Smithsonian Tropical Research Institute

HSBC Climate Partnership

Experimental design of the

'Aqua Salud'

Native Timber Species Plantation 2008

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Background: the larger research framework

The Agua Salud Project seeks to understand the diverse set of ecosystem services provided by forests within the Panama Canal Watershed. Given the importance of the Panama Canal to world trade and the fact that the Panama Canal Watershed is responsible for providing clean drinking water for residents of both Panama City and Colon, hydrological services are a major focus of the project. The project also seeks to understand and quantify the role of forests in terms of carbon sequestration and, to a lesser extent, biodiversity services.

In order to quantify ecosystem services, a two phased approach will be employed. Detailed studies will be undertaken at a focal research site centered on the Agua Salud and adjacent watersheds (Agua Salud Focal Research Area). Research results will then be scaled up through a variety of additional site based studies and/or surveys, as well as employing remote sensing and modeling techniques (see Box 1 for the general questions to be addressed by the Agua Salud Project; detailed presentation of the overall experimental design are provided elsewhere).

Within the Agua Salud Focal Research Area approximately 700 hectares of land have been acquired and made available for the experiment for the next 20 years with the possibility of extending the research and monitoring for an additional 20 years. Seven land use treatments will be monitored within this area where the main experiments are planned at the scale of entire stream-catchments. Catchment level treatments consist of one replicate (one stream catchment) and include:

- Mature or old secondary forest
- Grazed pasture;
- Partially deforested catchment (approximately 50% pasture and 50% forest);
- Secondary succession;
- Monospecific teak plantation;
- *Native timber species plantation*;
- Managed secondary forest;

Additional watersheds will be monitored at other sites:

- Native species reforestation with ACP treatment (Ciudad del Arbol);
- Canal grass (within the boundaries of Soberania National Park);

The purpose of this document is to provide details of the experimental design of the Native Timber Species Plantation within the Agua Salud Focal Research Area. The research design represents extensive consultation with a group of tropical ecologists and reforestation specialists from around the world, including those with vast experience in Panama and Central America. The consultation consisted of a there day period where participants came together for two days of field trips (to visit selected reforestation projects) and a day long meeting. Site visits to the Agua Salud Focal Research Area were conducted with reforestation specialists from the National Environmental Authority of Panama (ANAM) and the Panama Canal Authority (ACP) to solicit further input. Finally, as the experimental design developed, continued input was sought through in person and telephone discussions and e-mail communication (see Annex I for list of participants in consultations).

The document is not a consensus document but rather one that those charged with the overall experimental design feel best meets the overarching requirement of the native species reforestation in the Agua Salud Project (i.e. to manage for timber), affords the ability to test

applied theory but also has immediate management relevance, and is feasible within the logistical constraints of the project.

Box 1: Main questions Aqua Salud Project

1. **Is there indeed greater groundwater supply under forested land during the dry season than under deforested lands?**

2. **Do different land uses and/or management strategies such as reforestation promote groundwater storage and changes in other hydrologic pathways?**

3. **How do these land uses and management strategies affect timber production and quantifiable ecosystem services such as carbon storage, water quality, and biodiversity?**

4. **Can we design "proactive" treatments that seek to optimize forest production along with ecosystem services during reforestation both locally and at the scale of the Panama Canal Watershed?**

Experimental Rationale

Because most individuals or companies planting trees on a large scale in Panama do so for timber production, the overall management objective for the reforestation initiatives within this project is to manage for timber production. Teak (*Tecona grandis*) was chosen as an exotic timber species because it represents 75% of trees planted in plantations within Panama (ANAM 2003). Native species choice, spatial planting design and management of this treatment focus primarily on timber production. Although central to the overall experiment, ecosystem services such as biodiversity, hydrology or carbon sequestration are secondary to the specific management objective of the plantation.

Five timber species (Figure 1, Annex II) have been chosen as target timber producing species for this plantation. In terms of timber production, these are the species that are expected to be harvestable for revenue over the 20 to 40 year time horizon of the plantation. All species grow well in full sunlight in the PRORENA experimental plantations. Within the context of the timber management objective, the plantation is designed to test when and where these species are facilitated by companion or nurse species. Conversely, we seek to understand when and where these species act as competitors for growing space. Species mixtures include all possible two species combinations for these species as well as mixtures where companion species have been selected to enhance litter production and/or nutrient cycling (see below).

Experimental Set-up

Main objectives

1. To assess growth, survival and ontogenetic patterns in allometry, biomass allocation and architecture of selected timber species in monocultures and mixtures;
2. Relate variation in performance of the selected timber species within different treatments to spatial variation in topographic and soil variables;
3. Examine how the selected timber species affect/modify stand-level variables that represent or are (potentially) related to environmental services, for example:

- Soil and hydrology variables
- Biodiversity (e.g. regeneration, arthropod diversity)
- Carbon sequestration

4. Examine stand-level productivity and benefits in terms of ecosystem services of mixtures of the selected timber species in relation to monocultures;
5. Test if mixing selected timber species with a group of species with high litter production and known to enhance nutrient cycling (companion species) can positively influence the provision of ecosystem services, while minimally maintaining productivity, in comparison with monoculture stands of the selected timber species.

Objective 4 and 5 could include more theoretical questions on species interactions (e.g. facilitation or complementarity), or on the relationship between biodiversity and ecosystem functioning.

Experimental layout

The experiment looks primarily at the 'effects' of different species combination treatments:

a. Mono-culture of the selected timber species
b. Two-species mixtures of the selected timber species
c. Five-species mixture of the selected timber species
d. Six-species mixture of one selected timber species and a mixture of five companion species.
e. In a number of plots no trees will be planted, and no cleaning or other measures will be applied to allow for natural regrowth.

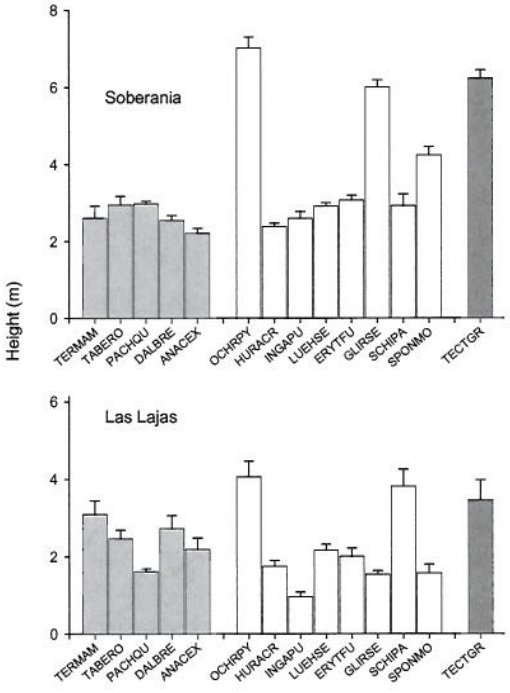


Figure 1. Average height of selected species in two plantation sites two years after planting. Average values are calculated from 9 plot averages, whiskers give one standard error. Grey bars: selected timber species; white bars: companion species, 5 species will be selected from this group; dark grey bar: Teak, for comparison. Plantation sites differ in rainfall and soil conditions. Data from the PRORENA species selection trials.

In all treatment except for the last, number of individuals will be divided evenly over the species. In the latter case, the mixture will consist of 50 percent of the selected timber species, and 50 percent of the mixture of all companion species. One of the main reasons for this is that the final objective of each stand is timber production; hence enough choice for selection is required during the thinning operations.

Five target species have been selected, all of them important native timber species. Five companion species will be selected; all of them pioneer species with presumably high litter production (Figure 1, Annex II). This will result in a total of 22 treatments (Figure 2).

While the overall area to be planted is 75 ha, practical constraints (e.g., fitting square plots in a irregularly shaped area will leave a part of the area unused) will constrain the experimental area available to ~70 ha. The experiment will be situated in two different areas. To the extent possible, we will evenly divide the number of replicates per treatment between areas.

One of the areas is property 2, at the entrance of the Aqua Salud area. The boundaries of this property are mostly similar to the limits of a subcatchment (see Annex III). This site will constitute the 'native timber species plantation' treatment of the catchment-level hydrological study. A small sub-catchment (~6.5 ha) of a tributary stream will be used as the 'secondary forest succession' treatment (Annex IV). The area consist largely of open pasture with scattered trees, but also patches with recent secondary regrowth and patches with a relatively higher density of larger remnant trees are present in the area. The second area is adjacent to the Soberania national park at one side, and to the teak plantation at another side (Annex IV). This area covers (parts of) several smaller catchments and consists largely of a patchy secondary regrowth of a few years old on pastures, with patches of open pasture mainly limited to the ridges. In both areas cattle density was very low in the last couple of years (<1 head per ha).

Treatments will be randomly allocated to plots. A DEM of the areas will be used to define slope classes. When feasible the layout of the experiment will be a stratified according to these slope classes, with a number of replicates per treatment proportional to the total area covered by each slope class. However, as the allocation of treatments to plots will be done in the field as part of a continuous process of laying out the planting grid and planting the seedlings, we have figure out if stratification will be feasible, and in case of a affirmative answer, how to organize it.

Trees will be planted in a triangular layout with 3 meter distances between neighbor trees. This

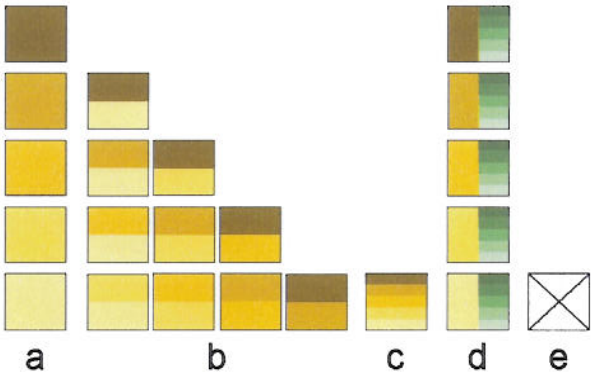


Figure 2. Diagram of species mixtures (treatments). Yellow colors indicate the five selected timber species (target); the green colors indicate the five companion species.

comes to a plant density of 1282 trees/ha, with 3 m between trees in a row, and 2.6 m distance between rows (Figure 3). This spatial layout is according to ACP regulations for slopes ≥12%. To maintain the same planting density we will apply this layout throughout the whole plantation. have Spatial planting pattern in the two-species treatments is designed to include trees of both species with six heterospecific neighbors (Figure 4A). The combination of one timber species with five non-timber companion species will be as indicated in figure 4B. We still have to draft the spatial planting patterns of the other treatments.

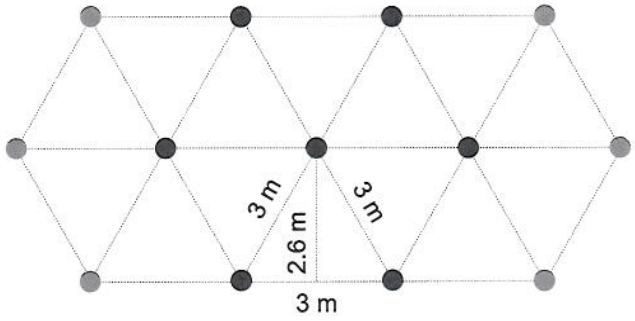


Figure 3. Triangular planting layout, with 3 meter distances between adjacent trees. In this design, distance between rows is 2.6 m, total planting density is 1283 plants/ha, and all trees are surrounded by 6 neighbors at equal (3 m) distance.

Plot size and number of replicates

Small-scale spatial heterogeneity across the NTSP areas is high:

- Topography. Slopes range from … to ….
- Land-use history. The areas exist of active pastures and early secondary regrowth of different ages.
- Isolated large trees. Across the areas, the origin (remnants vs. later regrowth) and density of large isolated trees vary strongly across the land
- Remnant vegetation. Within the catchments patches of forest (degraded old-growth and older regrowth) are present, especially around the streams.
- We do not have data on local variation in soil characteristics in the NTSP areas

The expected high spatial variation in environmental variables requires a high number of replicates per treatment and small plot size. Another reason to maintain plot size small is that the catchment-level study seeks to study the hydrological effects of a mixed timber plantation on whole-catchment level. Experimental plots should be small to create species mixture on a small spatial scale (≤0.5 ha Bob Stallard, personal communication) across the catchment.

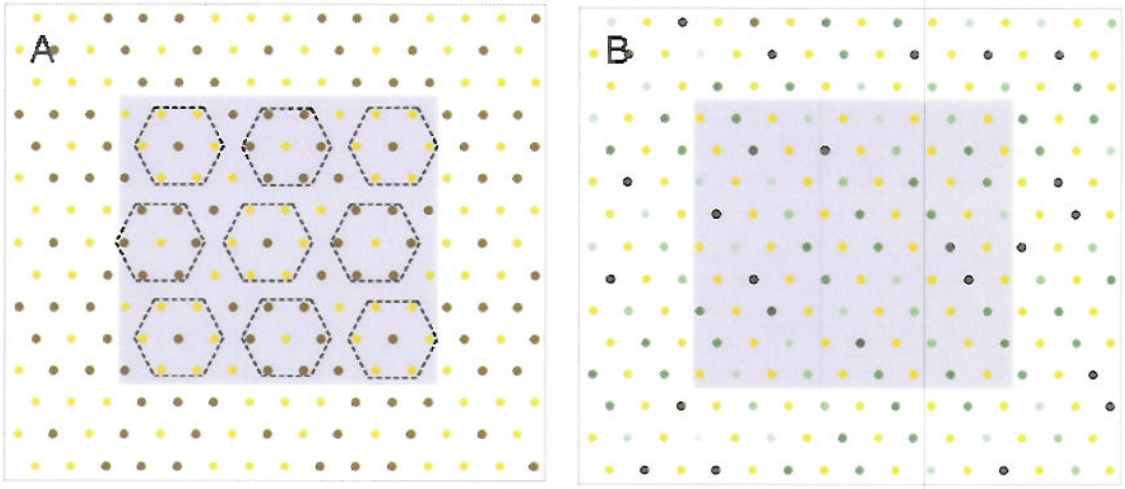


Figure 4. Spatial planting pattern of the two species combinations (A) and the combination of one timber species and 5 non-timber companion species (B). Spatial planting pattern of A is designed to include trees of both species with six heterospecific neighbors, as exemplified by the points within the dashed lines. In pattern B, timber species (yellow) and companion species are alternated in each row. Non-timber trees are randomly drawn from the group of five companion species. The plot consists of 15 x 15 trees (45 x 39 m), and includes a buffer zone of three rows around a core plot of 9 x 9 trees (27 x 23.4 m; grey area).

Based on above mentioned considerations and discussions with colleagues, a plot size of 15 x 15 trees (45 x 39 m) has been chosen. Three planted rows will be taken as buffer zone, leaving a core area of 9 x 9 (80) trees (figure 4). For clarity, this plot size will result in a core area with about 9-10 trees after the last thinning if a final density of ~200 trees/ha is assumed and a buffer zone of 10 m. This plot size allows for 428 plots in total, and about 18 replicates per species combination treatment (Annex IV).

Stand management

Considering the catchment-level research objectives and questions, our experimental set up should largely follow normal forestry practices. In a timber plantation various silvicultural measures are taken during a rotation, aimed at improving timber production. Fertilizers and organic material are often applied to enhance establishment success and early growth. After establishment, one of the main instruments of stand management is thinning to limit competition and to ensure continuous growth of the remaining trees. The first thinning generally takes place after a period of 3-10 years, depending on how the stands develop, and may reduce initial density with about 40%. Further thinning reduces density to roughly 200 trees per hectare at the final harvest.

Within this framework, several points will be considered:

- Management decisions can only be taken when clear general objectives are being formulated, with a clear description of the expected result of each of the silvicultural measures. For example, in a mixed stand the objective of a thinning operation may be to liberate the target species from competition of the companion species, or to obtain a lower absolute density, while maintaining the same proportional densities. In the case of the Agua Salud Project, these objectives and aims are as much related to research questions as to stand development.

- Different species and species combinations will require different measures for an optimal result (timber production), i.e. management may be adaptive and not uniform across all treatments. On the other side, uniform treatments can be expected to be closer to optimal for one species than for another. In both cases comparability is an issue.
- Management decisions can be addressing silvicultural objectives (production oriented) or specific research questions (introducing experimental treatments). In the first case, the decisions have to be taken whether contrasting measures (including doing nothing) are implemented in a section in/of the plots to test for the effects of the measure. Given the limited land that is available, we will only be able to do so in a few cases. In the latter case, in how far / on which scale are experimental treatments allowed to interfere with the overall objectives that require a catchment-level mixed-species timber plantation?

The management decisions have pronounced consequences for the type of questions we can ask. Species interactions and 'natural' stand dynamics are manipulated by thinning and pruning, which limits the potential for addressing certain theoretical research questions on natural processes and interactions, while providing opportunities to address others. It is premature to make decisions of future silvicultural treatments at this time.

APENDICES

Annex I

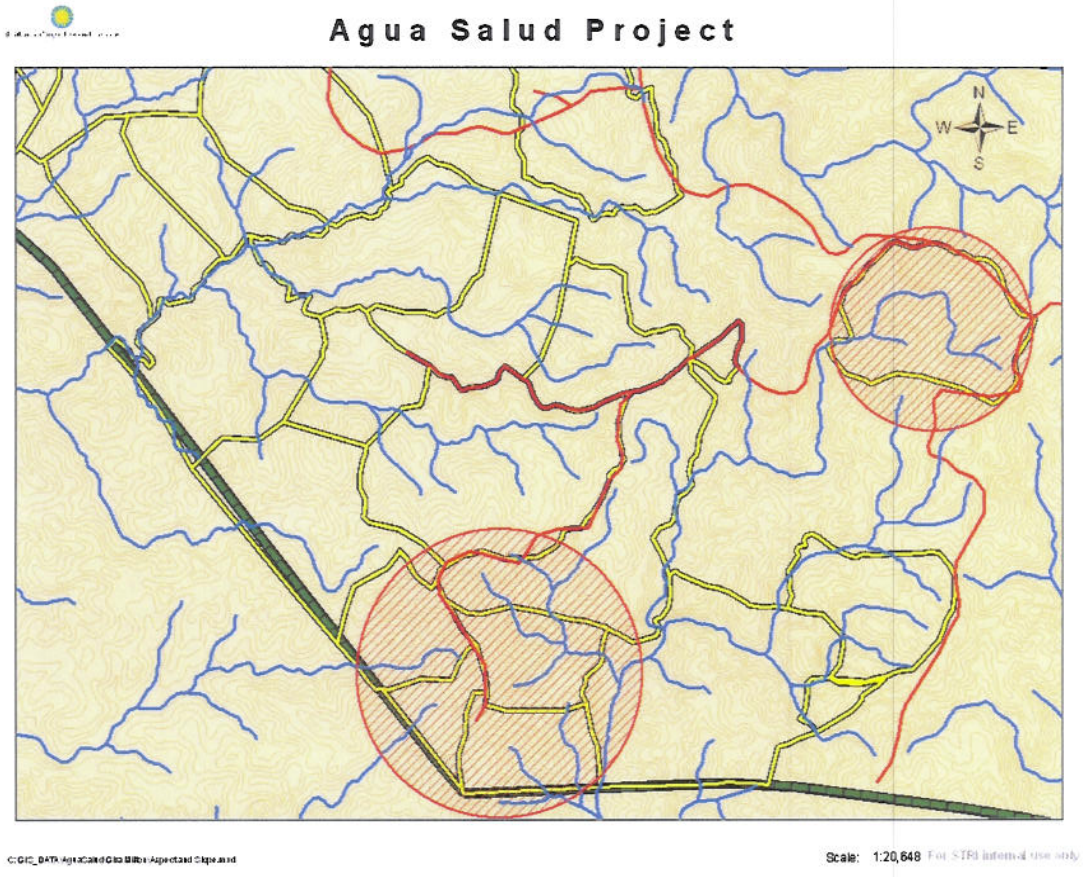
List of Participants of Workshop to Design the Native Species Plantation in the Agua Salud Project and Other Individuals Consulted:

Mark Ashton, School of Forestry and Environmental Studies, Yale University
Naira Camacho, Panama Canal Authority
Arturo Cerezo, Panama Canal Authority
N. Cubas, National Environmental Authority, Panama
Luis Cordoba, National Environmental Authority, Panama
Stuart Davies, Center for Tropical Forest Science, Smithsonian Tropical Research Institute & Harvard University
Jose Deago, Smithsonian Tropical Research Institute
Brent Frey, School of Forestry and Environmental Studies, Yale University
Susan Laurance, Smithsonian Tropical Research Institute
Carlos Melgarejo, National Environmental Authority, Panama
Florencia Montagnini, School of Forestry and Environmental Studies, Yale University
Andrew Park, Department of Biology / Center for Interdisciplinary Research, University of Winnipeg
Catherine Potvin, McGill University
Robert Stallard, United States Geological Survey & Smithsonian Tropical Research Institute
Joseph Wright, Smithsonian Tropical Research Institute

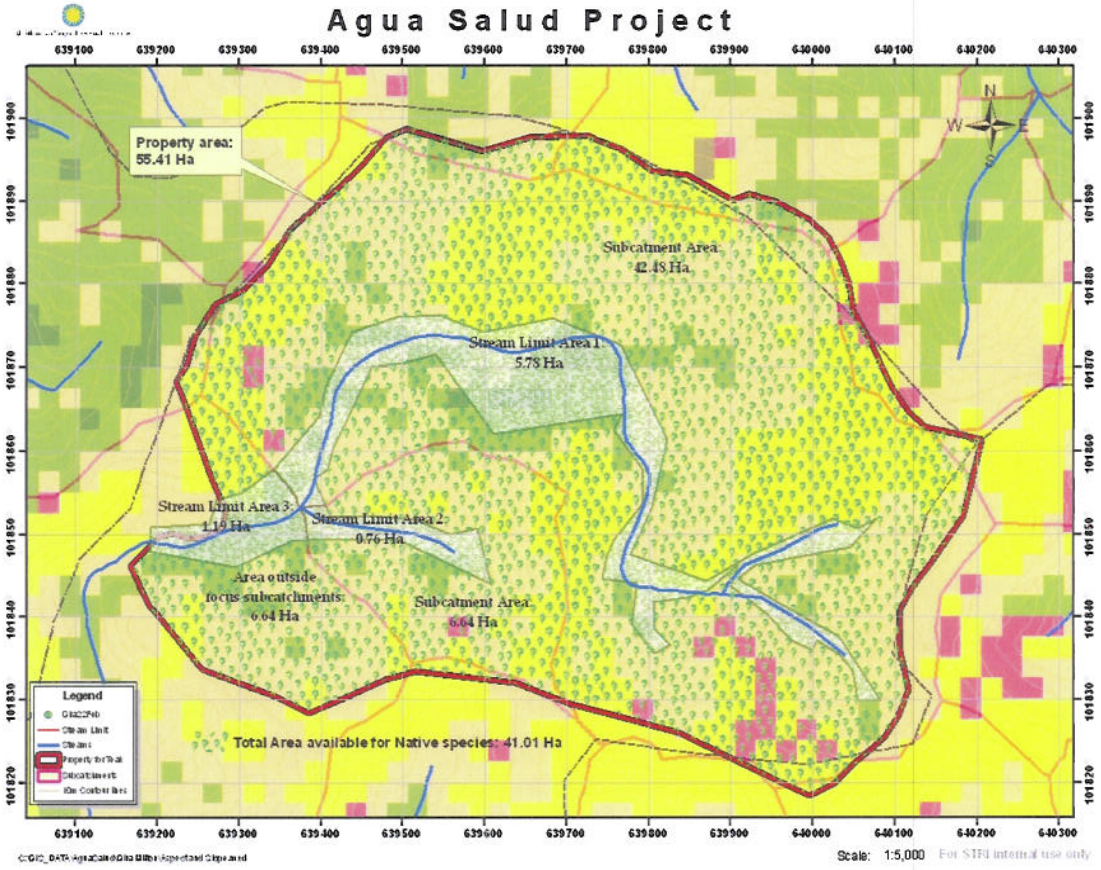
Annex II. Information on selected species from PRORENA species selection trials. Data from the Las Lajas and Soberania sites is presented, which are the two wettest PRORENA sites and most similar to the Aqua Salud area. Data give average survival and growth two years after planting. Averages are calculated from the mean values of 9 plots (20 trees per plot) per species and site.

	Survival (%)				Diameter (cm)				Height (m)			
	Las Lajas		Soberania		Las Lajas		Soberania		Las Lajas		Soberania	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Target species												
Terminalia amazonia	98.3	1.2	92.5	2.6	5.2	0.4	4.2	0.4	3.1	0.4	2.6	0.3
Dalbergia retusa	98.3	0.8	97.8	1.2	5.4	0.5	6.1	0.4	2.7	0.3	2.6	0.1
Pachira quinata	91.1	2.2	98.3	0.8	5.6	0.3	11.6	0.6	1.6	0.1	3.0	0.1
Tabebuia rosea	88.9	5.3	96.4	1.3	5.9	0.4	6.4	0.5	2.5	0.2	3.0	0.2
Anacardium excelsum	85.6	6.5	97.8	1.2	4.7	0.6	6.0	0.4	2.2	0.3	2.2	0.1
Companion species												
Gliricidia sepium	100.0	0.0	98.3	1.2	4.9	0.4	12.1	0.3	1.5	0.1	6.0	0.2
Hura crepitans	88.9	9.9	98.9	0.7	6.9	0.6	10.2	0.5	1.8	0.1	2.4	0.1
Inga puntata	66.1	4.0	86.7	4.6	2.7	0.4	7.8	0.4	1.0	0.1	2.6	0.2
Luehea seemannii	95.0	2.5	95.6	2.4	4.9	0.4	8.3	0.2	2.2	0.2	2.9	0.1
Ochroma pyramidale	77.8	6.5	90.0	1.4	8.1	0.8	15.1	0.6	4.1	0.4	7.0	0.3
Schizolobium parahyba	88.9	3.3	83.9	4.1	5.5	0.4	5.1	0.6	3.8	0.4	2.9	0.3
Spondias mombin	97.2	1.2	100	0.0	3.7	0.4	10.4	0.4	1.6	0.2	4.2	0.2
Erytrina fusca	84.4	6.2	97.2	1.2	6.3	0.4	10.8	0.3	2.0	0.2	3.1	0.1
Tectona grandis	100.0	0.0	100.0	0.0	7.4	0.7	10.8	0.3	3.5	0.5	6.2	0.2

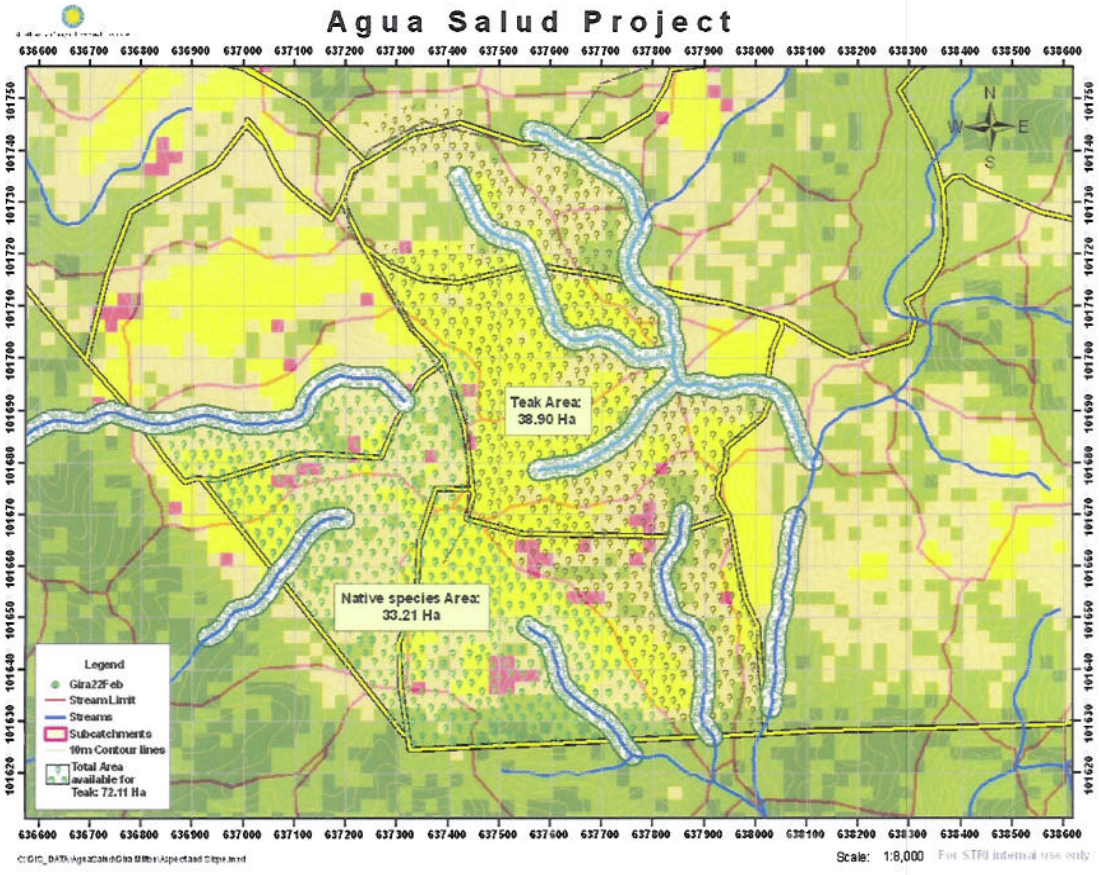
Annex IIIa. Map of the Aqua Salud research area, with the locations of the native timber species plantations.



Annex IIIb. Map of property 2 at the entrance of the Aqua Salud area, where about half of the native timber species plantation will be established. The sub-catchment area of 6.64 ha will be used as the secondary forest treatment, i.e. no planting or any other management will take place. The indicated zone around the main streams have been mapped in the field using GPS, and is unavailable for planting because of the presence of older growth forest.



Annex IIIc. Map of the area where the teak plantation will be established (dark green trees) and the other half of the native timber species plantation (light green trees). Areas are estimated, as no detailed mapping of landscape features such as creeks, riverine vegetation and patches of old-growth forest the available area has been done.



Annex IV. Experimental layout in numbers

Total plot area (m^2)	1754
Total plot size (m x m)	45 x 39
Plant distance within rows	3
Distance between rows	2.6
Assumed buffer width (# of rows)	3
Area core plot (m^2)	631
Area buffer zone (m^2)	1122
Core plot size (m x m)	27 x 23.4
Total number of planted trees	225
Number of planted trees / row	15 x 15
# of planted trees/row (core plot)	9 x 9
Number of trees in core plot	81
Number of trees in buffer zone	144

species	**#**	**repl**	**# of plots**	**plot area** (m^2)	**total** (ha)
target timber species (TS)	5	18	90	1754	15.8
2-species combinations (TS+TS)	10	18	180	1754	31.6
5-species combination (TS)	1	40	40	1754	7.0
Species combination (1 TS + 5 non-TS)	5	20	100	1754	17.5
control (empty)	1	18	18	1754	3.2
total			**428**		**75**