the logistics and getting the research permission. Further, in case of the presence of an NGO, it had the advantage that the NGO could use the collected information afterwards. However, this method had the disadvantage that the selected communities were not necessarily a random sample of the communities existing in the SDTFs of northern Peru and southern Ecuador.

Besides, the combination of selected communities was chosen in such a way that the woody species diversity of the study region was covered as much as possible, so that information about as much as possible woody species of the study region could be gathered. Therefore, a large altitudinal and geographical spread was implicated. Moreover, the communities were chosen in such a way that some socioeconomic variability was covered, mainly in terms of main economic activities. Last, there had to be some not-too-degraded forest left in the community and the forest ecosystem of the community territory had to consist of only SDTFs. Eight research sites were selected and investigated (Table 1).

Table 1: Overview on the research sites

Community name(s)	Country	Region/province	Coordinates
Dotor	Peru	Piura	79.72°W; 5.33°S
La Guayaba	Peru	Cajamarca	78.63°W; 5.51°S
San Vincente de Paúl	Peru	La Libertad	77.94°W; 6.99°S
Casa Blanca – Mirador	Peru	Cajamarca	79.27°W; 7.13°S
Culqui	Peru	Piura	80.01°W; 4.63°S
Fernández Bajo - Fernández Alto	Peru	Piura - Tumbes	80.86°W; 4.19°S
Bejucal – La Manga – Overal	Ecuador	Loja	80.30°W; 4.23°S
Las Cochas	Ecuador	Loja	79.56°W; 4.05°S

When the number of households in a community was not large enough to reach the desired number of interviews, a neighbouring community was included. As a result, in three of the eight research sites, the interviews were carried out in more than one community. Four research sites were situated in north-western Peru, of which two were located in the region of Piura and one at the border of Piura and Tumbes. Two other research sites were situated in the Marañón valley and the 2 remaining ones in the province of Loja, Ecuador. The focus was on the SDTFs higher than 250 masl altitude because SDTFs at lower altitudes have a low species richness (Linares-Palomino, 2006). Six of the eight research sites were positioned higher than 250 masl whereas two others were located lower than 250 masl altitude, but with forests close-by at higher altitudes.

3.1.2 Climate

The mean annual precipitation of the sites investigated ranges between 122 mm and 829 mm (Table 2) (Karger et al., 2017). The mean annual temperature in the research sites ranges between 20.3 °C to 26.1 °C (Table 2). The aridity index of the research sites ranges between 0.08 and 0.67, this can be translated to aridity classes from "arid" to "not classified", since the most humid aridity class has an upper limit aridity index of 0.65 (Table 2). Climate data for all research sites separate is shown in Table 2.

Table 2: Altitude and climate data for the eight investigated research sites. The aridity index (AI) was calculated as the mean annual precipitation divided by the potential evapotranspiration (UNEP, 1992). The potential evapotranspiration is estimated with the Hargreaves method (Hargreaves & Allen, 2003). Aridity values were classified following the United Nations Environment Programme (1992) classification: hyperarid (AI<0.05), arid (0.05<AI<0.20), semi-arid (0.20-0.50) and dry subhumid (0.50<AI<0.65). All climate data were extracted from CHELSA (Karger et al., 2017). Table ordered according to increasing altitude of the research sites.

Research sites	Altitude (masl)	Average annual precipitation (mm)	Average annual temperature (°C)	Aridity index	Aridity class
Fernández Bajo - Fernández Alto	142	145	23.4	0.12	Arid
Dotor	237	391	26.1	0.24	Semi-arid
Casa Blanca - Mirador	298	122	24.3	0.08	Arid
La Guayaba	398	829	25.5	0.53	Dry subhumid
Bejucal - La Manga - Overal	499	519	23.1	0.34	Semi-arid
Culqui	536	372	24.3	0.23	Semi-arid
Las Cochas	1211	813	20.3	0.67	Not classified
San Vincente de Paul	1445	667	20.4	0.43	Semi-arid

3.1.3 Vegetation

Peru's SDTFs have been separated in three groups by Linares-Palomino (2006), namely the equatorial SDTFs, the inter-Andean SDTFs and the eastern SDTFs. The equatorial SDTFs of north-western Peru extend further north in the province of Loja in the south of Ecuador. During this thesis research project, the classification of Linares-Palomino (2006) was used to describe forest types in both Peruvian and Ecuadorian SDTFs in the study region (Table 3). The study region is mainly situated in the equatorial SDTF group. The two research sites in the Marañón valley belong to the inter-Andean SDTF group, whereas the Las Cochas community in the south of Ecuador is situated in a transition zone between the montane equatorial dry forests and the Ecuadorian inter-Andean dry forests. None of the research sites is situated in the eastern SDTFs, since it is not a part of the study region.

The equatorial SDTF region is the least fragmented and most extensive SDTF area of the study region. Within the equatorial SDTFs, two vegetation types have been distinguished, the lowland SDTF vegetation and the montane SDTF vegetation (Linares-Palomino, 2006). The lowland areas are mainly located close to the coast and at altitudes below 600m. These forests have a low species richness, low canopy height and low stem densities in comparison with the montane SDTFs (Linares-Palomino, 2006). Further, these forests are characterized by xeric vegetation species such as *Parkinsonia praecox, Prosopis pallida, Caesalpinia paipai* and several *Cactaceae*. This forest type contains at least 12 species that are endemic to Peru and 19 species endemic to Peru and Ecuador (Linares-Palomino, 2006). The montane forests are mainly located on the west-facing slopes of the western cordillera between 700 and 1800 masl. These montane forests have up to twice the species richness and five times the stem density of the lowland areas (Linares-Palomino, 2006). Moreover, the forest is of taller structure and has a dense canopy. Characteristic species are *Ceiba trischistandra, Eriotheca ruizii, Eriotheca discolor* and *Terminalia valverdeae*. This forest type contains at least 24 species that are endemic to Peru and 36 species endemic to Ecuador and Peru (Linares-Palomino, 2006).

Two research sites are situated in the Marañón valley and belong to the inter-Andean SDTF group. The Marañón valley contains at least 143 endemic woody species, corresponding to 33% endemism in the woody flora (Marcelo-Peña et al., 2016b). *Ruprechtia aperta* and *Tetrasida chachapoyensis* are examples of endemic species with high local abundance (Marcelo-Peña et al., 2016b). The SDTFs in the Marañón valley have higher endemism values than the neighbouring SDTFs for both fauna and flora (Marcelo-Peña et al., 2010). The high biological diversity might be due to the isolation, the variated topography and the presence of the Marañón river (Marcelo-Peña et al., 2010). However, this valley also shares a large amount of woody species with the SDTFs from north-western Peru and southern Ecuador, as it is connected to these forests by the Huancabamba depression, where the Andes mountain range descends to its lowest altitude (Quintana et al., 2017). The valleys of the inter-Andean SDTFs have been very little explored and are highly threatened by deforestation (Linares-Palomino 2006). The inter-Andean SDTFs of the study region are biologically particularly valuable and are included in the conservation programme of Global 2000 (Marcelo-Peña et al., 2010).

Table 3: Information about the altitude, forest type, common woody species and conservation/degradation status for the surrounding forest in the eight different research sites. Table ordered according to increasing altitude of the sites. SDTF stands for seasonally dry tropical forest. (Part 1)

Research site	Altitude (masl)	Forest type	Common woody species	Forest conservation/ degradation status
Fernández Bajo - Fernández Alto	142	Lowland equatorial SDTF	*Prosopis pallida, Loxopterygium huasango, Caesalpinia paipai, Cordia lutea, Pithecellobium excelsum, Vachellia macracantha*	Degraded in many areas due to past charcoal production (high pressure on *Prosopis pallida*) and overgrazing, mainly by goats. Other parts are relatively well-conserved because of protected status of 'national park'. Valuable timber species such as *Loxopterygium huasango* are slowly recovering inside the protected area.
Dotor	237	Lowland equatorial SDTF	*Cordia lutea, Vachellia macracantha, Prosopis pallida, Erythrina velutina, Albizia multiflora, Celtis iguanaea, Caesalpinia paipai, Chloroleucon mangense*	Lower parts close to the village degraded due to overgrazing and timber extraction, higher parts better conserved, but valuable timber species such as *Handroanthus chrysanthus* have almost completely disappeared.
Casa Blanca - Mirador	298	Lowland equatorial SDTF	*Vachellia macracantha, Loxopterygium huasango, Bursera graveolens, Cordia lutea, Parkinsonia praecox, Colicodendron scabridum*	Highly degraded in all areas close to the village due to agriculture and timber extraction. Relatively well-conserved area at about 7km from the research site, where a conservation area is currently being installed.
La Guayaba	398	Inter-Andean SDTF (Marañón valley)	*Sideroxylon obtusifolium, Ceiba insignis, Cordia lutea, Maclura tinctoria, Croton thurifer, Eriotheca discolor, Cynophalla flexuosa, Ruprechtia aperta, Cactaceae*	Highly degraded, no forest left in the river plain due to installation of agricultural fields. In the hills around the community, degraded forest remains, affected by forest fires and timber extraction

Table 3: Information about the altitude, forest type, common woody species and conservation/degradation status for the surrounding forest in the 8 different research sites. Table ordered according to increasing altitude of the sites. SDTF stands for seasonally dry tropical forest. (Part 2)

Research site	Altitude (masl)	Forest type	Common woody species	Forest conservation/ degradation status
Bejucal - La Manga - Overal	499	Lowland equatorial SDTF	*Simira ecuadorensis, Ceiba trischistandra, Caesalpinia paipai, Centrolobium ochroxylum, Chloroleucon mangense, Citharexylum quitense, Cordia macrantha, Croton* spp.*, Eriotheca ruizii, Erythroxylum glaucum, Handroanthus* spp.*, Pisonia macranthocarpa, Vachellia macracantha*	Well-conserved due to protected status of the La Ceiba 'reserve' and low population density. Valuable timber species such as *Handroanthus chrysanthus* are recovering from over-extraction in the past.
Culqui	536	Lowland equatorial and montane equatorial SDTF	*Bursera graveolens, Ceiba trischistandra, Caesalpinia paipai, Cordia lutea, Croton* spp.*, Erythrina velutina, Eriotheca ruizii, Maclura tinctoria, Pisonia macranthocarpa, Terminalia valverdeae, Vachellia macracantha*	Relatively well-conserved in many parts of the hills, degraded to highly degraded in lower parts because of agriculture and cattle grazing.
Las Cochas	1211	Transition between montane equatorial and Inter-Andean SDTF	*Vachellia macracantha, Cordia lutea, Croton* spp.*, Cynophalla flexuosa, Cyathostegia matthewsii, Eriotheca ruizii, Erythrina velutina, Zanthoxylum fagara*	Highly degraded in all parts, there was much degradation due to goats in the past.
San Vincente de Paul	1445	Inter-Andean SDTF (Marañón valley)	*Croton thurifer, Eriotheca discolor, Anadenanthera colubrina, Colicodendron scabridum, Vachellia macracantha, Maraniona lavinii, Maclura tinctoria*	Highly degraded in all areas close to the community due to agriculture and forest fires. *Cedrela kuelapensis*, a valuable endemic timber species, has almost completely disappeared.

A checklist of native woody species present in the research area was created based on the checklists from Aguirre et al. (2006b) for the SDTFs of Loja, Ecuador, Linares-Palomino & Pennington (2007) for the coastal SDTFs of north-western Peru and Marcelo-Peña et al. (2016a) for the inter-Andean SDTFs of the Marañón valley. It should be noted that some species in the checklist are not really native but have been naturalised since a long time (e.g. *Jatropha curcas*). However, all species occurring in the checklist will be referred to as native species in this thesis. In the study region, Leguminosae is the most represented family with 105 from the 553 species. The top ten of most represented families is completed by Euphorbiaceae (40 species), Asteraceae (40 species), Malvaceae (32 species), Cactaceae (31 species), Boraginaceae (17 species), Solanaceae (17 species), Moraceae (15 species), Bignoniaceae (14 species) and Sapindaceae (12 species).

3.2 Data collection

Before going to Peru, a preliminary set of species to be studied was formed, based on information from forest inventory data and preparatory visits by Tobias Fremout. Subsequently, pictures of different parts of these species were compiled to use in the field. These pictures were meant to be used in all types of questionnaires whenever doubts existed on the identity of woody species mentioned by local respondents.

Data were obtained in Peru and Ecuador through 5 types of interviews. Interviews with key informants, household interviews, group discussions, LEK expert interviews and scientific expert interviews were carried out. Only the information from LEK expert interviews, scientific expert interviews and household interviews were used in this thesis project. Additional data were obtained from literature and databases.

3.2.1 Household interviews

The household interviews are individual interviews with randomly selected community members and the goal was to obtain information about the ecosystem services that different woody species deliver to the rural communities. In every research site, the best possible list of the local population (all adults or all households) was obtained. Next, a random selection of the population was made with the random number generator smartphone-application ‘Random UX’ in such a way that at least 10% of the households in every research site were interviewed. This led to a total of 197 interviews. The number of households interviewed in each research site can be found in Table 4. If a selected person lived far away and was not encountered or in case the house was repeatedly visited without encountering the person, the interview was carried out with another household member or a neighbour because of time constraints. The number of men and women was balanced as much as possible in every research site.

Table 4: Overview of the number of households and the number of interviewed households in the eight research sites. Table ordered according to increasing number of households in the research sites.

Research sites	Approximate number of households	Number of households interviewed
Fernández Bajo - Fernández Alto	38	20
Dotor	53	20
Bejucal- La Manga- Overal	66	24
Las Cochas	164	24
Casa Blanca - Mirador	183	25
La Guayaba	196	25
Culqui	214	29
San Vincente de Paul	290	30

During the household interviews, the focus was on the use of species-level ecosystem services. This type of interview was made up of four parts (Annex AAnnex A: Translation of household interview). In part one, questions about the household situation were asked. Questions about the woody species that respondents had on their properties were asked in part two. Part three was about the species-specific ecosystem services that people obtain from woody flora in the surrounding SDTFs. The questions from part four were intended to reveal the socioeconomic situation of the respondent. Only the data from part two and three were used in this thesis. The provisioning services included in the interview were firewood, charcoal, animal food, construction, food, medicine and bee plant.

3.2.2 Local ecological knowledge (LEK) expert interviews

The aim of the interviews with LEK experts for this thesis project was to obtain information about the ecosystem services and the ecology of the woody species occurring in the study region. The LEK experts were identified with the aid of key informants and the contact person/organisation. Further, the interviewed LEK experts were asked to suggest other LEK experts in the research site, when necessary. Moreover, LEK experts were sometimes identified during group discussions and household interviews. Preferably, experts from both sexes and with different specialities and interests were included, leading to a different type of knowledge and point-of-view (Souto & Ticktin, 2012). The number of LEK experts interviewed in each research site is given in Table 5.

Table 5: Overview of the number of local ecological knowledge (LEK) experts interviewed in the research sites. Table ordered according to increasing number of LEK experts interviewed in the research sites.

Research site	Number of local ecological knowledge experts interviewed
La Guayaba	3
Casa Blanca - Mirador	5
Las Cochas	5
Fernández Bajo - Fernández Alto	5
Dotor	6
Bejucal- La Manga- Overal	6
Culqui	8
San Vincente de Paul	9

LEK expert interviews consisted of three parts (Annex B: Translation of local ecological knowledge expert interview B). In part one, general information about the respondent was asked to learn about the reasons why this person has a good knowledge of the woody forest species and to understand his/her perspectives. During part two, the respondent was asked to free-list all "useful" woody species of the surrounding SDTFs he/she knew and this list could be completed during a walk in the forest. The respondent was then asked to free-list ecosystem services of the mentioned species. In part three, species-specific ecological information was obtained. The mentioned species were classified by the experts according to growth rate (fast, intermediate and slow growth) and regeneration (good and poor regeneration). Next, the experts were asked to free-list species that could be planted under local environmental stress factors. The LEK experts were asked to recommend species with respect to the following environmental stress factors: presence of strong slopes, cattle/goat grazing pressure, flooding risk, erosion, extreme drought, shallow or rocky soils, and presence of water. It has to be noted that these so-called local environmental stress factors are not a stress for all species. For clarity however, these environmental conditions will be referred to as environmental stress factors in the following, to distinguish them from other environmental characteristics such as soil and climate factors. Moreover, information was gathered about the potential of species to improve soil fertility, to be used in agri-silvicultural systems, and to contribute to the conservation of fauna and threatened woody species, through free-listing as well. By asking about the reason the respondent recommended species under specific environmental stress conditions or for specific restoration objectives, information about functional traits was occasionally collected.

Originally, it was planned to carry out LEK expert interviews both during walks in the forest (in-situ) and with pictures from the different parts of the woody species from the preliminary species set (ex-situ). The ex-situ method has the advantage that less mobile LEK experts could be interviewed and that it takes less time and therefore more interviews could be carried out in the same time frame. The main advantage of executing the interview during a walk in the forest, is the availability of the maximum of decisive variables for species recognition (Thomas et al., 2007). Many botanical and ecological characteristics are not observable from pictures. However, Thomas et al. (2007) carried out a recognition test and reported that the participants recognized about 94% of the pictures of species they had indicated before in the forest. During the first week of the fieldwork however, it was noted that the LEK experts didn't recognize the species on the pictures very well. Hence, the LEK expert interviews were carried out during a walk in the forest whenever possible. In the end, 79% (37/47) of the LEK expert interviews were carried out during walks in the forest. In this study, the in-situ method had the additional advantages that plant material could be collected and identified, local species names could be checked with their scientific names and geographical coordinates of the collected species could be noted. The walks were focused on finding the free-listed species with an ambiguous local name and/or the species of which the scientific name was not known.

The aim was to carry out 48 LEK expert interviews, divided over the eight different research sites. This amount was chosen given that the goal was to obtain sufficient interviews to make solid conclusions that could be used in the prototype DST and six per research site (one per day) was a feasible amount. Doing more than one interview per day would have been difficult since the walks in the forest were time-consuming and the identification of good LEK experts was not always easy. A total of 47 LEK expert interviews were carried out. Nine (19%) of these LEK experts were women and 38 (81%) were men. 44 of the 47 (94%) people interviewed cultivated crops, whereas 22 of the 47 (47%) owned cattle and eight of the 47 (17%) produced honey. One (2%) of the LEK experts had not received formal education, whereas 27 of the 47 (57%) people went to primary school, ten (21%) went to secondary school and nine (19%) of them had higher education. Most of the experts said they had good ecological knowledge because they were born and raised in the community in question and someone (mostly their parents) taught them. Having cattle was another very prominent reason, since cattle is often reared in the forest during a large part of the year.

3.2.3 Interviews with scientific experts

The interviews with scientific experts were meant to gain additional information about species' ecology. The methodology of these interviews was very similar as part three of the LEK expert interviews (Annex CAnnex C: Translation of the scientific expert interview). Consequently, information about species' regeneration was obtained. Instead of asking scientific experts about growth rates, species' growth strategies (pioneer, intermediate or late successional) were asked to obtain information that could not be gathered from the LEK expert interviews. Growth rates were not asked to limit the time of the interview because this type of question was time-consuming. Further, similar questions about suitability to be planted under environmental stress conditions or to contribute to restoration objectives were asked. This included information about strong slopes, cattle/goat grazing, flooding, extreme drought, shallow or rocky soils, presence of water, erosion and threatened woody species. Questions that were asked in the LEK expert interviews but not in the interviews with scientific experts are suitability for agri-silvicultural systems, improvement of soil fertility and the conservation of fauna. Additional questions in the interviews with scientists were about the potential of species to contribute to fire resistance, watershed protection and carbon sequestration, as well as the suitability to be planted on salty soils, on compacted soils, and in areas with a highly fragmented forest cover. An overview of the three interviewed scientific experts can be found in Table 6. Due to time constraints, it was not possible to carry out more interviews of this type.

Table 6: Overview on the scientific experts interviewed

Name of scientific expert	Organization	Specialization and relevant publications
José Luis Marcelo-Peña	Universidad Nacional Agraria La Molina: department of forestry management	Specialized in the seasonally dry tropical forests of the Marañón valley. Has contributed to some useful publications used to develop the decision support tool (Marcelo-Peña et al. 2016a; Marcelo-Peña et al., 2016b). Source: www.researchgate.net/profile/Jose_Luis_Marcelo_Pena
Eduardo Cueva	NGO Naturaleza y Cultura Internacional (NCI)	Forestry engineer who studied native fruits from southern Ecuador, species growth, forest seeds and reforestation. Source: www.naturalezaycultura.org/spanish/htm/about/senior.htm
Reynaldo Linares-Palomino	Smithsonian Conservation and Biology Institute's Center for Conservation and Sustainability	Tropical biologist who has studied several types of tropical ecosystems, ranging from deserts to rainforests, including seasonally dry tropical forests. Several vegetation descriptions of the research area are from his hand (Linares-Palomino 2002; Linares-Palomino & Pennington 2007; Aguirre et al., 2006b; Linares-Palomino 2006; Linares-Palomino et al. 2009; Linares-Palomino 2004). Further, he is a founding member of the DryFlor (Latin American Seasonally Dry Tropical Forest Floristic) Network. Source: https://nationalzoo.si.edu/conservation/reynaldo-linares-palomino

3.2.4 Functional traits

Data about functional traits are used in the prototype DST to determine species' suitability to deliver the desired ecosystem services and to estimate species' resistance or resilience towards local environmental stress factors. Most of this information was collected from literature (Table 7). An overview of all the functional traits for which information was collected, with the corresponding trait levels, information sources and number of species for which a value was obtained is given in Table 7. In total, 24 different functional traits were used.

Table 7: Overview of all functional traits used with the corresponding trait levels, information sources from which the functional trait information was obtained and the number of species for which a value was obtained. Table ordered according to decreasing number of species for which information was obtained per functional trait. The maximum number of species is 111. (Part 1)

Functional trait	Trait values	Source	Number of species
Nitrogen fixation	Yes/No	Literature	111
Maximum height	Quantitative (unit: meter)	Literature	104
Leaf type	Simple, Compound	Literature	104
Bark texture	Smooth, Rough, Cracked, Lenticelated	Literature	93
Presence of spines	Yes/No	Literature	87
Growth strategy	Pioneer, Intermediate, Late	Literature; Scientists	36; 79
Dispersal type	Wind, Water, Autochory, Insects, Bats, Birds, Mammals, Cattle/goats	Literature and LEK	78
Leaf phenology	Deciduous, Semi-evergreen, Evergreen	Literature	78
Diaspore type	Individual seed, Multiple seeds	Literature	78
Reproduction system	Dioic, Monoic, Polygamous	Literature	75
Growth rate	Fast, Intermediate, Slow	Literature; LEK	35; 70
Crown form	Globular, Conical, Cylindrical, Sparse, Umbrella-shaped, Irregular	Literature	70
Wood density	Very low (<0.3 g/cm³), Low (0.3-0.39 g/cm³), Intermediate (0.4-0.59 g/cm³), High (0.6-0.79 g/cm³), Very high (≥0.8 g/cm³)	Literature	67
Seed length	Quantitative (unit: mm)	Literature	61

Table 7: Overview of all functional traits used with the corresponding trait levels, information sources from which the functional trait information was obtained and the number of species for which a value was obtained. Table ordered according to decreasing number of species for which information was obtained per functional trait. The maximum number of species is 111. (Part 2)

Functional trait	Trait values	Source	Number of species
Pollinizer type	Insects, Birds, Bats, Mammals, Wind	Literature and LEK	45
Specific leaf area	Quantitative (unit: cm^2/g)	Literature	44
Leaf area	Quantitative (unit: cm^2)	Literature	42
Germination strategy	Orthodox, Recalcitrant	Literature	39
Resprouting/coppicing capacity	Not, Aboveground, Belowground	Literature and LEK	22
Bark thickness	Thin (<0.5 cm), Medium (0.5-1 cm), Thick (>1cm)	Literature and LEK	17
Deep roots	Yes/No	Literature and LEK	15
Cattle/goat palatability	Low palatability, high palatability	Literature	12
Stem succulence	Yes/No	Scientists	3
Radicular succulence	Yes/No	Scientists	2

3.2.5 Additional data sources

Although a considerable amount of information was gathered during the fieldwork, additional data were searched in existing databases, scientific articles, plant species information sheets and books. Most of the information obtained about species' functional traits and much information about their ecology and ecosystem services was found in these sources. A lot of the compiled secondary data were taken from two books containing information sheets of woody species occurring in parts of the study region (Marcelo-Peña et al. 2010; Aguirre 2012). Further, much useful information was found in plant information sheets from initiatives such as 'Trees and shrubs potentially valuable for ecological restoration and reforestation' from La Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO)' (Vázquez-Yanes et al., 1999), 'Ecocrop' (Ecocrop, 2013), 'AgroforesTree Database' from World Agroforestry Centre (ICRAF) (Orwa et al., 2009), 'Species for restoration' from the International Union for Conservation of Nature and Natural Resources (IUCN) (UICN, 2015) and 'Survey of Economic Plants for Arid and Semi-Arid Lands (SEPASAL)' (Royal Botanic Gardens, Kew, 1999), among others. Moreover, information was obtained from databases. TRY, a global database of plant traits (Kattge et al., 2011), was used to extract information on functional traits. The same was done for the species database behind ResTool (Thomas et al., 2017).

3.3 Data analysis

Before analysis, all data were organized in Microsoft Office Excel. First, all data obtained from the different interviews were entered in separate spreadsheets. Only the species that were mentioned for a category by at least two LEK experts or during two household interviews were included in data analysis, to eliminate potential erroneous information. Thus, when a species was mentioned only one time as a response to a specific question (single species recommendation), this information was discarded during data analysis, unless mentioned otherwise. Further, the focus was on trees and shrubs and therefore *Cactaceae* and herbaceous species, mentioned during interviews, were not included. Nonetheless, this does not imply that species of these groups cannot be valuable for FLR.

During the fieldwork, it was noted that local people often do not distinguish (i.e. under differentiation) the species within the genera *Handroanthus*, *Ficus, Cedrela, Piper* and *Bougainvillea.* The species of these genera had the same local name. Consequently, data about the specific species of these genera were only gathered if these species were encountered during a walk in the forest. As this was often not the case, much of the information about the species in these genera is not at the species level, but at the genus level. The reason that the species from these genera are usually not distinguished by local people is that their phenotypes are often very similar. Hence, it was assumed that the species within these genera, are ecologically very similar, so that information obtained at the genus level could be extrapolated to the species level. More specifically, the information obtained from LEK expert interviews about the *Handroanthus* genus was extrapolated to the species *Handroanthus billbergii, Handroanthus chrysanthus* and *Handroanthus ochraceus,* the info on the *Ficus* genus to the species *Ficus citrifolia, Ficus jacobii* and *Ficus obtusifolia*, the info on the *Cedrela* genus to the species *Cedrela odorata* and *Cedrela kuelapensis*, the info on the *Piper* genus to *Piper aduncum* and the info on the *Bougainvillea* genus to *Bougainvillea peruviana.* In all other cases where the information was only obtained at the genus-level, the information was not included.

The data analysis was carried out in Microsoft Office Excel and R. An overview of the research questions and the data sources used to answer to these questions is given in Table 8.

Table 8: Research questions and data sources used to answer to these questions

Research questions	Data sources
1. Which woody species are the most useful for the studied rural communities?	Local ecological knowledge (LEK) expert interviews and household interviews.
2. Can local ecological knowledge (LEK) be used for species recommendations for SDTF restoration?	Information from LEK experts, compared between themselves and with information from scientific experts and literature.
3. Which woody species are suitable for SDTF restoration for different restoration objectives and under different local environmental stress factors?	LEK expert interviews, scientific expert interviews, literature, functional traits and household interviews.

3.3.1 Which woody species are the most useful for the studied rural communities?

The aim of this research question was to reveal the most useful woody species for different use categories and for all use categories combined. An answer to this research question was sought by analysing information from LEK expert interviews and household interviews separately. The Economic Botany Data Collection Standard was used to standardize plant use categories (Cook, 1995). However, an additional use category "construction" was added, in line with other ethnobotanical studies in the tropics (Dewalt et al., 1999; Galeano, 2000; Thomas et al., 2009). Originally, construction is included in the use category "materials" (Cook, 1995). The considered use categories in this research question with an explanation are represented in Table 9.

Table 9: Use categories considered to determine the most useful woody species in the studied rural communities with an explanation of what the categories include. Adapted from the Economic Botany Data Collection Standard (Cook, 1995).

Use category	Explanation
Construction	Wood for construction, including poles
Fuel	Firewood, charcoal
Materials	Fibres, dye, handicrafts, wood for tools
Animal food	Forage and fodder for domesticated animals
Food	Edible plant parts (e.g. fruits), includes processed food, for humans only
Medical use	Both human and veterinary
Vertebrate poison	Plants poisonous to vertebrates (e.g. for hunting and fishing)
Non-vertebrate poison	Plants poisonous to non-vertebrate animals, plants, bacteria and fungi
Bee plant	Pollen or nectar sources for honey production
Social use	Plants with a social purpose, like smoking materials, narcotics, abortifacients, plants with ritual or religious significance
Environmental use	E.g. intercrops, ornamentals, shade plants, windbreaks, soil improvers

In order to identify the most useful species for rural communities, the Cultural Importance (CI) index was used (Tardío & Pardo-de-Santayana, 2016). The CI index is defined as the mean number of use-reports that the informants of a certain survey give for a species (Tardío & Pardo-de-Santayana, 2016). The formula of the CI index of species ‘s’ is the following:

$$CIs = \sum_{u=u_1}^{u_{NC}} \sum_{i=i_1}^{i_N} \frac{UR_{ui}}{N}$$

With ‘u’ the use category, NC the total number of use categories, ‘i’ the interviewed person and N the total number of interviewed people. UR is the use report (Tardío & Pardo-de-Santayana, 2016). Thus, first the number of interviewed people who mentioned a specific use-category for the species was obtained. Second, all the use reports of the different use-categories were summed for species ‘s’. This sum was divided by the number of interviewed people, so the denominator is fixed over all species.

In addition, an adjusted form of this formula was calculated to account for the fact that species composition changes between the investigated research sites:

$$adjusted\ CIs = \sum_{u=u_1}^{u_{NC}} \sum_{i=i_1}^{i_{Ns}} \frac{UR_{ui}}{Ns}$$

With Ns the total number of people interviewed in the communities where native species ‘s’ is present in the wild and/or cultivated (see example below). A species was assumed to be present in a community if a respondent mentioned the species during an interview. In the adjusted CI index, the denominator changes between species. In this way, a CI index was obtained that is independent from the number of research sites where the species are present. An example of how to calculate the adjusted CI index is given in Box 1.

Box 1: Example of a calculation of the adjusted CI index

Calculation of the adjusted CI index: A species ‘s’ is present in two of the eight research sites, where 24 and 29 households were interviewed, and only three provisioning services are considered in this example, e.g. fuel, construction and bee plant. The species was recommended for fuel by six and eight households, by zero and two households for construction and by 11 and 16 households for bee plant in the two research sites, where the species was present. Consequently, the adjusted CI index of species ‘s’ is the following:

$$CIs = \frac{6+8}{24+29} + \frac{0+2}{24+29} + \frac{11+16}{24+29} = \frac{43}{53} = 0.81$$

This resulted in an adjusted CI index of 0.81, whereas the maximum for this example is three (the number of use categories).

The CI index takes the diversity of a species' uses into account. Further, it is an intuitive index because the theoretical maximum equals the number of use categories (NC). This maximum would be reached if all interviewed people, mentioned all use-categories for the species in question (Tardío & Pardo-de-Santayana, 2016). Hence, the maximum of the CI index, calculated in this project, is eleven. Moreover, the CI index is highly correlated with the frequency at which species are mentioned. This is a good characteristic for an ethnobotanical index, because an objective index must rely more on the frequency at which species are mentioned than on the number of uses of a species, because the number of mentioned uses of a species is influenced by the amount of use-categories considered in the research (Tardío & Pardo-de-Santayana, 2016). For these reasons, the CI index is a good choice to use for this research question.

Subsequently, the CI indices calculated from LEK expert interviews and household interviews, were plotted against each other. Moreover, it was evaluated which use categories were mentioned the most. Bar plots for the number of use reports per respondent per use category were created for both LEK expert interviews and household interviews.

3.3.2 Can local ecological knowledge be used for species recommendations for SDTF restoration?

The aim of this research question was to determine if LEK expert recommendations can be used to select species for SDTF restoration. This was answered by calculating the internal consistency between information from different LEK experts and by comparing the information from LEK experts with information from literature and scientific experts. The comparison was only made for the species used in the prototype DST because information from literature and scientists was only collected for these species. The data from LEK experts that were compared with literature and scientific experts consist of species recommendations for the information categories that are given in Table 10. The analysis was carried out with both the single species recommendations (i.e. when a species was only recommended once for an information category) included and excluded to detect the influence of excluding single species recommendations.

Table 10: Information categories investigated in the research question "Can local ecological knowledge be used for species recommendations for seasonally dry tropical forest restoration?"

Information category	Explanation
Erosion	Plants that can grow in eroded soils and that control and prevent erosion
Soil fertility improvement	Plants useful for improvement of the soil fertility
Agri-silvicultural system	Plants suitable to grow together with agricultural crops in the same land at the same time
Extreme drought	Plants that can survive extreme drought events
Steep slopes	Plants that can grow on steep slopes and stabilize them
Shallow or rocky soils	Plants that can grow in shallow or rocky soils, mostly plants with shallow roots
Floods	Plants that can survive temporal floods
Presence of water	Plants that grow near rivers and streams
Grazing pressure	Plants that can resist grazing pressure (e.g. not palatable for animals)
Threatened woody species	Plants that are threatened in the study region

3.3.2.1 Consistency between species recommendation lists of LEK experts within the information categories

The recommendations of LEK experts were tested for internal consistency by calculating the Jaccard dissimilarity (JD) between species recommendations of different experts for the different information categories in Table 10 with the following formula (Cheetham & Hazel, 1969; Blanco & Carrière, 2016):

$$\Delta ij = 1 - \mathrm{J(i,j)} = \frac{Si1j0 + Si0j1}{|Si \cup Sj|}$$

With Si, the species recommended by LEK expert 'i' and Sj the species recommended by LEK expert 'j' for the same specific information category. *Si1j0* are the species mentioned by LEK expert 'i' but not by LEK expert 'j' and *Si0j1* are the species mentioned by LEK expert 'j' but not by LEK expert 'i' for the same information category. The denominator equals all species recommended by at least one of both LEK experts for this information category (Blanco & Carrière, 2016). The JD ranges between zero and one. One represents complete dissimilarity, so the species recommendations by the different LEK experts for an information category would differ completely. Zero represents complete similarity, so the species recommendations from all experts would be completely the same for an information category (Blanco & Carrière, 2016).

Per research site, a Jaccard distance matrix was formed for all information categories by calculating the pairwise Jaccard dissimilarities (JDs) between the LEK experts. Each pairwise combination between two LEK experts only considered the species that were mentioned by both experts at some point in the interview. Therefore, the species that are not known by both LEK experts are not included in the analysis. Subsequently, the mean JD per research site per information group was calculated. Next, the average of the mean JDs from the different research sites was calculated per information category, resulting in an overall mean JD per information category. The analysis was carried out with both the single species recommendations included and excluded to detect the influence of excluding single species recommendations. The R-package “vegan” was used for this analysis (Oksanen et al., 2015).

3.3.2.2 Comparison of information from LEK experts with information from literature and/or scientists

The species recommendations by LEK experts were compared with the information from literature and from the interviews with scientists, for the information categories in Table 10. Three comparisons were made: LEK experts vs. literature, LEK experts vs. scientific experts, and LEK experts vs. the combination of literature and scientific experts, all three following the same methodology. If a species was recommended for an information category by LEK experts, scientific experts and/or literature, a value of one, which will be referred to as one-value, was given to this species - information category combination (Box 2). Likewise, when negative information was collected for a species - information category combination, i.e. when a species was discouraged to be planted, a value of zero, which will be referred to as zero-value, was attributed (Box 2). Subsequently, the number of species for which consistent and inconsistent recommendations were obtained from the different information sources were counted per information category (Box 2). In the case that the recommendations by literature and scientists did not coincide, the comparison of LEK experts vs. the combination of literature and scientists was not carried out. The analysis was carried out with both the single species recommendations included and excluded to detect the influence of excluding single species recommendations. An example of the calculation carried out in this research question is given in Box 2.

Box 2: Example of a calculation of the number consistent and inconsistent recommendations of local ecological knowledge (LEK) experts vs. literature and scientific experts

A species 's' is recommended in literature to grow in shallow or rocky soils. During the fieldwork, four LEK experts also recommended species 's' to grow in shallow or rocky soils. However, a scientific expert discouraged species 's' to grow in shallow or rocky soils. Consequently, the values attributed to species 's' for growing in shallow or rocky soils would be:

	Literature	LEK experts	Scientific experts
Species 's'	1	1	0

So, for species 's' there is a consistent recommendation for LEK experts vs. literature but an inconsistent recommendation for LEK experts vs. scientific experts, and no comparison for LEK experts vs. the combination of literature and scientific experts because the recommendations by literature and scientists did not coincide. For each information category, this was carried out for all 111 species. The number of species for which consistent and inconsistent recommendations were obtained from the different information sources were subsequently counted per information category.

3.3.3 Which woody species are suitable for SDTF restoration for different restoration objectives under different local environmental stress factors?

The aim of this research question was to develop a prototype DST for native woody species selection for the restoration of SDTFs in the study region. The analysis of this research question consisted of creating and subsequently testing the prototype DST. To develop the prototype DST, a species list was constructed, an extensive database for these species created and R-scripts were written. To test the prototype DST, three case studies were created, and the DST was used to recommend species under different combinations of primary restoration objectives and environmental stress factors.

The suitability of tree and shrub species for restoration depends, among other factors, on their resilience towards local environmental stress factors (influenced by functional traits) and the extent to which they deliver the ecosystem services expected by the local communities. Taking into account the needs of the local communities is important, given that the support of the local people is necessary to achieve successful restoration. The aim of the prototype DST developed in this thesis research project is to provide recommendations on the most suitable species to plant, given user-defined inputs. These inputs are the priority restoration objectives, with their importance as a number between zero and one, and the local environmental stress factors at the planting site. An overview of all restoration objectives and environmental stress factors with their corresponding information sources and the functional traits used to calculate species suitability scores and their corresponding weights can be found in Table 11 and Table 12 respectively. The restoration objectives and environmental stress factors were adapted from those used in ResTool. The functional traits and the functional trait weights were adapted from the results of a workshop with scientists in the context of the development of ResTool (Thomas et al., 2017).

Table 11: Information sources used for all restoration objectives and the functional traits used, with their corresponding weight, to estimate species suitability scores. The weights of the functional traits sum to one per restoration objective. A similar table with the possible trait levels and attributed numerical values for the different trait levels, can be found in Annex D: 'Traits-weights-values' spreadsheet D. (Part 1)

Restoration objectives	Information source	Functional trait	Weight
Carbon sequestration	Functional traits	Maximum height	0.14
	Scientific expert	Leaf area	0.14
		Specific leaf area	0.14
		Growth rate	0.14
		Wood density	0.14
		N-fixation	0.11
		Leaf phenology	0.08
		Growth strategy	0.11
Soil fertility improvement	Functional traits	N-fixation	0.26
	Scientific expert	Leaf phenology	0.16
	Literature	Specific leaf area	0.21
	LEK	Crown form	0.21
		Growth rate	0.16
Watershed protection	Scientific expert		
	Literature		
Agri-silvicultural systems	Functional traits	Specific leaf area	0.15
	Literature	N-fixation	0.25
		Resprouting/coppicing capacity	0.20
		Growth rate	0.20
		Growth strategy	0.20
Silvopastoral systems	Functional traits	Resprouting/coppicing capacity	0.14
	LEK expert	Leaf phenology	0.14
	Literature	Growth rate	0.14
		Deep roots	0.14
		Growth strategy	0.14
		Specific leaf area	0.06
		N-fixation	0.14
		Crown form	0.11
Life fence	LEK expert		
	Literature		
Ornamental	LEK expert		
	Literature		

Table 11: Information sources used for all restoration objectives and the functional traits used, with their corresponding weight, to estimate species suitability scores. The weights of the functional traits sum to one per restoration objective. A similar table with the possible trait levels and attributed numerical values for the different trait levels, can be found in Annex DAnnex D: 'Traits-weights-values' spreadsheet. (Part 2)

Restoration objectives	Information source	Functional trait	Weight
Fire-wood	Functional traits	Wood density	0.33
	LEK expert	Growth rate	0.33
	Literature	Resprouting/coppicing capacity	0.33
	Household interview		
Construction	Functional traits	Wood density	0.29
	LEK expert	Maximum height	0.29
	Literature	Growth rate	0.24
	Household interview	Resprouting/coppicing capacity	0.18
Forage	Functional traits	Growth rate	0.18
	LEK expert	Leaf phenology	0.18
	Literature	Crown form	0.14
	Household interview	N-fixation	0.11
		Specific leaf area	0.11
		Resprouting/coppicing capacity	0.14
		Presence of spines	0.14
Medicine	LEK expert		
	Literature		
	Household interview		
Food	LEK expert		
	Literature		
	Household interview		
Charcoal	Functional traits	Wood density	0.33
	LEK expert	Growth rate	0.33
	Literature	Resprouting/coppicing capacity	0.33
	Household interview		
Bee plant	LEK expert		
	Literature		
	Household interview		
Materials	LEK expert		
	Literature		
	Household interview		
Commercial wood	LEK expert		
	Literature		
NWFP with commercial potential	LEK expert		
	Literature		

Table 11: Information sources used for all restoration objectives and the functional traits used, with their corresponding weight, to estimate species suitability scores. The weights of the functional traits sum to one per restoration objective. A similar table with the possible trait levels and attributed numerical values for the different trait levels, can be found in Annex D. (Part 3)

Restoration objectives	Information source	Functional trait	Weight
Threatened woody species conservation	LEK expert		
	Scientific expert		
	Literature		
Endemic woody species conservation	Literature		
Bird species conservation	LEK expert		
	Literature		
White-tailed deer conservation	LEK expert		
	Literature		
White-winged guan conservation	Literature		
Spectacled bear conservation	Literature		
General forest fauna conservation	LEK expert		
	Literature		

Table 12: Information sources used for all environmental stress factors and the functional traits used, with their corresponding weight, to estimate species suitability scores. The weights of the functional traits sum to one per environmental stress factor. A similar table, with the trait levels and attributed numerical values for the different trait levels, can be found in Annex D. (Part 1)

Environmental stress factor	Information source	Functional trait	Weight
Extreme drought	Functional traits	Leaf phenology	0.12
	LEK expert	Wood density	0.12
	Scientific expert	N-fixation	0.10
	Literature	Leaf area	0.10
		Leaf type	0.07
		Radicular succulence	0.12
		Stem succulence	0.12
		Deep roots	0.12
		Germination strategy	0.12
Fire stress	Functional traits	Maximum height	0.09
	Scientific expert	Leaf phenology	0.09
	Literature	Wood density	0.09
		Bark texture	0.07
		Radicular succulence	0.09
		Resprouting/coppicing capacity	0.11
		Germination strategy	0.11
		Bark thickness	0.11
		Stem succulence	0.11
		Deep roots	0.11
Fragmentation	Functional traits	Dispersal	0.19
	Scientific expert	Growth strategy	0.19
	Literature	Diaspore type	0.15
		Pollinizer type	0.19
		Reproduction system	0.19
		Germination strategy	0.11
Grazing pressure	Functional traits	Dispersal	0.21
	LEK expert	Growth rate	0.21
	Scientific expert	Resprouting/coppicing capacity	0.17
	Literature	Palatability	0.21
		Presence of spines	0.21
Compacted soils	Functional traits	Seed length	0.20
	Scientific expert	N-fixation	0.20
	Literature	Deep roots	0.20
		Germination strategy	0.20
		Maximum height	0.20

Table 12: Information sources used for all environmental stress factors and the functional traits used, with their corresponding weight, to estimate species suitability scores. The weights of the functional traits sum to one per environmental stress factor. A similar table, with the trait levels and attributed numerical values for the different trait levels, can be found in Annex D*Annex D: 'Traits-weights-values' spreadsheet*. (Part 2)

Environmental stress factor	Information source	Functional trait	Weight
Shallow or rocky soils	LEK expert		
	Scientific expert		
	Literature		
Flooding risk	LEK expert		
	Scientific expert		
	Literature		
Saline soils	Scientific expert		
	Literature		
Strong slopes	Functional traits	Growth strategy	0.14
	LEK expert	Growth rate	0.14
	Scientific expert	Leaf phenology	0.11
	Literature	N-fixation	0.14
		Dispersal	0.08
		Leaf area	0.08
		Crown form	0.11
		Deep roots	0.08
		Maximum height	0.14
Constant presence of water	LEK experts		
	Scientific experts		
	Literature		
Seasonal presence of water	LEK experts		
	Scientific experts		
	Literature		
Contaminated soil	Functional traits	Growth strategy	0.22
	Literature	Growth rate	0.28
		N-fixation	0.22
		Leaf phenology	0.28
Erosion	Functional traits	N-fixation	0.31
	LEK expert	Crown form	0.31
	Scientific expert	Maximum height	0.38
	Literature		

Before compiling information from literature, a species list for the prototype DST was constructed. The process of creating this species list is given in Figure 2. Three checklists of the woody species of the SDTFs in the study region were used as a starting point. The checklists used are the ones from Aguirre et al. (2006b) for the SDTFs of Loja, Ecuador, Linares-Palomino & Pennington (2007) for the coastal SDTFs of north-western Peru and

Marcelo-Peña et al. (2016b) for the inter-Andean SDTFs of the Marañón valley. A subset of species was constructed by combining all species that were mentioned in literature to be useful for FLR, all species that have economic timber or non-timber potential, and all species that were used in past or current restoration projects of SDTFs in the study region (Cerrón et al., 2017). Further, all species from the checklist that were recommended during the interviews with scientific experts were added, as well as all species reported to be useful following at least 50% of the LEK experts in at least one of the investigated research sites. *Croton thurifer* was excluded from the final set of species, since it is a small, short-lived, and common shrub that easily colonizes degraded areas, and therefore it was not considered to be worthy for active planting. By only adding species occurring in the checklists, exotics were not included. Exotics also include cultivated species that are native to other ecosystems in the Americas (except for some species that are naturalised since a long time) since the checklists only included species that were considered native (or naturalised since a long time) to the SDTFs of the study region. In the final DST that will be developed by Tobias Fremout, some exotic species will be included. This process resulted in 111 species to integrate in the prototype DST, these species are represented in Annex E.

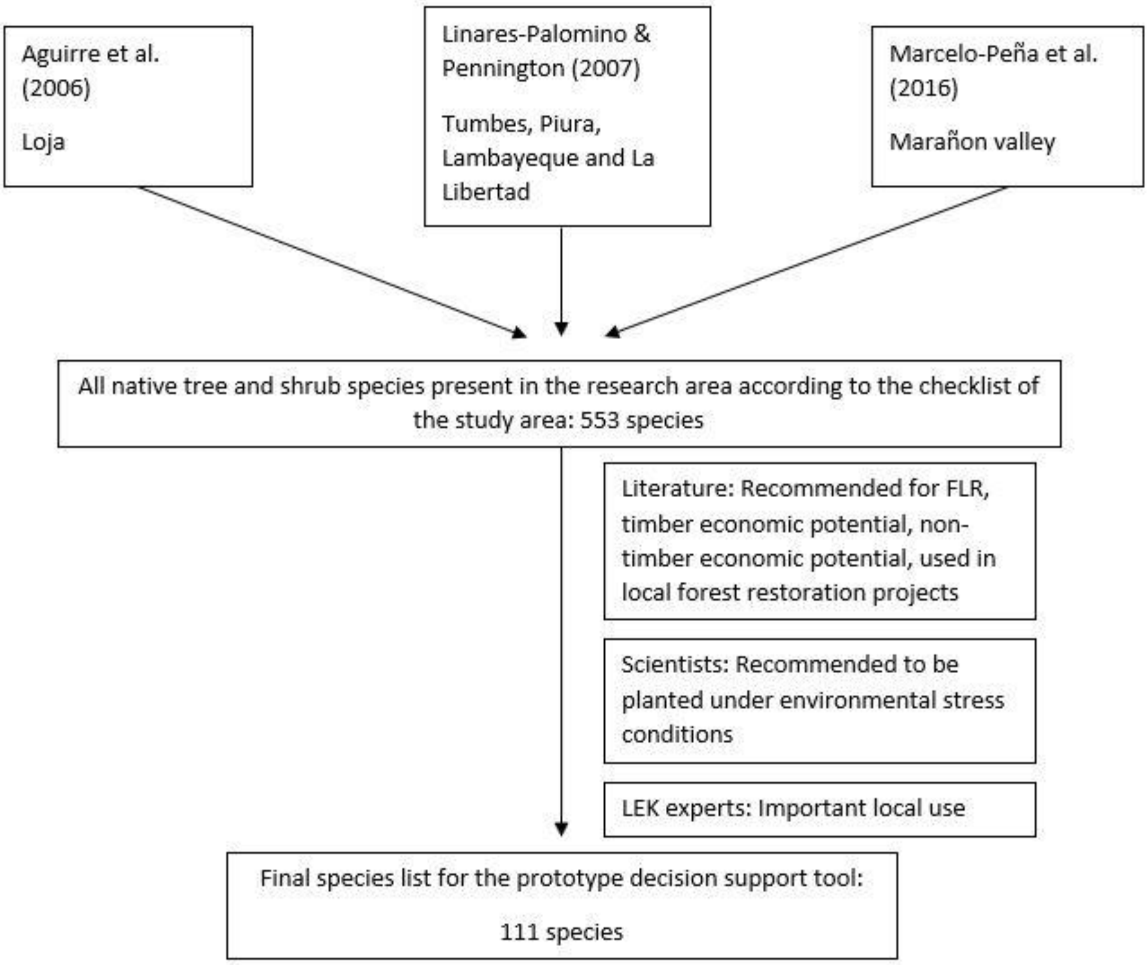

Figure 2: Process of constructing the species list for the prototype decision support tool

Once the species list was formed, all data from the fieldwork to be used in the DST was integrated together with information from literature in an extensive Excel database. The tabs ‘species suitability scores’ and ‘functional traits’ are the most important ones. In the tab ‘species suitability scores’, values between zero and one can be found as species suitability scores for the different restoration objectives and environmental stress factors, according to five different information sources (LEK experts, scientific experts, literature, randomly selected community members and estimates based on functional traits). The higher the score, the more a species can be considered suitable to be planted for a restoration objective or to withstand an environmental stress factor. The tab ‘functional traits’ contains information about species’ functional traits. Most of this information was obtained by searching publications. The ‘functional traits’ tab consists of functional trait values for the 111 species for the functional traits represented in Table 7. The values of binary and categorical functional traits were inserted directly, whereas the continuous functional traits were rescaled between zero and one.

It should be noted that the continuous functional traits wood density and bark thickness were converted to categorical functional traits (Table 7). Wood density was classified into discrete categories because there was not always a linear relationship assumed with the restoration objectives or environmental stress factors (e.g. heavy wood and very heavy wood were assumed equally good for construction). Bark thickness was classified into discrete categories because the collected data were often categorical rather than numerical. A lack of functional trait information was interpreted as if the value of the functional trait of the species is not known. Thus, a missing value in the ‘functional traits’ tab, means that this specific species - functional trait combination was not included in the functional trait estimate for the species suitability score. However, there were two exceptions. Presence of spines was attributed a zero-value (no spines), if the presence of spines was not mentioned in at least two botanic descriptions, because it was assumed that the presence of spines is a standard trait to mention in a botanic description. Further, belonging to the *Leguminosae*-family was used as a proxy for nitrogen fixation (Andrews & Andrews, 2017). All species belonging to the *Leguminosae*-family and the species that were mentioned in literature to fix nitrogen were attributed a one-value (nitrogen fixer) and all other species a zero-value (no nitrogen fixer). This may not be completely correct, but it was expected to be a good approximation.

An additional spreadsheet, named ‘Traits-weights-values’ was constructed to link functional traits with restoration objectives and environmental stress factors, containing weights of different functional traits (like Table 11 and Table 12) and scores for the categorical trait values to be used in the calculation of species suitability scores. An example of how the ‘Traits-weights-values’ looks for the environmental stress factor ‘Compacted soils’ is represented in

Table 13. The full spreadsheet is given in Annex D: 'Traits-weights-values' spreadsheetAnnex D.

Table 13: Part of the 'Traits-weights-values' table for the environmental stress factor 'Compacted soils'

Stress/objective	Weight	Functional trait	Scores	Value
Compacted soils	0.20	Maximum height	Quantitative: Negative correlation (-1)	
	0.20	Seed length	Quantitative: Positive correlation (+1)	
	0.20	N-fixation	1.00	Yes
			0.50	No
	0.20	Deep roots	0.00	Yes
			0.50	No
	0.20	Germination strategy	1.00	Orthodox
			0.00	Recalcitrant
			0.50	Intermediate

The weights of different functional traits in the calculation of species suitability scores were adapted from the results of a workshop with scientists in the context of the development of ResTool (Thomas et al., 2017). However, some functional traits were not included in the prototype DST because insufficient information was found or to more clearly separate restoration objectives and functional traits (e.g. commercial wood was used as a functional trait in ResTool). Further, the importance attributed to a relation between functional trait and restoration objective or environmental stress factor was adapted sometimes if a good reason was found and, in some cases, additional functional traits were used in the prototype DST. Moreover, species suitability for some restoration objectives was not estimated based on functional traits in ResTool but it was in the prototype DST developed here. E.g. wood density, growth rate and resprouting/coppicing capacity were used to estimate species' suitability for firewood (example Box 3).

In addition, the 'Traits-weights-values' database contains a score for the binary and categorical functional trait values for all used combinations of functional traits with restoration objectives and environmental stress factors (see Table 13). These scores were situated between zero and one, with 0.5 the neutral / intermediate situation. For continuous traits for which a positive relationship exists with the restoration objective or environmental stress factor in question, scores were equal to the trait value rescaled between zero and one, whereas for continuous traits with a negative relationship, the score was calculated as one minus the rescaled trait value. These scores and correlations were also adapted from the results of a workshop with scientists for the development of the ResTool DST (Thomas et al., 2017).

Subsequently, the species suitability scores based on functional traits were calculated as follows. First, all species were attributed a starting score of 0.5 for all restoration objectives and environmental stress factors. This starting score was given a weight equal to $\frac{1}{N+1}$, with N the number of relevant functional traits for which a value was found for the species in question. The principle of this starting score is that all species suitability scores start with a 0.5 value, which is then adjusted upwards or downwards based on the favourability of the species' functional trait values for the restoration objective or environmental stress factor in question. The final species suitability scores were calculated with the following formula:

$$(0.5 * \frac{1}{N+1}) + \sum_{i=1}^{N} functional\ trait\ score * \left(weight\ of\ the\ functional\ trait * \left(1 - \frac{1}{N+1}\right)\right),$$

with N the number of relevant functional traits for which a value was found for the species in question. The weights attributed to the functional traits, had to be multiplied with a factor $(1 - \frac{1}{N+1})$ to take into account that a starting score was given to the species. The starting score and its corresponding weight buffer the species suitability scores, so that they only become close to zero or one if information is available for a large number of respectively negative or positive traits (e.g. in the case that only one trait is available, the score cannot be lower than 0.25 or higher than 0.75 (example Box 3)). In the end, all species suitability scores based on functional traits were rescaled between zero and one per restoration objective or environmental stress factor. The calculation of the species suitability scores based on functional traits, as explained here, is different as the method from ResTool. A comparison of the method applied for the prototype DST with the method applied in ResTool is visualized in Box 3. Because of the different method, the species scores from the ResTool database had to be adjusted for the 'Traits-weights-values' database (Annex D: 'Traits-weights-values' spreadsheetAnnex D). More specific, the intermediate / neutral values were always set to 0.5.

Box 3: Example of estimating species suitability scores based on functional traits and comparison with scoring method of ResTool.

The species suitability scores for firewood are calculated based on functional traits for two different species. Both species 'x' and 'y' are known as good species for firewood. The functional traits, weights and values (as in the 'Traits-weights-values' spreadsheet) to estimate suitability for firewood are the following:

Objective	Weight	Functional trait	Score	Value
Firewood	0.33	Wood density	0.00	Very light
			0.25	Light
			0.50	Intermediate
			0.75	Heavy
			1.00	Very heavy
	0.33	Growth rate	1.00	Fast
			0.50	Intermediate
			0.00	Slow
	0.33	Resprouting/coppicing capacity	0.50	Not
			1.00	Aboveground
			0.70	Belowground

Subsequently, the functional trait values for species 'x' and 'y' are searched in the 'functional traits' tab. This results the following:

	Wood density	Growth rate	Resprouting/coppicing capacity
Species 'x'	Very heavy	Fast	Aboveground
Species 'y'	NA	Fast	NA

Then, the species suitability score based on functional traits is calculated as the weighted sum of the scores in ResTool and as explained before in the prototype DST:

	ResTool	Prototype DST
Species 'x'	=(1*0.33)+(1*0.33)+(1*0.33) =1	$= \frac{0.5}{4} + \frac{1 * 0.33 * 0.75}{0.33} + \frac{1 * 0.33 * 0.75}{0.33} + \frac{1 * 0.33 * 0.75}{0.33} = 0.875$
Species 'y'	=(1*0.33)=0.33	$= \frac{0.5}{2} + \frac{1 * 0.33 * 0.5}{0.33} = 0.75$

So, in ResTool species with few information about functional traits are strongly disadvantaged, which is less the case in the scoring method of the prototype DST. When the scores are calculated for all species, the scores are rescaled between zero and one in the prototype DST. Consequently, only the species with a large number of known 'disadvantageous' traits obtain a score close to zero and only the species with a large number of known 'advantageous' traits obtain a score close to one.

Next to the species suitability scores based on functional traits, there are species suitability scores based on household interviews, LEK expert interviews, scientific expert interviews and literature. The calculation of these is explained in the following. The species suitability scores for the information source ‘literature’ are based on explicit recommendations for one of the information categories (e.g. an article that states that a specific species can grow on steep slopes). They should not be confused with the suitability scores based on functional trait data, which was also mostly collected from literature.

For the provisioning services (food, animal food, fire-wood, charcoal, construction, materials, medicine and bee plant), the attributed suitability scores obtained from the LEK expert interviews and household interviews were derived from the adjusted Cultural Importance (CI) index, calculated in the first research question. Every term in the summation of the CI index corresponds to the cultural importance of a species for a particular use category. Consequently, a value based on the CI index was obtained per species per use category for the provisioning services. The CI values per use category were rescaled between zero and one and used as species suitability scores for the corresponding provisioning ecosystem services.

Further, the results of the LEK expert interviews were used to determine species suitability scores for the restoration objectives life fence, soil fertility improvement, non-wood forest products with commercial potential, commercial wood, conservation of white-tailed deer, conservation of bird species and conservation of forest fauna in general. The species suitability scores for these restoration objectives are binary, with one-values indicating that a species was recommended for a restoration objective by at least two LEK experts. In the same manner, species suitability scores from LEK experts were attributed to the environmental stress factors extreme drought, grazing pressure, shallow or rocky soils, floods, erosion, strong slopes, constant presence of water and seasonal presence of water.

Species suitability scores based on literature and scientific experts were always binary, with zero-values indicating that a species was discouraged and one-values indicating that a species was recommended for a restoration objective or environmental stress factor by literature or a scientific expert. A zero-value from literature was granted for the most common provisioning service if the provisioning service in question was not mentioned. The lack of information was interpreted as the absence of the local use, since it was assumed to be mentioned otherwise. Although this methodological decision might be incorrect in some cases, the same was assumed by Reubens et al. (2011) and it is supposed to be a good approach of the reality. No value was attributed (NA) to a species when information lacked, for the species suitability scores to be planted under different environmental stress factors and to contribute to other restoration objectives than the provisioning services. The difference is that the provisioning services are more frequently mentioned in literature and during the fieldwork than the other restoration objectives and environmental stress factors.

Further, it is noteworthy to remark that during the LEK expert and scientific expert interviews, it was asked which species grow close to water. However, a distinction can be made between constant presence of water and seasonal presence of water. Based on observations during the fieldwork and information from literature, the mentioned species were later subdivided over these two categories.

In the prototype DST application, the user can define the importance of 24 different restoration objectives, as a number between one and ten. Moreover, the user has to define the local environmental stress factors that are present at the restoration site, there are 13 different environmental stress factors included. First, the prototype DST excludes all species that don't meet a minimum score, set to 0.7, for all environmental stress factors since it is considered necessary that the recommended species can withstand the local environmental stress factors of the restoration site. This implies that species for which no information is available for a defined environmental stress factor were excluded as well. The reason of setting the minimum score to 0.7 is discussed in paragraph 5.3.

Subsequently, the prototype DST calculates the species suitability scores for the defined restoration objectives and environmental stress factors. All information sources are given the same weight in this calculation. The result is a score for each species for the defined objectives and environmental stress factors. Then, the score for all the defined objectives together is calculated as the weighted mean of the scores of the different objectives, with the weights defined by the user. This score is further referred to as "overall objective score". If there was no information for a species for a specific restoration objective, then this species was attributed an intermediate species suitability score of 0.5 for this restoration objective. The overall objective scores are subsequently rescaled between zero and one. Similarly, an "overall environmental stress factor score" is calculated by summing the scores of all defined environmental stress factors. The overall environmental stress factor scores are also rescaled between zero and one. Last, a final species suitability score is calculated by taking the sum of the overall objective score and the overall environmental stress factor score. Subsequently, the final species suitability scores are divided by the highest possible score a species would be able to obtain, as a result, all scores are situated between zero and one. Then the scores are multiplied by 100 to represent the scores as a % of the best possible score. Last, the final species suitability scores and ranked from high to low for all species that meet the minimum scores for the environmental stress factors. The prototype DST can be found at https://siebe.shinyapps.io/PrototypeDST/.

The user can compare the species suitability scores of the recommended species with a 'perfect species', this is a hypothetical species which was attributed one-values for the species suitability scores of all restoration objectives and environmental stress factors. Hence, the perfect species will always have the highest possible 'final score' equal to 100%. The species suitability scores of the other species represent the score they obtained relative to the 'perfect species'.

The operation of the prototype decision support tool was tested with 3 test cases. The user-defined input of these three test cases are given in Table 14. The first test case is straightforward with three restoration objectives and two local environmental stress factors. As a second test case, a restoration project with the aim of attracting ecotourism was assumed. The site was characterised by different local environmental stress factors in the low and high areas. In the third test case, two contrasting environmental stress factors were defined. The aim of defining two contrasting environmental stress factors was to check if there were no species recommended by the DST, like expected. For the three test cases, the number of recommended species will be represented when the minimum score for the environmental stress factors was set to 0.6, 0.7 and 0.8. Further, the recommended species mix with their final species suitability scores will be represented with the minimum score set to 0.7. The final DST will be checked by scientists and restoration-experts. This was not possible for the prototype DST because of time constraints.

Table 14: Examples of running the prototype decision support tool that are discussed in this thesis

	Restoration objective	**Importance**	**Environmental stress factor**
Test case 1	Food for humans	5	Extreme drought
	Wood for construction	10	Fire
	Firewood	8	
Test case 2	Conservation of threatened flora	8	Strong slopes (high areas)
	Conservation of spectacled bear	4	
	Conservation of forest fauna	10	Rocky or shallow soils (high areas)
	Human food	2	
	Bee plant (honey)	3	Fragmentation (low areas)
	Materials	7	
	NWFP with commercial potential	4	Grazing pressure (low areas)
	Wood for construction	6	
	Ornamentals	3	
Test case 3	-		Extreme drought
	-		Constant presence of water

4 Results

4.1 Which woody species are the most useful for the studied rural communities?

The 30 species with the highest Cultural Importance (CI) index based on the LEK expert interviews can be found in Figure 3. *Vachellia macracantha, Prosopis pallida, Cordia lutea, Colicodendron scabridum* and *Bursera graveolens* are the five most useful species in the investigated communities, based on LEK expert interviews.

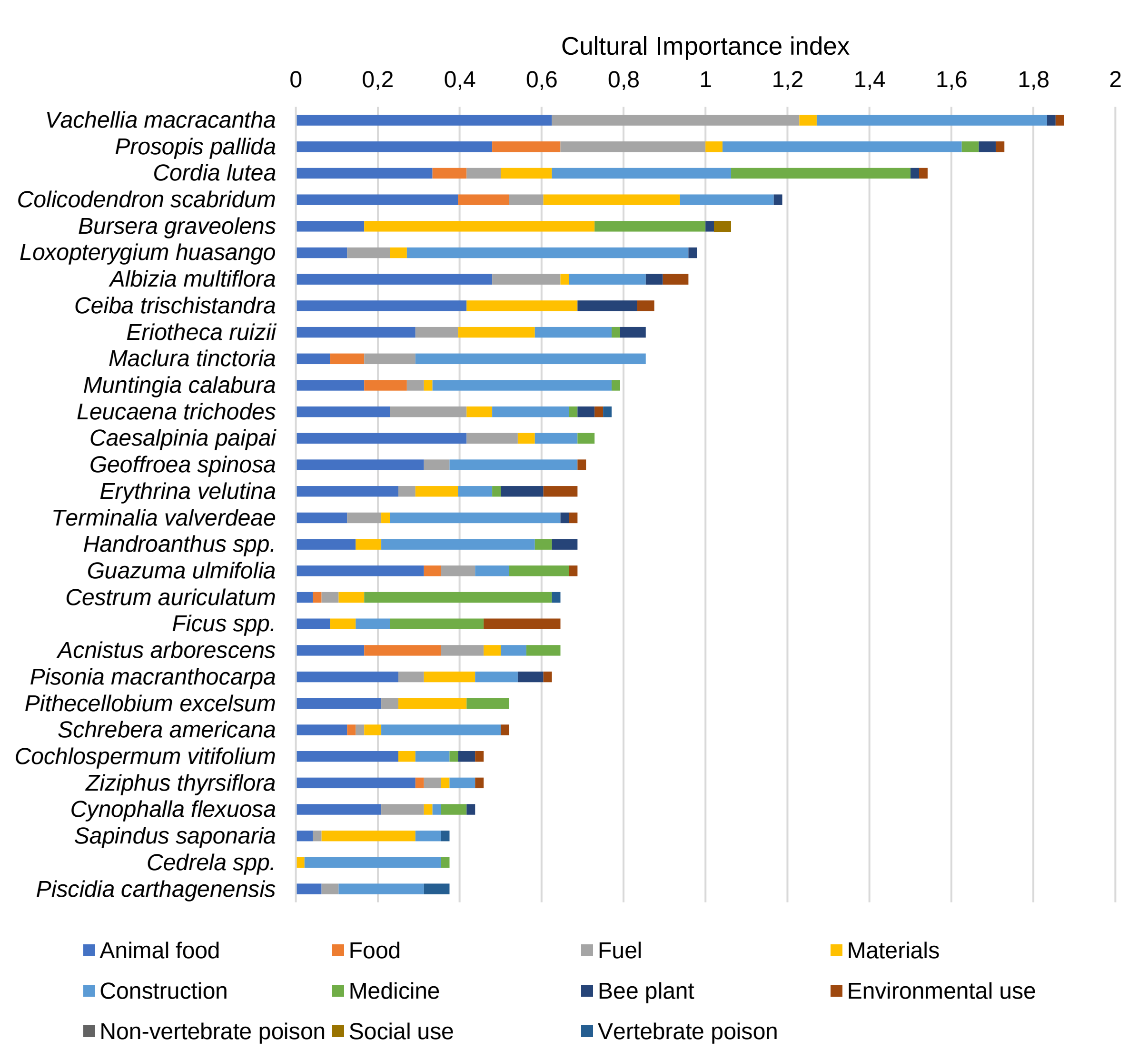

Figure 3: The 30 species with the highest Cultural Importance index from the local ecological knowledge expert interviews. The different colours correspond to the different use categories (see legend).

In Figure 4, the 30 species with the highest adjusted CI index based on the LEK expert interviews are represented. The adjusted CI index takes only into account the data from communities where the species are known to occur (see paragraph 3.3.1). *Bonellia mucronata,* *Prosopis pallida, Cordia lutea, Vachellia macracantha* and *Coccoloba ruiziana* were the most useful species where they were present, based on the LEK expert interviews. It must be noted however, that *Bonellia mucronata* was only present in one of the studied communities.

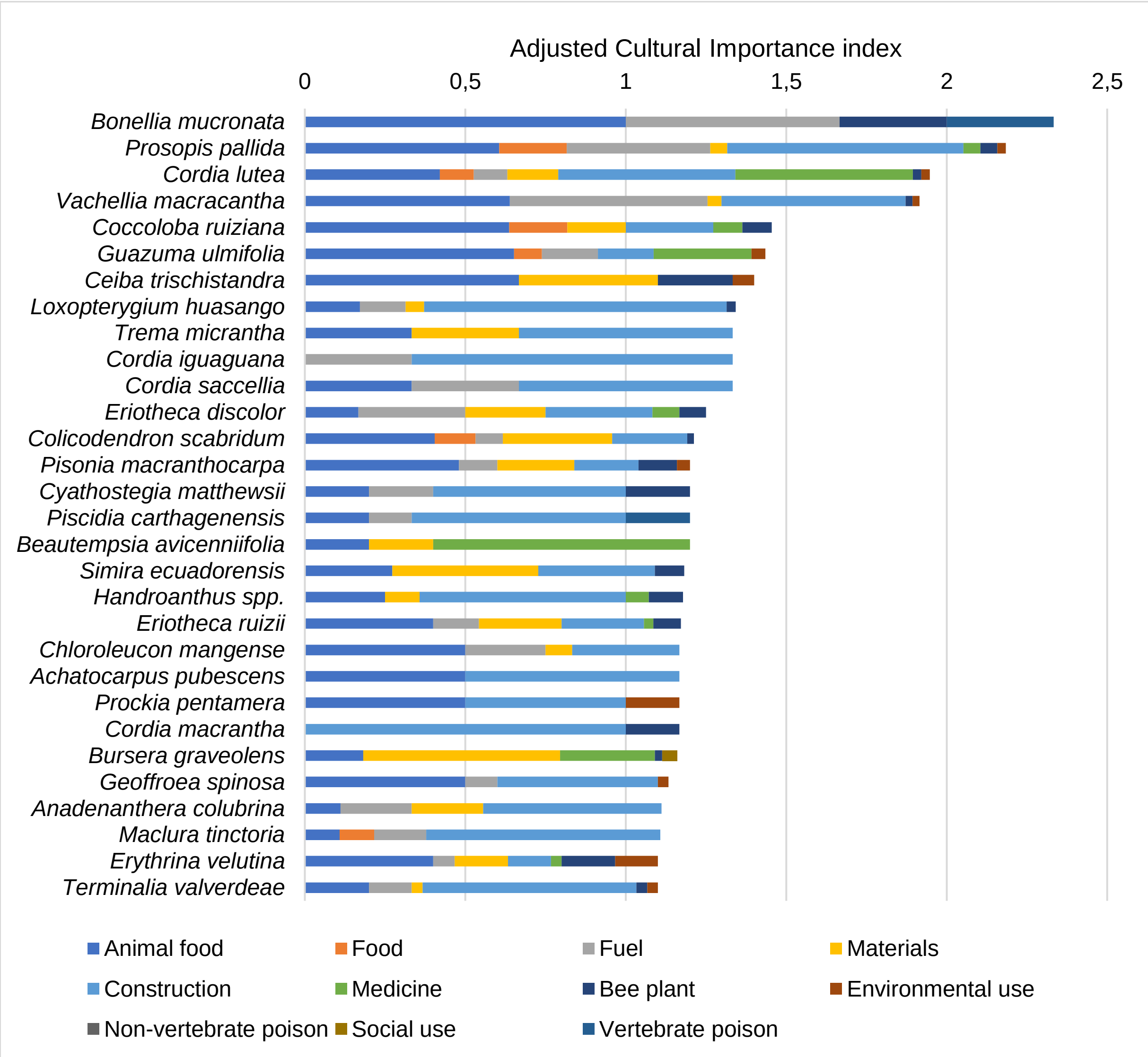

Figure 4: The 30 species with the highest adjusted Cultural Importance index from the local ecological knowledge expert interviews. The different colours correspond to the different use categories (see legend).

14 of the 30 species differed between the two lists of 30 species with highest CI index and highest adjusted CI index based on LEK expert interviews (Figure 3 and Figure 4). The species that occurred in the list with highest adjusted CI index but not in the list with highest CI index are *Achatocarpus pubescens, Anadenanthera colubrina, Beautempsia avicenniifolia, Bonellia mucronata, Chloroleucon mangense, Coccoloba ruiziana, Cordia iguaguana, Cordia macracantha, Cordia saccellia, Cyathostegia matthewsii, Eriotheca discolor, Prockia pentamera, Simira ecuadorensis* and *Trema micrantha.* The species that occurred in the list with highest CI index but not in the list with highest adjusted CI index are *Acnistus arborescens,*

Albizia multiflora, Caesalpinia paipai, Cedrela spp., *Cestrum auriculatum, Cochlospermum vitifolium, Cynophalla flexuosa, Ficus* spp., *Leucaena trichodes, Muntingia calabura, Pithecellobium excelsum, Sapindus saponaria, Schrebera americana* and *Ziziphus thyrsiflora*. Based on the LEK expert interviews, five species belonged to both the 10 species with the highest CI index and the highest adjusted CI index. These species are *Vachellia macracantha, Prosopis pallida, Cordia lutea, Loxopterygium huasango* and *Ceiba trischistandra*.

The 30 species with the highest CI index based on household interviews can be found in Figure 5. *Vachellia macracantha, Prosopis pallida, Cordia lutea, Loxopterygium huasango* and *Piscidia carthagenensis* are the five most useful species in the investigated communities.

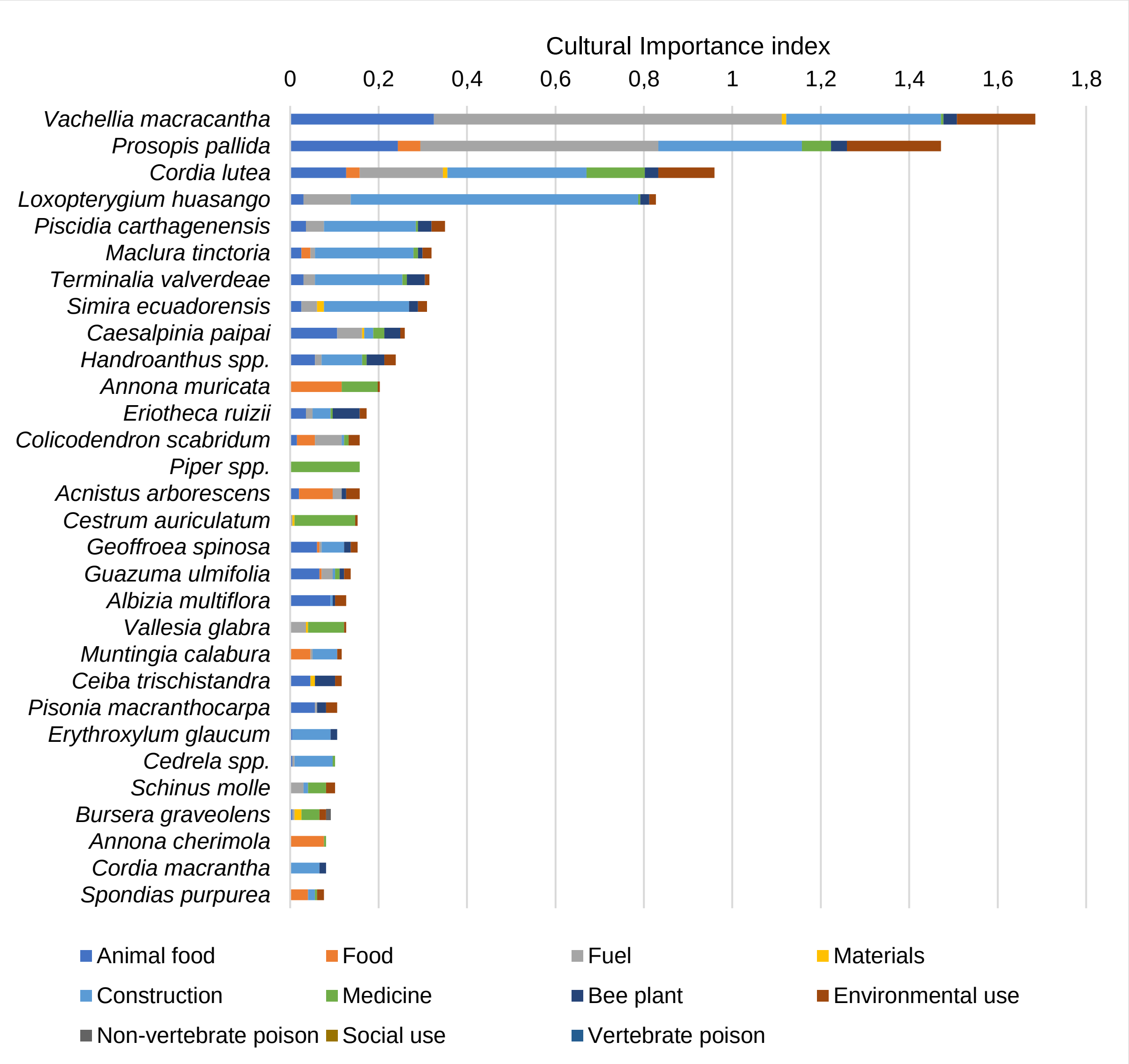

Figure 5: The 30 species with the highest Cultural Importance index from information obtained during household interviews. The different colours correspond to the different use categories (see legend).

In Figure 6, the 30 species with the highest adjusted CI index based on household interviews can be found. *Prosopis pallida, Vachellia macracantha, Simira ecuadorensis, Loxopterygium huasango* and *Piscidia carthagenensis* are the five most useful species in the investigated communities where they were present, based on the household interviews.

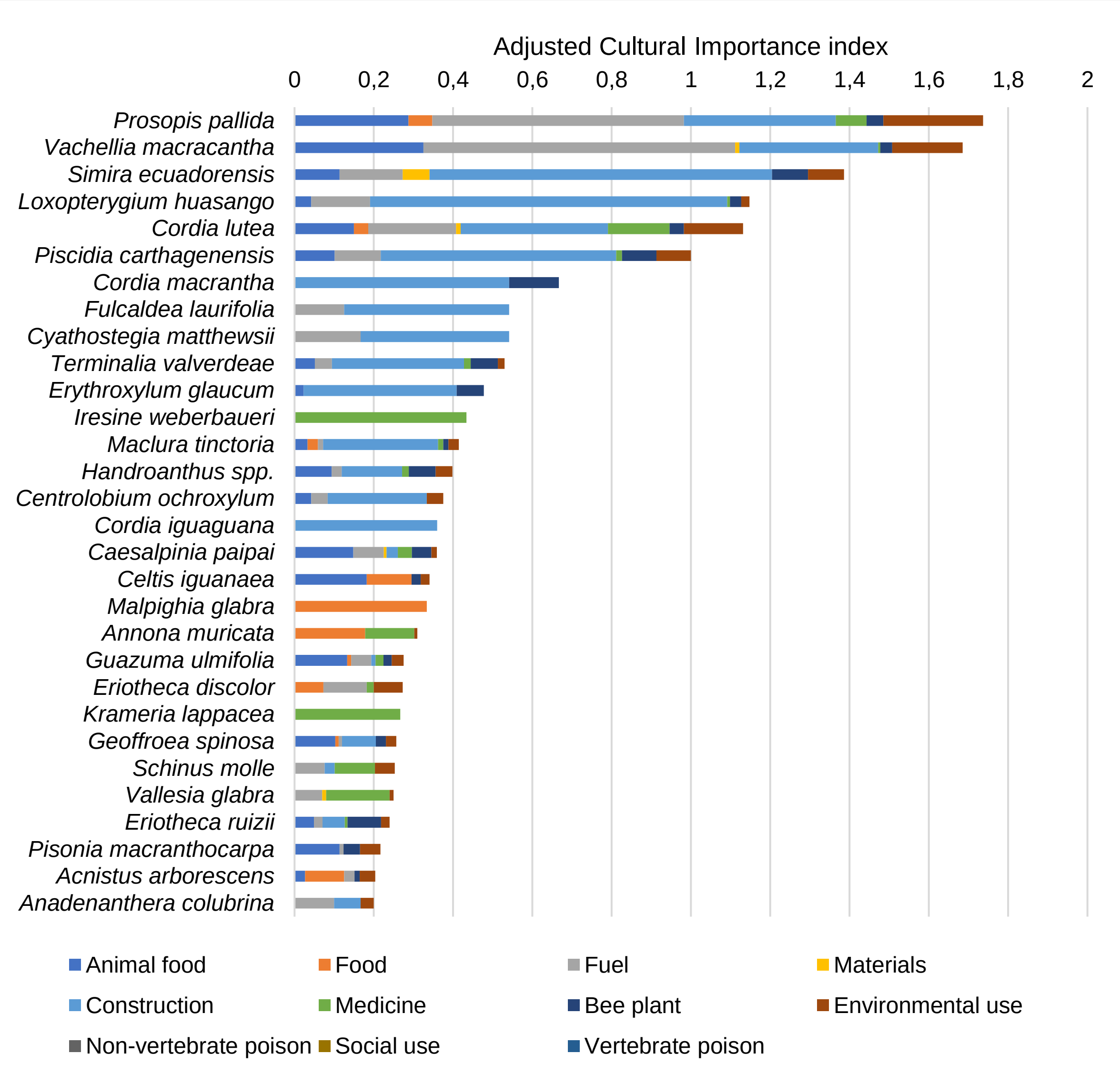

Figure 6: The 30 species with the highest adjusted Cultural Importance index from information obtained during household interviews. The different colours correspond to the different use categories (see legend).

Comparing the 30 species with highest CI index and highest adjusted CI index based on the household interviews, 10 species differed between the lists (Figure 5 and Figure 6). The species that are present in the list with highest adjusted CI index but not in the list with highest CI index are *Anadenanthera colubrina, Celtis iguanaea, Centrolobium ochroxylum, Cordia iguaguana, Cyathostegia, matthewsii, Eriotheca discolor, Fulcaldea laurifolia, Iresine weberbaueri, Krameria lappacea* and *Malpighia glabra.* Similarly, the species occurring in the list with highest CI index but not in the list with highest adjusted CI index are *Albizia multiflora,* *Annona cherimola, Bursera graveolens, Cedrela* spp.*, Ceiba trischistandra, Cestrum auriculatum, Colicodendron scabridum, Muntingia calabura, Piper* spp. and *Spondias purpurea.* Seven species belong to both the ten species with the highest CI index and the highest adjusted CI index from the household interviews. These species are *Vachellia macracantha, Prosopis pallida, Cordia lutea, Loxopterygium huasango, Piscidia carthagenensis, Simira ecuadorensis* and *Terminalia valverdeae*.

When comparing the interview types, 21 species coincided in both lists of the 30 species with the highest CI index and 18 species in both lists of the 30 species with the highest adjusted CI index. Figure 7 shows a plot with the CI indices calculated from the LEK expert interviews against the CI indices from the household interviews. The regression line was fitted as a polynomial function, the intercept and the third- and fourth-degree coefficients were not significantly different from zero. The regression resulted in a quadratic function with an R^2-value of 0.84.

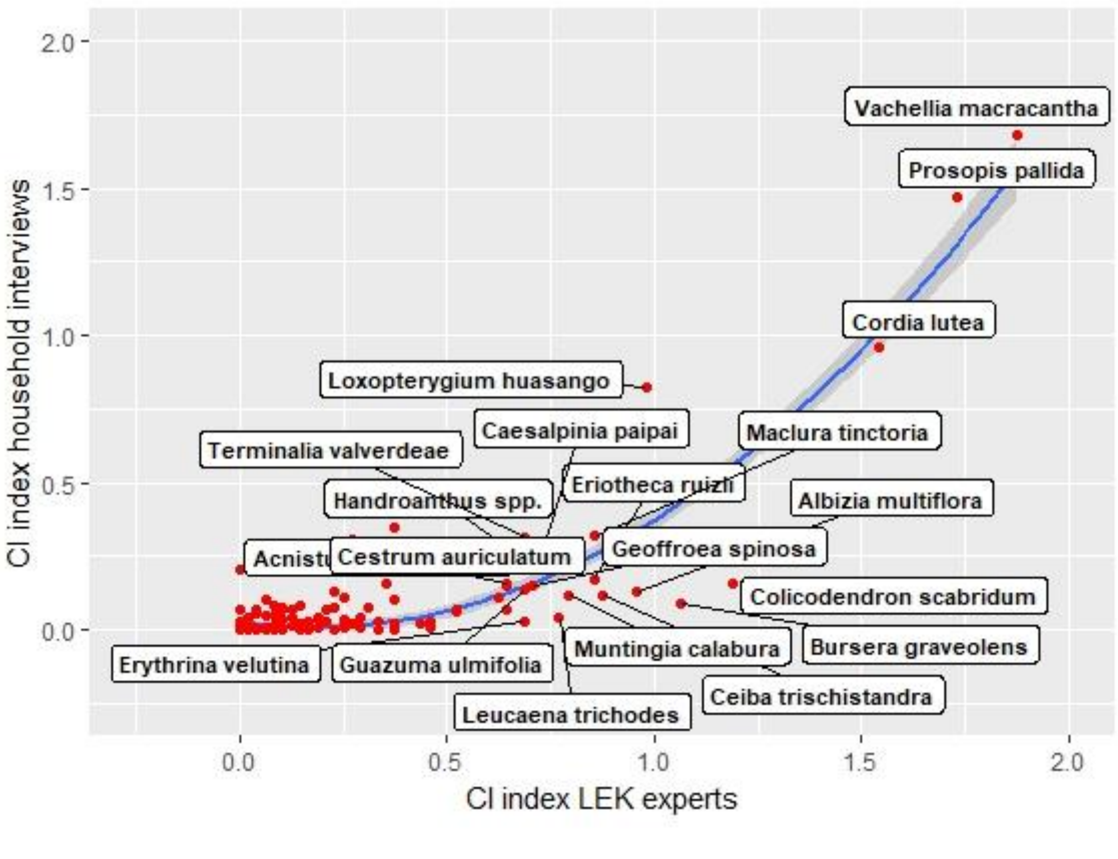

Figure 7: Cultural Importance (CI) indices from local ecological knowledge (LEK) expert interviews plotted against the corresponding CI indices from household interviews. Species names are given for the 20 species with the highest CI index based on LEK expert interviews. The equation of the quadratic regression line is $CI_{LEK}=-0.19*CI_{IND}+0.54*CI_{IND}^2$, with $R^2=0.84$.

To determine which use categories are the most important in the investigated communities, the average number of use reports per respondent per use category was calculated. The resulting bar plots from LEK expert interviews can be found Figure 8 and from household interviews in Figure 9. The use categories construction, fuel and medicine were mentioned the most in the household interviews. Whereas LEK experts mentioned the use categories animal food and construction the most, followed by fuel, medicine and materials almost equally. Vertebrate poison, non-vertebrate poison and social use were almost never mentioned in both interview types. Materials was only very few times mentioned during household interviews. Moreover, it can be observed that the average number of use reports per respondent for almost all use categories is higher from the LEK expert interviews than from the household interviews.

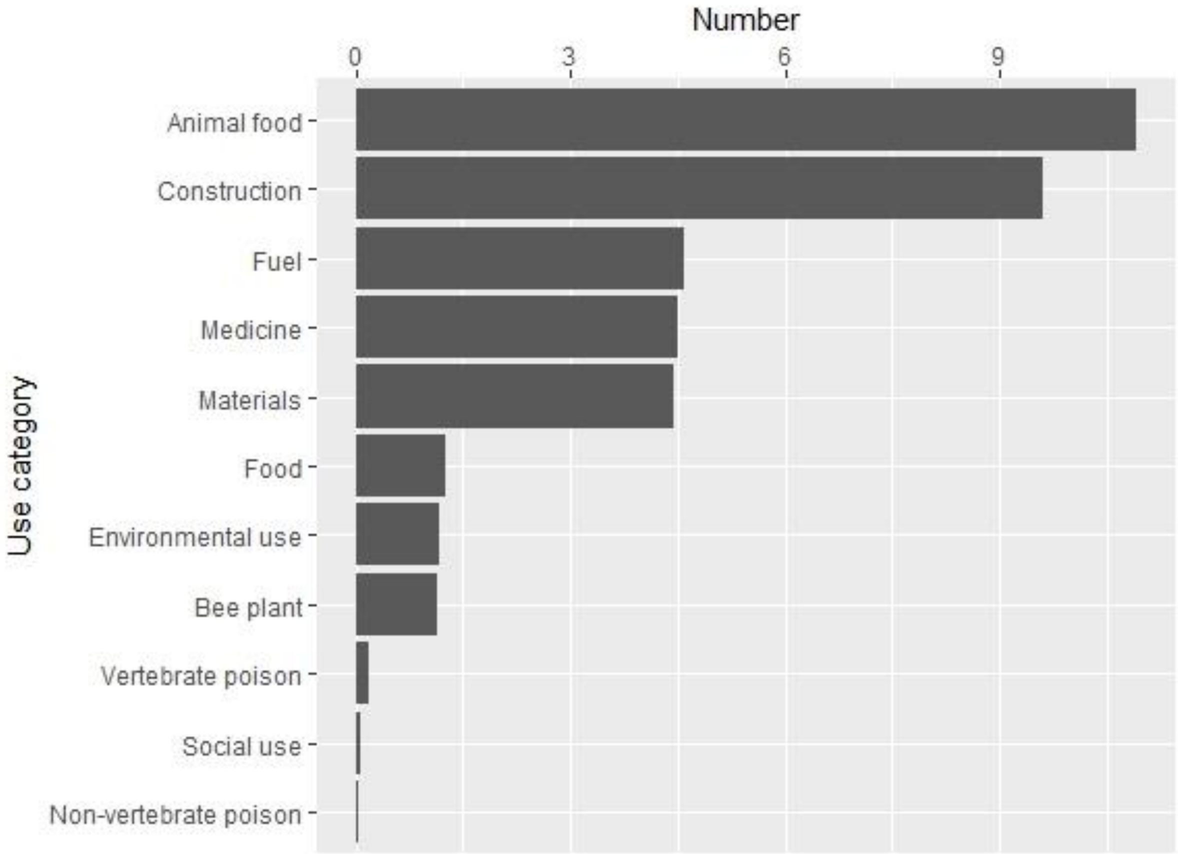

Figure 8: Average of use reports per respondent per use category from the information obtained from the local ecological knowledge expert interviews

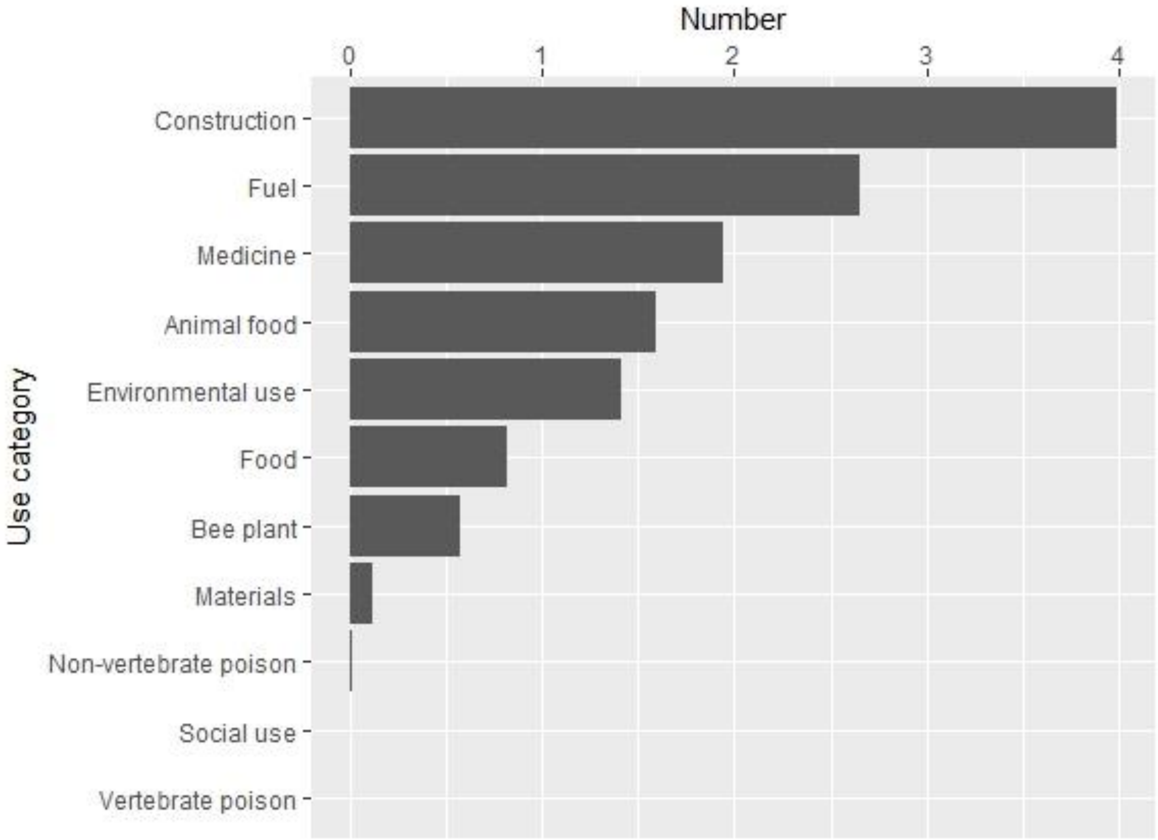

Figure 9: Average number of use reports per respondent per use category from the information obtained from the household interviews

4.2 Can local ecological knowledge (LEK) be used for species recommendations for SDTF restoration?

4.2.1 Consistency between species recommendation lists of LEK experts within the information categories

The mean Jaccard dissimilarities (JD) for the different information categories both with the species that are recommended only once for an information category (single species recommendations) included and excluded are represented in Table 15. With the single species recommendations included, all mean JDs were situated between 0.69 and 0.89. Hence, some similarity between the LEK expert recommendations was observed within each information category. With the single species recommendations excluded, the mean JDs were situated between 0.66 and 0.80 (Table 15). Excluding the single species recommendations led to a decrease in mean JD for all information categories and thus an increase in similarity between the recommendation lists within all information categories. Especially for the information categories grazing pressure and agri-silviculture systems, the mean JD decreased strongly, with 0.16 and 0.22. These two information categories had originally the highest mean JDs.

Table 15: Mean Jaccard dissimilarities (JD) of the species recommended by local ecological knowledge experts for different information categories with both the single species recommendations included (left) and excluded (right). Table ordered according to increasing mean JD with the single species recommendations included.

Information category	Mean JD (single species recommendations included)	Mean JD (single species recommendations excluded)
Extreme drought	0.69	0.67
Threatened woody species conservation	0.70	0.66
Presence of water	0.74	0.72
Soil fertility improvement	0.75	0.71
Floods	0.77	0.72
Shallow or rocky soils	0.79	0.76
Steep slopes	0.83	0.80
Erosion	0.84	0.79
Grazing pressure	0.84	0.68
Agri-silviculture system	0.89	0.67

4.2.2 Comparison of information from LEK experts with information from literature and/or scientists

The results of the comparisons of the LEK expert recommendations with information from literature and scientists can be found in Table 16, both with the single species recommendations included and excluded. With the single species recommendations included, there were 298 species recommendations for different information categories by LEK experts (Table 16). There were 70 consistent recommendations between LEK experts and literature. Further, 13 inconsistent recommendations between LEK experts and literature were found. Comparisons between LEK experts and literature were made for ten different information categories. The recommendations of LEK experts and scientific experts were 75 times the same and differed two times. These comparisons were made for nine different information categories. The number of consistent recommendations when comparing LEK experts vs. the combination of literature and interviews with scientists was 116 and there were 11 inconsistent recommendations (Table 16). With the single species recommendations excluded, there were 162 species recommendations by LEK experts over ten information categories (Table 16). There were 39 consistent recommendations between LEK experts and literature and one inconsistent recommendation. The inconsistent recommendation is *Cordia iguaguana* for growing in shallow/rocky soils. The recommendations of LEK experts and scientific experts were 49 times the same and did not differ. The number of consistent species recommendations between LEK experts and the combination of literature and interviews with scientists was 75 and there was one inconsistent recommendation (Table 16). It can be noted that in some cases, the number of consistent or inconsistent recommendations was bigger when compared with a single information source (literature or scientific experts) than the joint comparison (literature and scientific experts together). This is because a species recommendation for a specific information category was sometimes contradictory between literature and scientific experts and when the recommendation by literature and scientists did not coincide, the joint comparison was not carried out.

The LEK experts were asked which species are good to plant under different environmental stress factors or for environmental objectives, but they were not asked which species would perform poorly for the different information categories. Consequently, only one-values were attributed based on LEK expert interviews. The same methodology was used in the interviews with scientific experts. Information on species performing poorly for a specific information category was only collected three times. Moreover, in literature most recommendations are "positive" as well (e.g., it is common to find in literature that a plant can grow on steep slopes, but not common to find that it cannot grow on steep slopes). In total, info on 38 non-recommended species for a specific information category was found from literature. Thus, there were only 41 zero-values in total. For one of these zero-values, there was a one-value obtained from the LEK expert interviews when the single species recommendations were excluded. This was *Cordia iguaguana* for growing in shallow/rocky soils, as already mentioned.

Moreover, some LEK experts mentioned functional trait values that are good for some environmental objectives or stresses. An example is the ability of deciduous species to withstand extreme drought better than evergreen species. The same was assumed in the prototype DST to estimate the performance of species under extreme drought stress based on functional traits. Further, some LEK experts had an idea about some functional traits, e.g. bark thickness, of different species. This information was integrated in the 'functional trait' tab and used to estimate species suitability scores, when it was collected from at least two LEK experts.

Table 16: Comparison of species recommendations from local ecological knowledge (LEK) experts to literature (LIT) and scientists (SCI) for different information categories, both with the single species recommendations included (left) and excluded (right). The total number (N°) of recommendations by LEK experts, LIT and SCI are represented. The column 'LEK vs LIT AND SCI' represents the comparison of LEK experts to literature and scientists together.

	Single species recommendations included							Single species recommendations excluded						
Information category	**N° LEK**	**N° LIT**	**N° SCI**	**Comparison**	**LEK vs LIT**	**LEK vs SCI**	**LEK vs LIT AND SCI**	**N° LEK**	**N° LIT**	**N° SCI**	**Comparison**	**LEK vs LIT**	**LEK vs SCI**	**LEK vs LIT AND SCI**
Extreme drought	30	6	23	Consistent	2	15	16	23	6	23	Consistent	0	12	12
				Inconsistent	0	0	0				Inconsistent	0	0	0
Shallow/rocky soils	35	21	22	Consistent	4	12	13	18	21	22	Consistent	1	8	8
				Inconsistent	2	0	2				Inconsistent	1	0	1
Floods	27	31	8	Consistent	7	6	12	16	31	8	Consistent	5	4	9
				Inconsistent	4	0	4				Inconsistent	0	0	0
Erosion	38	30	17	Consistent	13	7	14	17	30	17	Consistent	6	5	7
				Inconsistent	0	0	0				Inconsistent	0	0	0
Presence of water	26	22	23	Consistent	14	13	18	15	22	23	Consistent	7	9	11
				Inconsistent	0	1	1				Inconsistent	0	0	0
Steep slopes	36	26	20	Consistent	7	8	13	22	26	20	Consistent	4	6	10
				Inconsistent	1	1	1				Inconsistent	0	0	0
Soil fertility improvement	27	29	4	Consistent	6	3	6	14	29	4	Consistent	3	1	3
				Inconsistent	1	0	0				Inconsistent	0	0	0
Grazing pressure	33	8	7	Consistent	1	4	4	12	8	7	Consistent	1	0	1
				Inconsistent	3	0	2				Inconsistent	0	0	0
Agri-silviculture system	7	18	0	Consistent	4	NA	4	3	18	0	Consistent	3	NA	3
				Inconsistent	0	NA	0				Inconsistent	0	NA	0
Threatened woody species conservation	39	26	8	Consistent	12	7	16	22	26	8	Consistent	9	4	11
				Inconsistent	2	0	1				Inconsistent	0	0	0

4.3 Which woody species are suitable for SDTF restoration for different restoration objectives and under different local environmental stress factors?

The result of this research question is presented as a prototype DST for native woody species selection for seasonally dry tropical forest restoration in northern Peru and southern Ecuador. This DST is based on an extensive spreadsheet that integrates species suitability scores derived from literature, LEK expert interviews, household interviews, interviews with scientific experts and functional trait-based estimations. Three test cases of the prototype DST are given in the following. More information on the test cases can be found in the captions of Table 17, Table 18, Table 19 and Table 20. The prototype DST can be found at https://siebe.shinyapps.io/PrototypeDST/.

The species recommended for test case 1 are represented in Table 17. 22 species were recommended to withstand extreme drought and fire stress, with the minimum score for the environmental stress factors set to 0.7. The recommended species scored between 40% and 81% of the maximum score (i.e. the score of a ‘perfect species’). These scores contain a term based on the restoration objectives and a term based on the environmental stress factors. The higher the overall environmental stress factor score and the overall objective score, the bigger the chance the species will be suitable for the user-defined input. If the minimum score was set to 0.6 for the environmental stress factors, 28 species were recommended. With the minimum score for the environmental stress factors set to 0.8, only nine species were recommended.

Table 17: Recommended species mix resulting from the prototype decision support tool for test case 1, with restoration objectives human food (5), construction (10) and firewood (8) and local environmental stress factors extreme drought and fire. The hypothetical ‘perfect species’ would score 100%.

Recommended species	Score (%) relative to ‘perfect species’
Prosopis pallida	81
Maclura tinctoria	71
Vachellia macracantha	69
Parkinsonia aculeata	68
Guazuma ulmifolia	63
Cordia alliodora	61
Jacaranda mimosifolia	60
Handroanthus ochraceus	59
Handroanthus chrysanthus	58
Senna pistaciifolia	57
Albizia multiflora	55
Cedrela odorata	55
Cybistax antisyphilitica	54
Vachellia aroma	54
Hura crepitans	53
Handroanthus billbergii	53
Colicodendron scabridum	53
Brosimum alicastrum	44
Ceiba trischistandra	42
Cochlospermum vitifolium	42
Ficus citrifolia	40

The second test case was the ecotourism restoration project. Here, the environmental stress factors differed between the high and low areas. The recommended species, with the minimum score for the environmental stress factors set to 0.7, for the low areas are given in Table 18, this list consists of 15 species with scores ranging between 47% and 78%, relative to the maximum score. 30 species and three species were recommended if the minimum score for the environmental stress factors was set to 0.6 and 0.8, respectively.

Table 18: Recommended species mix resulting from the prototype decision support tool for test case 2 in the low areas, with restoration objectives conservation of threatened flora (8), conservation of spectacled bear (4), conservation of forest fauna (10), human food (2), bee plant, (3), materials (7), non-wood forest products with commercial potential (4), construction (6) and ornamental (3) and local environmental stress factors grazing and fragmentation. The hypothetical 'perfect species' would score 100%.

Recommended species	Score (%) relative to 'perfect species'
Psidium guajava	78
Ochroma pyramidale	64
Vachellia macracantha	61
Tecoma stans	60
Hura crepitans	59
Maclura tinctoria	58
Annona muricata	58
Acnistus arborescens	57
Cordia alliodora	54
Tecoma rosifolia	53
Senna pistaciifolia	51
Chloroleucon mangense	50
Piptadenia flava	48
Senegalia polyphylla	48
Cestrum auriculatum	47

In Table 19, the recommended species for the high areas, with the minimum score for the environmental stress factors set to 0.7, are represented, this are 28 species, which scored between 49% and 72% relative to 'perfect species'. With a minimum score for the environmental stress factors of 0.6 and 0.8, 33 species and 17 species, respectively, were recommended.

Table 19: Recommended species mix resulting from the prototype decision support tool for test case 2 in the high areas, with restoration objectives conservation of threatened flora (8), conservation of spectacled bear (4), conservation of forest fauna (10), human food (2), bee plant, (3), materials (7), non-wood forest products with commercial potential (4), construction (6) and ornamental (3) and local environmental stress factors shallow or rocky soils and strong slopes. The hypothetical 'perfect species' would score 100%.

Recommended species	Score (%) relative to 'perfect species'
Colicodendron scabridum	72
Anadenanthera colubrina	72
Eriotheca ruizii	72
Bursera graveolens	71
Tecoma stans	70
Caesalpinia paipai	70
Vachellia macracantha	70
Loxopterygium huasango	70
Vachellia aroma	69
Handroanthus chrysanthus	67
Eriotheca discolor	67
Ceiba trischistandra	64
Cochlospermum vitifolium	63
Handroanthus billbergii	62
Parkinsonia praecox	61
Tecoma rosifolia	61
Schinus molle	60
Annona muricata	60
Mimosa incarum	60
Maclura tinctoria	60
Tecoma castanifolia	59
Ficus jacobii	58
Cyathostegia matthewsii	57
Senna galegifolia	56
Maraniona lavinii	55
Ipomoea pauciflora	53
Mimosa pectinatipinna	51
Mimosa acantholoba	49

In test case 3, contrasting environmental stress factors were defined. The recommended species for this test case are represented in Table 20, with the minimum score for the environmental stress factors set to 0.7. There was one recommended species for this combination of environmental stress factors. With the minimum score for the environmental stress factors set to 0.6 and 0.8, one and none species were recommended, respectively.

Table 20: Recommended species mix resulting from the prototype decision support tool for test case 3, with the contrasting local environmental stress factors extreme drought and constant presence of water. The hypothetical 'perfect species' would score 100%.

Recommended species	Score (%) relative to 'perfect species'
Ficus citrifolia	89

5 Discussion

5.1 Which woody species are the most useful for the studied rural communities?

The species with high adjusted CI values but low CI values were often mentioned in the communities where they occur but occurred in a low number of communities. Hence, these species have a high local usefulness, but they are less important when considering the usefulness of woody species of the study region as a whole. Three species belong to the five most useful species derived from both the CI index and the adjusted CI index, based on both the LEK expert interviews and the household interviews: *Vachellia macracantha, Prosopis pallida* and *Cordia lutea* (Figure 3, Figure 4, Figure 5 and Figure 6). Further, *Loxopterygium huasango* belongs to the top ten most useful species based on both types of CI indices and both interview types. These species are the most useful for the studied rural communities and probably among the most useful for the rural communities in the study region in general. Considering only the results of the LEK expert interviews, *Ceiba trischistandra* belongs to both the 10 species with the highest CI index and the highest adjusted CI index as well (Figure 3 and Figure 4). The CI values based on the household interviews of *Ceiba trischistandra* are lower, because this species' provisioning services were used more in the past than nowadays (e.g. the cotton-like "kapok" produced in its fruits). Considering only the household interviews, there are three more species that belong to both the 10 species with the highest CI index and the highest adjusted CI index: *Piscidia carthagenensis, Simira ecuadorensis* and *Terminalia valverdeae* (Figure 5 and Figure 6). These three species were frequently mentioned for the use category construction, which is by-far the use category with the highest average number of use reports per respondent in the household interviews (Figure 9). The CI values of these species based on the LEK expert interviews were less high, possibly because the number of use reports per respondent of the use category construction was not as pronounced as in the household interviews, when compared to the other use categories (Figure 8). It can be said with a high degree of certainty that all before-mentioned species are very useful to the investigated communities and probably to the communities in the study region in general. However, generalizing the results to the entire study region should be done with caution.

Franzel et al. (2008) state that the most important use categories vary between regions, which complicates the estimation of the usefulness of species. During the fieldwork, variation in the most important use categories was even noticed between the communities within the study region. This variation is mainly due to socioeconomic reasons. In Ecuador, where the living standards are slightly higher than in Peru, firewood is almost not used anymore since the local population uses gas for cooking. Another use category of which the proportion of use reports depends strongly on the research site is animal food. This is caused by the varying main economic activities in the research sites, in some communities many households owned cattle, whereas this was not the case in other research sites. The use as bee plant also depends highly on the research site, as there was only one research site (Bejucal - La Manga - Overal) where a considerable amount of people produced honey from native bee species. It is not known how similar the uses in the research sites are in comparison to an 'average' community in the study region. The deviation from an 'average' community could have led to higher or lower usefulness for some species in this research.

When evaluating which species are the most useful for the studied communities, it can be argued that the active use of plants is more important than their potential use. Under this assumption, the 'best' answer to this research question was found by combining the ten species with highest CI index and highest adjusted CI index from the household interviews. These results were combined with the ten species with highest CI index and highest adjusted CI index from the LEK expert interviews, to result the most useful species that serve for a wide range of use categories.

The quadratic relation between the CI index and the adjusted CI index is relatively strong (R^2=0.84) (Figure 7). There is a quadratic relation because the CI index was generally lower when obtained from household interviews than from LEK expert interviews, for the lower ranges of CI indices, whereas the reported CI indices were similar between the interview types for the higher ranges of CI values (Figure 3 and Figure 5). These latter CI values correspond to the species that are highly used in the communities, e.g. *Vachellia macracantha, Prosopis pallida, Cordia lutea* and *Loxopterygium huasango* (Figure 7). The three species with highest CI index were the same from household interviews and LEK expert interviews. The lesser-known species mostly had a higher difference in CI index between LEK expert interviews and household interviews. Hence, households seem to mostly actively use only a few well-known species for a limited number of uses, whereas the rarer species and uses are almost only mentioned by LEK experts. The fact that the LEK experts mentioned less-common species is probably caused by a better knowledge of the species occurring in the community.

The methodology of the interview types differed since they were aimed at obtaining separate information about the actual uses and the potential uses. The LEK experts were asked to list all potential uses of the species they know, whereas the households were asked which species they actually use for which use categories. This explains the higher average number of use reports per respondent per use category from the LEK expert interviews than from the household interviews (Figure 8 and Figure 9). Further, the average number of use reports per respondent was higher from the LEK expert interviews (i.e. knowledge about potential uses) than from the household interviews (i.e. actual uses). This is in line with the findings of Sá e Silva et al. (2009) for fuelwood in rural dryland communities in north-eastern Brazil. They found significant differences between the local knowledge and the actual use (i.e. local people knew more species for fuel than they effectively used). If a research would be conducted for the purpose of comparing the actual uses and the knowledge of uses on the individual level, the methodology of the interviews should be adjusted. Then, the selection method of the respondents for the interviews, to investigate the actual uses and the knowledge of uses, should be the same. Another possibility would be to ask the same person which species he/she uses for the different use categories and all species he/she knows that can be used for the different use categories. For this thesis project, the methodology of the different interviews is considered good since the main objective was to gather information on the actual and potential uses to integrate in the prototype decision support tool.

The fact that the average number of use reports of animal food relative to the other use categories was higher from LEK expert interviews than from household interviews can be due to the fact that many LEK experts owned cattle (Figure 8 and Figure 9). Owning cattle was a common reason to have good ecological knowledge and therefore being a LEK expert. Further, the use category materials was mentioned only a few times during the household interviews in comparison with the LEK expert interviews (Figure 8 and Figure 9). The materials category includes dye, fibre, wood for tools and wood for handicrafts. These uses are rather traditional and are not commonly used anymore in the study region. Thus, materials have been mentioned only a few times because the households were asked what they actually use. The LEK experts were asked to list all potential ecosystem services, leading to a higher proportion of use reports for materials. Moreover, for all the use categories that had a higher proportion of use reports than materials, the households were explicitly asked which species they used for these use categories, but this was not asked for materials, which was only included in a question on “other uses”. There were almost no social uses reported (Figure 8 and Figure 9). This could be because the people living in the SDTFs in the study region are generally no indigenous people but mestizos. Macía et al. (2011) reported a lower proportion of use reports for social uses of palm species in mestizo communities than in indigenous communities, although the use category ‘rituals’ had a similar use value for indigenous and mestizo communities in the SDTFs of the Balsas river basin in Mexico (Maldonado et al., 2013). Rosero-Toro et al. (2018) reported medical use, fuel and animal food as the most abundant use categories for the SDTFs in the Doche vereda, Colombia. Maldonado et al. (2013) reported medical use, construction, fuel and human food as the most important use categories for LEK experts in mestizo communities in the SDTFs in the Balsas river basin, Mexico. These results are similar to the ones reported in this thesis, in which animal food, construction, fuel, medical use and materials were the use categories with the highest number of use reports in the LEK expert interviews (Figure 8), and construction, fuel, medical use, animal food and environmental use were the use categories with most use reports in the household interviews (Figure 9). Summarizing, the most important use categories in the investigated communities were construction, fuel, medical use and animal food. Thus, the results were very similar with the results from Maldonado et al. (2013) and Rosero-Toro et al. (2018), suggesting that the principal use categories are similar for rural communities in neotropical dry forests. A difference was the high proportion of use reports of human food in the SDTFs investigated by Maldonado et al. (2013). In the rural communities investigated in this project, few woody species with human food uses were reported, leading to a low proportion of use reports by the LEK experts.

The most useful species in the studied communities can be considered as priority species for restoration projects in the study region because of their importance to the rural population and thus to the success of restoration projects (Suárez et al., 2012; Uprety et al., 2012). Consequently, it is recommended to conduct further research on these species. For many species of the study region, no or only few information is available about their propagation and management, especially for endemic species. However, appropriate propagation and management practices are crucial for the success of restoration projects. The environmental ranges (i.e. biophysical limits) of these species should also be investigated to know more accurately how these species react to environmental stress factors. Another necessity for future research is the identification of high-quality seed sources of these species to ensure the genetic quality of the reproductive material and therefore an increase of the chance of success of restoration projects.

5.2 Can local ecological knowledge (LEK) be used for species recommendations for SDTF restoration?

A certain degree of similarity of the species recommendations by LEK experts was detected for all information categories, both with the single species recommendations included and excluded. The lower similarity between the species lists recommended by LEK experts, with the single species recommendations included is not necessarily a result of inconsistent knowledge. It could also be due to the good knowledge of some LEK experts that therefore mentioned species that no other LEK experts mentioned. Excluding the single species recommendations if the information from LEK expert interviews is used is advised, since the mean JD decreased for all information categories, and thus the similarity between the species recommendations in the information categories became more pronounced

The low number of inconsistencies after removing the single species recommendations (Table 16) is partly due to the low amount of information about species' poor performance under environmental stress factors (i.e. negative species recommendations, zero-values). In order to increase the reliability of the recommendations, species recommendations from LEK experts were only integrated in the prototype DST if mentioned by at least two LEK experts. An exception were the species suitability scores that were based on the adjusted CI index, because the low certainty resulting from the fact that a use is only mentioned by one LEK expert is then also reflected in a low CI value.

Not a single LEK recommendation coincided with the information from literature to withstand extreme drought, with the single species recommendations excluded (Table 16). This is probably caused by the fact that extreme drought events are relative to the aridity of a site (i.e. extreme drought in one site may represent normal conditions in another). Some species occurring in the study region also thrive in more humid places, so they can be advised in literature to be planted under extreme drought stress for these places but not for the study region. 12 of the 23 species recommended by LEK experts for extreme drought coincided with the species recommended by scientific experts. Here the consistency was high because the scientific experts study the SDTFs of the study region, whereas information from literature was sometimes obtained from other regions.

There was only one LEK expert recommendation coinciding with literature or scientific experts for grazing pressure, with the single species recommendations excluded (Table 16). No reason could be found, since it was expected that the LEK experts have a good knowledge about appropriate species to withstand grazing pressure. During the field work, it was noted that the LEK experts have a good knowledge about leaf palatability, toxicity and presence of spines, all important plant characteristics to make their decision.

The only inconsistency between species recommendations by LEK experts vs. literature and/or scientific experts was found for growing in shallow/rocky soils (Table 16), where *Cordia iguaguana* was recommended by two LEK experts, but discouraged in literature. No reason for this inconsistency was found since the two LEK experts who made this recommendation for *Cordia iguaguana* were considered among the best LEK experts.

It was planned to collect functional trait data during the fieldwork. Anyhow, this information was obtained to a lesser extent than initially aimed for. However, when this information was collected from at least two LEK experts, it was integrated in the prototype DST.

In order to answer this research question, the methodology of the fieldwork could be improved by not only asking which species the LEK experts and scientific experts would recommended for different information categories but also which species they would discourage for these information categories. Although this is more time consuming, there would be more species recommendations by LEK experts that could be compared to literature and scientific experts and more solid conclusions could be made. This methodology change would have been advantageous for this thesis research project since it would provide additional useful information to use in the prototype DST.

The results indicate that LEK can be used for species recommendations for SDTF restoration in the study region. Many species in the study region are hardly documented in literature, therefore the collection of extra information about these species through LEK is useful. However, it was considered necessary to only include information on the species that were mentioned more than one time for a specific information category as a safety measure. Further, care should be taken when selecting LEK experts and LEK should not be seen as a replacement of scientific data but rather as complementary information to integrate in the decision-making process (Uprety et al., 2012; Van der Wolf et al., 2016). Using more data sources is expected to increase the robustness of the species recommendations.

Reubens et al. (2011) created a DST for tree species selection for land rehabilitation in Ethiopia, the information is partly based on LEK, collected similarly as during this thesis project. Van der Wolf et al. (2016) used LEK in a DST for tree selection in agroforestry systems. Suárez et al. (2012) and He et al. (2015) also used LEK for species selection, but not in the form of a DST. All of them stressed the importance of including local interests and knowledge to improve the success of FLR projects.

5.3 Which woody species are suitable for SDTF restoration for different restoration objectives and under different local environmental stress factors?

In all test cases, there were two local environmental stress factors defined. Comparing the number of recommended species for all test cases based on the minimum score for the environmental stress factor(s) set to 0.6, 0.7 and 0.8, it is decided to set the minimum score of the prototype DST to 0.7. The reason is that with the minimum score set to 0.6, rather much species are recommended and because of the low minimum score, species can be wrongly recommended to withstand the defined environmental stress factors. With the minimum score set to 0.8, the chance of wrongly recommending species to withstand the defined environmental stress factors is small but the number of recommended species is also rather low (e.g. only three species for the combination of the environmental stress factors fragmentation and grazing pressure). If the minimum score for the environmental stress factors is set to 0.7, a reasonable amount of species is recommended and the chance of wrongly recommending species to withstand the defined environmental stress factors is rather low. The number of recommended species in test case 1 and 2 (low and high areas) was 22, 15 and 28 (Table 17, Table 18, Table 19). This number of species can be considered sufficient to be able to further select locally adapted species that are also suitable to obtain the desired restoration objectives. The species recommended in the first two test cases, were intuitively considered as good recommendations. In the third test case, in which contrasting environmental stress factors were defined, zero recommended species were expected but the prototype DST recommended *Ficus citrifolia* anyhow (Table 20). The reason for this unexpected result was that a one-value was assigned to this species based on LEK expert and scientific expert recommendations for constant presence of water, whereas a one-value for extreme drought was obtained from the scientific expert interviews. Field observations suggest that *Ficus citrifolia* is not tolerant to extreme drought, as it was observed alongside streams, where its extensive roots search their way for water. Subsequently, the one-value for *Ficus citrifolia* for extreme drought was removed from the database.

The final species suitability scores can be rather low relative to the hypothetical ‘perfect species’, however the user should not be deterred by this, as a maximum score can only be obtained if information is available on all relevant traits, which is rarely the case. In general, the recommended species should be able to withstand the defined environmental stress factors and a combination of the recommended species will provide the defined restoration objectives (except if there are no species that meet the minimum scores of the environmental stress factors that can provide one of the defined restoration objectives).

It is important to restore the SDTFs in the study region using a sufficiently high number of recommended species. If only a few species are used, it is possible that not all defined restoration objectives are met. Further, a broader range of ecosystem services will be provided when restoring with a high number of different species, which is favourable for the local communities. Moreover, the resilience of the restored SDTF will increase if more species are used for restoration because of a higher functional diversity (i.e. interspecific competition may be reduced and facilitative interactions increased because of complementarity in resource acquisition strategies (Gazol & Camarero, 2016)) (Suárez et al., 2012; Giannini et al., 2017). There is a positive relationship between biodiversity and the resilience of ecosystem functions (Oliver et al., 2015). If only a low number of species are used for restoration and the plants of a certain species all die after some years because of some reason (e.g. an environmental stress event), this poses already a great risk for the success of the restoration project. Further, pests and diseases often harm only one or a few different species. Thus, using many species for restoration, leads to a lower probability of many plants being susceptible to a pest or disease. Summarizing, the use of a high number of recommended species for restoration creates an insurance effect. Thomas et al. (2017) reported that in the mid to longer term, the cost of using many species, should not be seen as a deterrent, as long as legal economic or social incentives are in place. Restoration of SDTFs is a complex process and the management of the species should be known before starting the restoration. Ideally, the species used for restoration can easily be grown in nurseries, can handle some unfavourable conditions, are fast-growing and able to shade out unwanted plant species in early succession (ITTO, 2002).

The ranking of the recommended species according to their final species suitability scores should not be considered as an exact ranking of the suitability of the species for the user-defined restoration objectives and environmental stress factors. Towards application, the approximate rankings should be considered rather than the exact positions of the species (Reubens et al., 2011).

As mentioned before, data about woody species in the study region is fragmented. A lack of information, both on particular species and particular characteristics, are common bottlenecks. The problem of fragmented knowledge about the species in SDTFs in the study region has been solved partly by collecting and integrating information from literature and existing databases in the spreadsheet. Data gaps were also filled in partly by data collected during the fieldwork. Reubens et al. (2011) encountered the same problem of knowledge gaps in literature for the species of dryland regions in Ethiopia. They reported that especially, species' root characteristics were almost not found in literature. The same was noted during this project, consequently the functional traits root length and root type were not used for estimation of species suitability scores. The limited availability of information on root characteristics is due to methodological difficulties of studying root characteristics (Reubens et al., 2007). However, root characteristics are important for a wide range of environmental stress factors and environmental restoration objectives (Reubens et al., 2011; ResTool weights database).

The species suitability scores based on functional traits should be used with some caution. Often, several literature references were found with the same functional trait values for specific species. However, it should be noted that different literature sources often get their information from the same original research, without citing the original source (Reubens et al., 2011). Thus, not every additional literature source adds new information and the functional trait data may not be as trustworthy as expected from the number of references given in the database. In addition, there are large knowledge gaps in literature on functional traits for the species of the study region. Therefore, species suitability scores may not always be a close representation of reality. Species suitability scores based on functional traits were "buffered" using a 0.5 starting score, so that they can only be close to zero or one if information on many traits was available. In further research, functional traits of species in the study region should be measured and incorporated in the decision support tool to make the species recommendations more reliable.

The prototype DST from this thesis project was compared to ResTool. In contrast to ResTool, the prototype DST is not spatially-explicit and does not include the genetic quality of forest reproductive material (Thomas et al., 2017). These two features will be included in the final version of the DST, developed by Tobias Fremout. The most important similarity between ResTool and the prototype DST is the use of functional traits. The weights of the functional traits and the scores of the functional trait values used in this project ('Trait-weights-values' spreadsheet) were adapted from those of ResTool. However, the scoring system that starts with an intermediate score for the species suitability scores based on functional traits is not used in ResTool.

Reubens et al. (2011) stated the following about their DST: "The key aspects were a broad set of species to start from, a wide range of criteria for evaluation, and knowledge from an extensive set of literature sources and different groups of local stakeholders." The same holds for the prototype DST developed here, both DSTs integrated fragmented knowledge on a large number of species and information categories in an extensive database. The database from Reubens et al. (2011) covers 91 species and 45 species-specific characteristics, whereas the database for the prototype DST covers 111 species and 61 species-specific characteristics, of which 24 functional traits, 24 restoration objectives and 13 environmental stress factors. Information sources used in both DSTs are literature, functional traits and local knowledge (Reubens et al., 2011). A dissimilarity is the way how weights were attributed to the different species-specific characteristics. Whereas Reubens et al. (2011) obtained information for this during the fieldwork, it was adapted from the results of a workshop with scientists that was held in the context of the development of ResTool.

The next steps in the development of the decision support tool presented here should be to (1) incorporate species suitability maps to take into account the soil and climate characteristics of the restoration site, (2) include seed source recommendations to assure the use of adapted reproductive material, (3) provide information on propagation and management of the recommended species, (4) validate the species recommendations with restoration practitioners and (5) test the prototype DST in practice. It is also recommended to carry out more scientific expert interviews. Tobias Fremout aims at integrating these additional aspects into the decision-support tool during his PhD project. It is expected that these adaptations to the DST will lead to better decisions on woody species and seed sources selection, contributing to the long-term restoration success of SDTFs in the study region.

The high number of species characteristics and information sources makes the species selection a complex process. As a result, the development of a DST proved useful to handle the large amount of information from different sources on different criteria, bringing the existing knowledge into appropriate practice (Reubens et al., 2011). Consequently, the species recommendations were considered more consistent and more objective than the common practice of selecting only a few well-known species.

6 Conclusion

The main objective of this thesis project was to develop a decision support tool (DST) for native woody species selection for seasonally dry tropical forest (SDTF) restoration in northern Peru and southern Ecuador. Thereto, two other research questions were first solved.

Vachellia macracantha, Prosopis pallida and *Cordia lutea* were among the most useful species with a wide range of uses in the studied communities. Further, *Loxopterygium huasango, Piscidia carthagenensis, Simira ecuadorensis* and *Terminalia valverdeae* were also considered among the most useful species, mostly because of their high usefulness for construction. Next, it was found that the potential uses strongly exceed the actual uses in the studied communities. Households in the study region seem to mostly actively use only a few well-known species for a limited number of uses. The most important use categories in the investigated communities were construction, fuel, medicine and animal food. The use of the categories materials and charcoal are considered to only have been strongly reduced recently, since the local ecological knowledge (LEK) experts mentioned many plants with these potential uses, but most households do not actively use any materials from the forest or charcoal. Further research (management, propagation, biophysical limits, seed sources) about the most useful species is urgent.

Second, it was concluded that LEK can be used for species recommendations in the study region when excluding the species that were recommended by only one LEK expert for an information category. Removing these species led to an increase in the internal consistency of species recommendations by LEK experts for all information categories, and also the number of inconsistent species recommendations with literature and/or scientific experts decreased sharply. Consequently, only the species recommendations that were made by at least two LEK experts were included in the prototype DST. Information from LEK experts about functional traits was obtained to a lesser extent than planned, despite their good ecological knowledge. It is recommended that in future research for the collection of species recommendations under different environmental stress factors, the LEK experts are not only asked which species perform positive, but also which species perform negative under these environmental stress factors. In this way, the internal consistency of LEK expert recommendations could be evaluated to a greater extent, just as the comparison with species recommendations by scientific experts and literature, and additional useful information would be obtained. Last, it is noteworthy to remark that the obtained LEK should not be used as a replacement of scientific data, but rather to complement the existing information.

Last, the research question “Which woody species are suitable for SDTF restoration for different restoration objectives and under different local environmental stress factors?” was answered. Thereto, a wide range of literature sources and databases was searched, in this way addressing the problem of the fragmented knowledge about woody species in the study region. This information was integrated together with information from LEK experts, household interviews, scientific experts, literature and functional trait-based species suitability estimates in an extensive database. The answer to the research question is presented as a prototype DST (available at https://siebe.shinyapps.io/PrototypeDST/) that results in a ranking of recommended species for the user-defined restoration objectives and local environmental stress factors. The ranking is based on a final score, which represents how good a species is relative to (in %) the maximum score a species can obtain in the prototype DST. This ranking should not be considered as exact. Further, it is important to restore the SDTFs with a sufficiently high number of recommended species. This will create an insurance effect, improve the resilience of the restored forest and deliver a wide range of ecosystem services. The developed prototype DST shares a number of desirable features with the DSTs for forest restoration developed by Thomas et al. (2017) and Reubens et al. (2011).

Selecting appropriate tree species for different combinations of restoration objectives and local environmental stress factors is not the only necessary step in the successful restoration of the SDTFs in the study region. The propagation and management of the species is an important issue in SDTF restoration. Further, genetic quality of the forest reproductive material and future climates are important to consider. This was not integrated in the prototype DST, but a future version will integrate these topics.

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8 Annex

8.1 Annex A: Translation of household interview

HOUSEHOLD INTERVIEW N°:

Date: / / Starting hour: Ending hour: Community:

Name: M/F:

Interviewer 1: Interviewer 2:

Part 1: Family situation

Part 2: Tree and shrub species present in the family's land

Part 3: The use, perception and knowledge of ecosystem services obtained from trees/shrubs and the seasonally dry tropical forests

8. What are the benefits from the forest (ask first), trees and shrubs (ask next) for you and your family? (write done the answers in the same order as mentioned)

9. Do you think the forest influences the agricultural production? What is this influence? Yes (1) / No (0)

10. Do you think the forest influences the amount of available water? What is this influence? Yes (1) / No (0)

11. Do you think the forest influences floods and/or landslides/mud streams? What is this influence? Yes (1) / No (0)

12. Tourists come to visit the forest here?

12.1. Yes (1) / No (0):

12.2. In the affirmative case, do you receive a benefit? Si (1) / No (0):

12.3. What is this benefit?

13. Do you sometimes go to the forest to relax?

13.1 Yes (1) / No (0):

13.2 In the affirmative case, why?

14. In which moment of the year, the forest looks the most beautiful? And why? 1: Winter, 2: Summer, 3: Spring, 4: Autumn (ask the months)

15. The forest has a religious/spiritual meaning for you or do you realize spiritual activities in the forest, to something or someone from the forest?

15.1 Yes (1) / No (0):

15.2 In the affirmative case, how?

16. The forest has a historical meaning for you in the life of your family or community?

16.1 Yes (1) / No (0):

16.2 In the affirmative case, how?

17. Edible forest plants

1. Is it sometimes consumed in your family? Yes (1) / No (0):		3. With which frequency? (1: daily, 2: weekly, 3: monthly 4: every 3 months, 5: every 6 months, 6: yearly)		
2. Which species? (Clarify the identity if needed)		4. Do you harvest/collect (1), buy (2) or both (3)?		
		5. In the case you harvest/collect, who does it?		
		6. Have you sold the last year? (0: No, 1: Si, 2: No, but before)		
		7. Which species you sold?		

18. Medicinal plants

1. Is it sometimes consumed in your family? Yes (1) / No (0):		3. With which frequency? (1: daily, 2: weekly, 3: monthly 4: every 3 months, 5: every 6 months, 6: yearly)		
2. Which species? (Clarify the identity if needed)		4. Do you harvest/collect (1), buy (2) or both (3)?		
		5. In the case you harvest/collect, who does it?		

	6. In the case you harvest/collect, where? (1: forest, 2: garden, 3: agricultural field, 4: other (specify))	
	7. Do you consume more medicinal plants (1) or more products from the pharmacy (2) or equally (3)?	
	8. Have you sold the last year? (0: No, 1: Si, 2: No, but before)	
	9. Which species you sold?	

19. Forage for cattle

19.1 Do you have cattle? (1: Yes, 0: No)

19.2 Number of goats and/or sheep:

19.3 Number of cows:

19.4 Do you have other animals? How many from each species?

19.5 Who manages the cattle in your family?:

19.6 Your goat and/or sheep eat forage from the forest? (Yes: 1 / No: 0):

19.7 In the affirmative case: from all forage they consume, how many is from the forest? (1: <25%, 2: approx. 25%, 3: approx. 50%, 4: approx. 75%, 5: >75%):

19.8 Your cow eat forage from the forest? (Yes: 1/ No: 0):

19.9 In the affirmative case: from all forage they consume, how many is from the forest? (1: <25%, 2: approx. 25%, 3: approx. 50%, 4: approx. 75%, 5: >75%):

19.10 Plant species they mainly consume:

20 Honey.

20.1 Honey is consumed in your family?: [ ]

20.2 In your family, you collect (1), buy (2) or both (3)? [ ]

20.3 In the case you collect: It are the bees with sting (1) or without sting (2) or both (3): [ ] [ ]

20.4 In the case of bees with sting, where are the hives? (1: forest, 2: garden, 3: agricultural field, 4: other (specify)): [ ]

20.5 In the case of bees without sting, from where do you collect? (1: forest, 2: garden, 3: agricultural field, 4: other (specify)):

20.6 From which trees do you collect:

20.7 In your family, you produce honey? (Yes: 1 / No: 0): [ ]

20.8 In the case you produce, it are the bees with sting (1) or without sting (2) or both (3): [ ]

20.9 In the case you produce, do you sell honey? (Yes: 1 / No: 0): [ ]

Fire-wood

1. Is it sometimes consumed in your family? Yes (1) / No (0):		3. With which frequency? (1: daily, 2: weekly, 3: monthly 4: every 3 months, 5: every 6 months, 6: yearly)	
2. Which species? (Clarify the identity if needed)		4. Do you harvest/collect (1), buy (2) or both (3)?	
		5. In the case you harvest/collect, who does it?	
		6. In the case you harvest/collect, where? (1: forest, 2: garden, 3: agricultural field, 4: other (specify))	
		7. Do you consume gas as well?	

	8. If you consume gas, do you consume more fire-wood (1), more gas (2) or equally (3)?	
	9. Have you sold the last year? (0: No, 1: Si, 2: No, but before)	
	10. Which species do you sell?	

21 Charcoal

1. Is it sometimes consumed in your family? Yes (1) / No (0):		3. With which frequency? (1: daily, 2: weekly, 3: monthly 4: every 3 months, 5: every 6 months, 6: yearly)	
2. Which species? (Clarify the identity if needed)		4. Do you produce (1), buy (2) or both (3)?	
		5. In the case you produce, who does it?	
		6. In the case you produce, from where do you get the wood? (1: forest, 2: garden, 3: agricultural field, 4: other (specify))	
		7. Have you sold the last year? (0: No, 1: Si, 2: No, but before)	
		8. Which species do you sell?	

22 Wood

1. A part of your house is constructed with wood? Yes (1) / No (0):		3. Do you have wooden fences? Yes (1) / No (0)	

2. Which species for which part? (Clarify the identity if needed)		4. Which species? (clarify the identity if needed)	
5. Have you sold wood the last year? Yes (1) / No (0):		6. Which species you have sold?	

23 Wild game animals

23.1 In your family, game animal products are consumed? (Yes: 1, No: 0): [ ]

23.2 Which species?

[ ]

23.3 In your family, wild game animals are sold? (Yes: 1, No: 0) [ ]

24 Use of other products

24.1 In your family, other forest products that still haven't been mentioned are used or consumed? (Yes: 1, No: 0) [ ]

24.2 Which products?

[ ]

25 Sale of other products

25.1 In your family, other forest products that still haven't been mentioned are sold? (Yes: 1, No: 0) [ ]

25.2 Which products?

[ ]

Part 4: Socio-economic

8.2 Annex B: Translation of local ecological knowledge expert interview

LEK EXPERT INTERVIEW N°:			
Date: / /	Starting hour:	Ending hour:	Community:
Name:			M/F:
Interviewer 1:			Interviewer 2:

Part 1: Occupation and reasons for the local ecological knowledge

1. Do you farm? (1: Yes, 0: No):
2. In the affirmative case:
   2.1. How many hectares of agricultural land do you have?
   2.2. Which crops do you have?

3. In the case the person farms: do you have trees in your agricultural lands?
   3.1. 1:Yes, 0: No
   3.2. Which species? And which ones you sowed yourself?

4. Do you have cattle? (1: Yes, 0: No)

5. In the case the person has cattle: How many you have?
   5.1. Number of goats:
   5.2. Number of cows:

6. Do you produce honey?
   6.1. 1: Yes, 0: No

6.2. In the affirmative case: which type of bees (1: with sting, 2: without sting, 3: both)

7. What is the reason that you have a good knowledge about the tree and shrub species?

8. Do you participate in any way in the protection or management of the forest? In which way?

9. Do you have received any type of training about the protection or management of the forest? (1: Yes, 0: No)

10. Do you have received any type of training about the propagation or seeding of trees? (1: Yes, 0: No)

11. How old are you?

12. Have you been living whole your live in....? (the studied community) (1: Yes, 0: No)

13. Educational grade? (1: primary, secondary, 3: higher education)

Part 2: Useful species

14. Which useful tree/shrub species can or could be encountered in the forests surrounding the community?

	Nombre local	Código científico		Nombre local	Código científico
1			26		
2			27		
3			28		
4			29		
5			30		
6			31		
7			32		
8			33		
9			34		
10			35		

11			36		
12			37		
13			38		
14			39		
15			40		
16			41		
17			42		
18			43		
19			44		
20			45		
21			46		
22			47		
23			48		
24			49		
25			50		

Afterwards there are 2 options: (1) Ask the person to make a walk to indicate some species. (2) Do the interview without makeing a walk.

15. For each species mentioned in question 14: For what does this species serve?

Take notes on separate paper.

16. For the species we still don't have this information: do you know when the seeds of this species can be collected to sow them?

17. For the species we still don't have this information: how are the seeds dispersed? Which animals eat the fruits or seeds?

18. Ask them to classify the species according to their growth speed.

19. Ask them to classify the species according to the ease of regeneration. ("Many young trees of this species can be encountered in the forest?)
20. Which forest animals live in this community? And what do they eat? (and which part of the tree/shrub)

Part 3: Recommendations about the restoration potential

Ask to recommend tree/shrub species to sow with respect to different forest restoration objectives and local environmental stress conditions. List and rank species with respect to the following questions.

- *They can list as many species as they want*
- *If the person does not know very well, it's not necessary to respond these questions.*
- *Ask for the reasons and characteristics of the plants why the person advises these species.*

21. Which species are the most threatened?
22. Which species are the most resistant to extreme drought?
23. Which species grow the best in undeep or very rocky soils?
24. Which species are to most resistant to flooding?
25. Which species are the most resistant when water takes the earth with it?
26. Which species only grow where water is present?
27. Which species are the best to produce honey? (only ask the persons who produce honey)
28. Which species are the best forage for cattle? (only ask persons who own cattle)
29. Which species are the most resistant to grazing pressure? (only ask persons who own cattle)
30. Which species are the best to improve the soil fertility? (only ask the farmers)
31. Which species are the best to stabilize strong slopes?
32. If the person has agroforestry systems, we can ask which woody species are the best for these agroforestry systems and why. They may mention species that are not native.
33. Which tree/shrub species would you like to be sown or planted in the case of a forest restoration initiative in this place?

8.3 Annex C: Translation of the scientific expert interview

SCIENTIFIC EXPERT INTERVIEW N°:
Date: / / Starting hour: Ending hour:
Name:
Interviewer 1: Interviewer 2:

The scientist is asked to appoint all species he knows from a checklist of the study region.

1. Ask them to classify the appointed species according to their successional strategy (pioneer, intermediate, late)
2. Ask them to classify the appointed species according to the ease of regeneration.

Ask to recommend tree/shrub species to sow with respect to different forest restoration objectives and local environmental stress conditions. List and rank species with respect to the following questions. (free-listing)

1. Which species are the most threatened?
2. Which species are the most resistant to extreme drought?
3. Which species are the most resistant to fire-stress?
4. Which species grow best in fragmented areas?
5. Which species grow the best in undeep or very rocky soils?
6. Which species grow the best in compacted soils?
7. Which species are the best to be planted on salty soils?
8. Which species are to most resistant to flooding?
9. Which species only grow where water is present?
10. Which species are the most resistant to grazing pressure?
11. Which species are the best to improve the soil fertility?
12. Which species are the best to stabilize strong slopes?
13. Which species are the best to sequestrate carbon?
14. Which species are the best for erosion control?
15. Which species are the best for watershed protection?

8.4 Annex D: ‘Traits-weights-values’ spreadsheet

Stress/objective	Weight	Functional trait	Scores	Value
Extreme drought	0.12	Leaf phenology	1.00	Deciduous
			0.50	Semi-deciduous
			0.00	Evergreen
	0.12	Wood density	0.00	Very light
			0.25	Light
			0.50	Intermediate
			0.75	Heavy
			1.00	Very heavy
	0.10	N-fixation	1.00	Yes
			0.50	No
	0.10	Leaf area	Quantitative: Negative correlation (-1)	
	0.07	Leaf type	0.50	Simple
			1.00	Compound
	0.12	Radicular succulence	1.00	Yes
			0.50	No
	0.12	Stem succulence	1.00	Yes
			0.50	No
	0.12	Deep roots	1.00	Yes
			0.50	No
	0.12	Germination strategy	1.00	Orthodox
			0.00	Recalcitrant
			0.50	Intermediate
Fire stress	0.09	Maximum height	Quantitative: Positive correlation (+1)	
	0.09	Leaf phenology	0.00	Deciduous
			0.50	Semi-deciduous
			1.00	Evergreen
	0.09	Wood density	0.00	Very light
			0.25	Light
			0.50	Intermediate
			0.75	Heavy
			1.00	Very heavy
	0.07	Bark texture	0.50	Smooth
			0.50	Rough
			1.00	Cracked
			0.50	Lenticelated
	0.09	Radicular succulence	0.50	No
			1.00	Yes
	0.11	Resprouting/coppicing capacity	0.50	Not
			1.00	Aboveground
			0.80	Belowground
	0.11	Germination strategy	1.00	Orthodox

			0.00	Recalcitrant
			0.50	Intermediate
	0.11	Bark thickness	0.00	Thin
			0.50	Intermediate
			1.00	Thick
	0.11	Stem succulence	1.00	Yes
			0.50	No
	0.11	Deep roots	1.00	Yes
			0.50	No
Fragmentation	0.19	Reproduction system	0.00	Dioic
			0.50	Monoic
			0.50	Polygamous
	0.19	Dispersal	1.00	Wind
			0.50	Cattle/goat
			0.50	Water
			0.20	Insects
			0.50	Autochory
			1.00	Birds
			0.66	Bats
			0.50	Mammals
	0.19	Growth strategy	1.00	Pioneer
			0.50	Intermediate
			0.00	Late
	0.15	Diaspore type	0.50	Individual
			1.00	Multiple seeds
	0.19	Pollinizer type	0.20	Insects
			1.00	Birds
			0.66	Bats
			0.50	Mammals
			1.00	Wind
	0.11	Germination strategy	1.00	Orthodox
			0.00	Recalcitrant
			0.50	Intermediate
Grazing pressure	0.21	Presence of spines	1.00	Yes
			0.50	No
	0.21	Dispersal	0.50	Wind
			1.00	Cattle/goat
			0.50	Water
			0.50	Insects
			0.50	Autochory
			0.50	Birds
			0.50	Bats
			0.50	Mammals
	0.21	Growth rate	0.00	Slow

			0.50	Intermediate
			1.00	Fast
	0.17	Resprouting/coppicing capacity	0.50	Not
			1.00	Aboveground
			0.80	Belowground
	0.21	Palatability	0.00	High
			0.50	Intermediate
			1.00	Low
Compacted soils	0.20	Maximum height	Quantitative: Negative correlation (-1)	
	0.20	Seed length	Quantitative: Positive correlation (+1)	
	0.20	N-fixation	1.00	Yes
			0.50	No
	0.20	Deep roots	0.00	Yes
			0.50	No
	0.20	Germination strategy	1.00	Orthodox
			0.00	Recalcitrant
			0.50	Intermediate
Strong slopes	0.14	Maximum height	Quantitative: Negative correlation (-1)	
	0.14	Growth strategy	1.00	Pioneer
			0.50	Intermediate
			0.00	Late
	0.14	Growth rate	1.00	Fast
			0.50	Intermediate
			0.00	Slow
	0.11	Leaf phenology	1.00	Deciduous
			0.50	Semi-deciduous
			0.00	Evergreen
	0.14	N-fixation	1.00	Yes
			0.50	No
	0.08	Dispersal	0.80	Wind
			0.20	Water
			0.33	Insects
			0.50	Autochory
			0.50	Birds
			0.50	Bats
			0.50	Mammals
	0.08	Leaf area	Quantitative: Positive correlation (+1)	
	0.11	Crown form	0.80	Globular
			1.00	Umbrella
			0.50	Conical
			0.50	Cylindric
			0.50	Irregular
			0.20	Sparse

	0.08	Deep roots	0.00	Yes
			0.50	No
Carbon sequestration	0.14	Maximum height	Quantitative: Positive correlation (+1)	
	0.14	Leaf area	Quantitative: Positive correlation (+1)	
	0.14	Specific leaf area	Quantitative: Positive correlation (+1)	
	0.14	Growth rate	1.00	Fast
			0.50	Intermediate
			0.00	Slow
	0.14	Wood density	0.00	Very light
			0.25	Light
			0.50	Intermediate
			0.75	Heavy
			1.00	Very heavy
	0.11	N-fixation	1.00	Yes
			0.50	No
	0.08	Leaf phenology	0.00	Deciduous
			0.50	Semi-deciduous
			1.00	Evergreen
	0.11	Growth strategy	0.00	Pioneer
			0.50	Intermediate
			1.00	Late
Soil decontamination	0.22	Growth strategy	1.00	Pioneer
			0.50	Intermediate
			0.00	Late
	0.28	Growth rate	1.00	Fast
			0.50	Intermediate
			0.00	Slow
	0.22	N-fixation	1.00	Yes
			0.50	No
	0.28	Leaf phenology	0.00	Deciduous
			0.50	Semi-deciduous
			1.00	Evergreen
Erosion control/prevention	0.31	N-fixation	1.00	Yes
			0.50	No
	0.31	Crown form	0.80	Globular
			1.00	Umbrella
			0.50	Conical
			0.50	Cylindric
			0.50	Irregular
			0.20	Sparse
	0.38	Maximum height	Quantitative: Negative correlation (-1)	
Soil fertility improvement	0.26	N-fixation	1.00	Yes
			0.50	No

	0.16	Leaf phenology	1.00	Deciduous
			0.50	Semi-deciduous
			0.00	Evergreen
	0.21	Specific leaf area	Quantitative: Positive correlation (+1)	
	0.21	Crown form	0.80	Globular
			1.00	Umbrella
			0.50	Conical
			0.50	Irregular
			0.50	Cylindric
			0.20	Sparse
	0.16	Growth rate	1.00	Fast
			0.50	Intermediate
			0.00	Slow
Agri-silvicultural systems	0.15	Specific leaf area	Quantitative: Positive correlation (+1)	
	0.25	N-fixation	1.00	Yes
			0.50	No
	0.20	Resprouting/coppicing capacity	0.50	Not
			1.00	Aboveground
			0.50	Belowground
	0.20	Growth rate	1.00	Fast
			0.50	Intermediate
			0.00	Slow
	0.20	Growth strategy	0.00	Pioneer
			0.50	Intermediate
			1.00	Late
Silvopastoral systems	0.14	Resprouting/coppicing capacity	0.50	Not
			1.00	Aboveground
			0.50	Belowground
	0.14	Leaf phenology	0.00	Deciduous
			0.50	Semi-deciduous
			1.00	Evergreen
	0.14	Growth rate	1.00	Fast
			0.50	Intermediate
			0.00	Slow
	0.14	Deep roots	1.00	Yes
			0.50	No
	0.14	Growth strategy	1.00	Pioneer
			0.50	Intermediate
			0.00	Late
	0.06	Specific leaf area	Quantitative: Positive correlation (+1)	
	0.14	N-fixation	1.00	Yes
			0.50	No
	0.11	Crown form	0.50	Globular

			0.50	Umbrella
			0.50	Conical
			0.50	Irregular
			0.50	Cylindric
			1.00	Sparse
Firewood	0.33	Wood density	0.00	Very light
			0.25	Light
			0.50	Intermediate
			0.75	Heavy
			1.00	Very heavy
	0.33	Growth rate	1.00	Fast
			0.50	Intermediate
			0.00	Slow
	0.33	Resprouting/coppicing capacity	0.50	Not
			1.00	Aboveground
			0.70	Belowground
Construction	0.29	Wood density	0.00	Very light
			0.25	Light
			0.50	Intermediate
			1.00	Heavy
			1.00	Very heavy
	0.29	Maximum height	Quantitative: Positive correlation (+1)	
	0.24	Growth rate	1.00	Fast
			0.50	Intermediate
			0.00	Slow
	0.18	Resprouting/coppicing capacity	0.50	Not
			1.00	Aboveground
			0.70	Belowground
Forage	0.18	Growth rate	1.00	Fast
			0.50	Intermediate
			0.00	Slow
	0.18	Leaf phenology	0.00	Deciduous
			0.50	Semi-deciduous
			1.00	Evergreen
	0.14	Crown form	0.20	Globular
			0.50	Umbrella
			0.20	Conical
			0.50	Irregular
			0.20	Cylindric
			1.00	Sparse
	0.11	N-fixation	1.00	Yes
			0.50	No
	0.11	Specific leaf area	Quantitative: Positive correlation (+1)	
	0.14		0.50	Not

		Resprouting/coppicing capacity	1.00	Aboveground
			0.70	Belowground
	0.14	Presence of spines	0.00	Yes
			0.50	No
Charcoal	0.33	Wood density	0.00	Very light
			0.25	Light
			0.50	Intermediate
			0.75	Heavy
			1.00	Very heavy
	0.33	Growth rate	1.00	Fast
			0.50	Intermediate
			0.00	Slow
	0.33	Resprouting/coppicing capacity	0.50	Not
			1.00	Aboveground
			0.70	Belowground

8.5 Annex E: The 111 species included in the prototype decision support tool

Species	Family	Species	Family
Achatocarpus pubescens	Achatocarpaceae	*Cordia lutea*	Boraginaceae
Acnistus arborescens	Solanaceae	*Cordia macrantha*	Boraginaceae
Agonandra excelsa	Opiliaceae	*Cordia saccellia*	Boraginaceae
Albizia multiflora	Leguminosae	*Cyathostegia matthewsii*	Leguminosae
Alseis peruviana	Rubiaceae	*Cybistax antisyphilitica*	Bignoniaceae
Anadenanthera colubrina	Leguminosae	*Cynophalla flexuosa*	Capparaceae
Annona cherimola	Annonaceae	*Eriotheca discolor*	Malvaceae
Annona muricata	Annonaceae	*Eriotheca ruizii*	Malvaceae
Aspidosperma polyneuron	Apocynaceae	*Erythrina velutina*	Leguminosae
Baccharis salicina	Asteraceae	*Erythroxylum glaucum*	Erythroxylaceae
Beautempsia avicenniifolia	Capparaceae	*Ficus citrifolia*	Moraceae
Bonellia mucronata	Primulaceae	*Ficus jacobii*	Moraceae
Bougainvillea peruviana	Nyctaginaceae	*Ficus obtusifolia*	Moraceae
Brosimum alicastrum	Moraceae	*Fulcaldea laurifolia*	Asteraceae
Bursera graveolens	Burseraceae	*Geoffroea spinosa*	Leguminosae
Caesalpinia paipai	Leguminosae	*Grabowskia boerhaaviifolia*	Solanaceae
Caesalpinia spinosa	Leguminosae	*Guazuma ulmifolia*	Malvaceae
Calliandra tumbeziana	Leguminosae	*Handroanthus billbergii*	Bignoniaceae
Capparidastrum petiolare	Capparaceae	*Handroanthus chrysanthus*	Bignoniaceae
Cascabela thevetia	Apocynaceae	*Handroanthus ochraceus*	Bignoniaceae
Cedrela kuelapensis	Meliaceae	*Hura crepitans*	Euphorbiaceae
Cedrela odorata	Meliaceae	*Inga feuilleei*	Leguminosae
Ceiba insignis	Malvaceae	*Ipomoea pauciflora*	Convolvulaceae
Ceiba Trichistandra	Malvaceae	*Jacaranda mimosifolia*	Bignoniaceae
Celtis iguanaea	Cannabaceae	*Jatropha curcas*	Euphorbiaceae
Celtis loxensis	Cannabaceae	*Lafoensia acuminata*	Lythraceae
Centrolobium ochroxylum	Leguminosae	*Leucaena trichodes*	Leguminosae
Cestrum auriculatum	Solanaceae	*Loxopterygium huasango*	Anacardiaceae
Chloroleucon mangense	Leguminosae	*Machaerium millei*	Leguminosae
Citharexylum quitense	Verbenaceae	*Maclura tinctoria*	Moraceae
Coccoloba ruiziana	Polygonaceae	*Malpighia glabra*	Malpighiaceae
Cochlospermum vitifolium	Bixaceae	*Maraniona lavinii*	Leguminosae
Colicodendron scabridum	Capparaceae	*Mimosa acantholoba*	Leguminosae
Cordia alliodora	Boraginaceae	*Mimosa incarum*	Leguminosae
Cordia iguaguana	Boraginaceae	*Mimosa pectinatipinna*	Leguminosae

Species	Family	Species	Family
Muntingia calabura	Muntingiaceae	*Senna mollissima*	Leguminosae
Myroxylon peruiferum	Leguminosae	*Senna pistaciifolia*	Leguminosae
Ochroma pyramidale	Malvaceae	*Senna spectabilis*	Leguminosae
Parkinsonia aculeata	Leguminosae	*Sideroxylon obtusifolium*	Sapotaceae
Parkinsonia praecox	Leguminosae	*Simira ecuadorensis*	Rubiaceae
Piper aduncum	Piperaceae	*Spondias purpurea*	Anacardiaceae
Piptadenia flava	Leguminosae	*Tecoma castanifolia*	Bignoniaceae
Piscidia carthagenensis	Leguminosae	*Tecoma rosifolia*	Bignoniaceae
Pisonia macranthocarpa	Nyctaginaceae	*Tecoma stans*	Bignoniaceae
Pithecellobium excelsum	Leguminosae	*Terminalia valverdeae*	Combretaceae
Prockia pentamera	Salicaceae	*Tessaria integrifolia*	Asteraceae
Prosopis pallida	Leguminosae	*Trema micrantha*	Cannabaceae
Psidium guajava	Myrtaceae	*Triplaris cumingiana*	Polygonaceae
Ruprechtia aperta	Polygonaceae	*Vachellia aroma*	Leguminosae
Salix humboldtiana	Salicaceae	*Vachellia macracantha*	Leguminosae
Sapindus saponaria	Sapindaceae	*Vallesia glabra*	Apocynaceae
Schinus molle	Anacardiaceae	*Vernonanthura patens*	Asteraceae
Schrebera americana	Oleaceae	*Zanthoxylum fagara*	Rutaceae
Senegalia polyphylla	Leguminosae	*Zanthoxylum rigidum*	Rutaceae
Senegalia riparia	Leguminosae	*Ziziphus thyrsiflora*	Rhamnaceae
Senna galegifolia	Leguminosae		

Vulgariserende samenvatting

Seasonally dry tropical forests are tropical forests with a marked dry season of at least five months. They are often situated in relatively densely populated areas, which causes their degradation (i.e. deterioration of the ecosystem). Overgrazing and fire are some of the main degrading agents for seasonally dry tropical forests. The drought causes these forests to be easier cleared than tropical rainforests. Seasonally dry tropical forests are recognized as one of the world's most threatened ecosystems.

Seasonally dry tropical forests deliver a wide range of products and services to the local population. Further, these forests harbour a high number of important plant and animal species. Unfortunately, many species are threatened. Although the importance of conserving the seasonally dry tropical forests, the scientific attention is focused more on tropical rainforests than tropical dry forests.

To the present, restoration (i.e. actions to induce the recovery of the ecosystem) practices in seasonally dry tropical forests often involved the active planting of a few well-known tree or shrub species. As these species are not necessarily adapted to the local environmental stresses (e.g. steep slope, compacted soils) and do not provide an optimal generation of products and services to the local population, restoration projects often fail. Delivering the desired products and services to the local population is crucial to gain the support of the local communities, which is an important factor for the success of a restoration project.

During this thesis project, the problem of largely opportunistic species choices in restoration projects was addressed for the study region in northern Peru and southern Ecuador. A computer-based tool to guide decision making in the selection of native woody species for seasonally dry tropical forest restoration was developed. The user of the tool specifies the local environmental stresses at the planting site and the restoration objectives of his/her restoration project. Consequently, the tool gives the recommended species mix to be planted, ranked according to their suitability. The tool integrates information from fieldwork in the study region, literature and plant characteristics that influence the species' ecological roles. The computer-based tool can be found at https://siebe.shinyapps.io/PrototypeDST/.