9a | Tree diversity and tree–site matching **(WhichTreeWhere?)**

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The slogan, 'The right tree in the right place for a clear function', points to the need to be specific about which trees grow where and how they can be managed to meet expectations of functions. The method described here starts with an inventory of tree presence in the landscape and local knowledge and perceptions of identity and function compared with taxonomic identity and recorded uses in existing databases. A second level of analysis in tree and site matching is understanding how tree growth and productivity depends on site conditions, which is closely linked to the question of which aspects of site conditions actually matter. A third level takes a critical look at functions in relation to landscape niches.

Introduction

Trees have both positive and negative attributes from a human perspective and the right-tree-at-the-right-place slogan suggests that specific choices out of the global spectrum of tree diversity should be combined with an appropriate concept of niches or locations where such trees are allowed to grow (if they survived and were retained from previous vegetation), allowed to settle (for spontaneously established trees) or are planted (based on availability of planting material). To further operationalize the concept we need to know 1) which trees currently grow where; 2) how well they grow at the locations where they grow; 3) what direct and indirect functions they have associated with their properties; and 4) how important tree diversity is at multiple scales of management.

Tree diversity depends on the scale of consideration. At global scale there are approximately 100 000 species of trees, which is one quarter of all plants, spread over about 250 plant families[1]. Woody perennials occur in six of 11 divisions of plants: *Angiospermae* (including monocots, eudicots), *Magnoliophyta*, *Gnetophyta*, *Pinophyta* (=Coniferae), *Cycadophyta*, *Pteridophyta*). In many genera there are trees and non-trees. This implies that either the genetic base of being a woody perennial has been reinvented many times or that such genes can be easily switched off and on during evolutionary change.

On the other end of the scale, we can consider a single tree species with its intraspecific genetic diversity and an often complex network of relationships with relatives that can be teased apart with genetic markers. At scales in between, we consider the tree diversity of a plot, a farm, a landscape transsect, watershed or ecoregional zone. With respect to human use, some value chains demand specific properties, defined below the species level as in tree crops with distinct cultivars, others use broad 'trade names' that can refer to multiple species. The simplest distinction of timber (floaters

[1] In the discussions around the definition of 'forest', the concept of 'tree' is important because forests tend to be defined relative to the presence of trees; and if an oil palm is a tree, conversion of forests to oil-palm plantations is not 'deforestation'.

versus sinkers) not only indicates consequences for the mode of downstream transport but also the wood density and correlates of strength and durability.

At plot level, (alpha) tree diversity comes in four shades of grey: no trees; monoculture of a single species; simple mixed system with limited (usually 2–5) species diversity; and complex mixed systems with higher diversity. The beta diversity describes the diversity across a category of plots: even for systems that are 'simple mixed' systems at plot level, the total diversity can be high if the companion trees of the dominant component are varied from plot to plot. On the high end of diversity, where the pre-human diversity of the natural landscape is the point of reference, we can quantify and understand the characteristics of the 'diversity deficit' [2]. At the gamma diversity scale of a landscape we can consider which groups of species from the original flora are underrepresented in the human-dominated landscape and which ones are overrepresented. Research so far suggests that the dispersal mode of tree seeds, as well as the direct use value for humans, are both involved, interacting with human management styles and local ecological knowledge (Joshi et al 2003, Tata et al 2008). Databases with such tree properties need to be combined with survey data.

In the background of the 'forest transition curve', a 'tree diversity transition' is taking place (Ordonez et al 2014, Figure 9a.1): depending on the part of the tree life cycle considered (seedbank, seedlings, saplings, poles or reproductive trees), we can now expect multiple lines for the loss of tree diversity during forest conversion, while the recovery phase of agroforestation or reforestation involves a gradual increase of the diversity of planted trees. Agroforestry systems differ in tree origin, although systematic data on this aspect are not yet available.

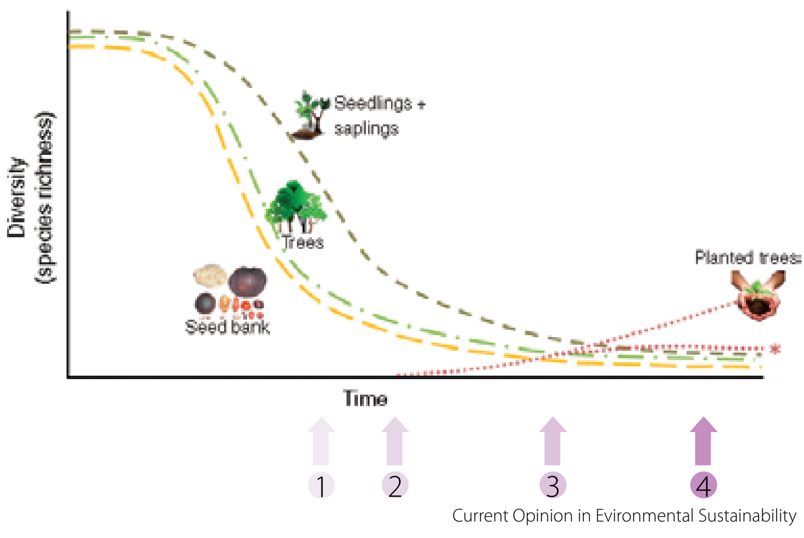

Figure 9a.1. Tree diversity transition curve

Source: Ordonnez et al 2014

[2] Villamor et al (2011) considered diversity deficits in three domains: 1) in the real world where actual diversity is less than a potential state that is deemed desirable (hence we worry about loss of biodiversity and cultural diversity); 2) in representation and modelling of the real world (where 'residual variance' may represent a diversity deficit of the model); and 3) in our recognition of the driving forces that are used to construct a model (a diversity deficit due to oversimplification). Diversity in the real world is lost when it disappears from the knowledge that is being shared.

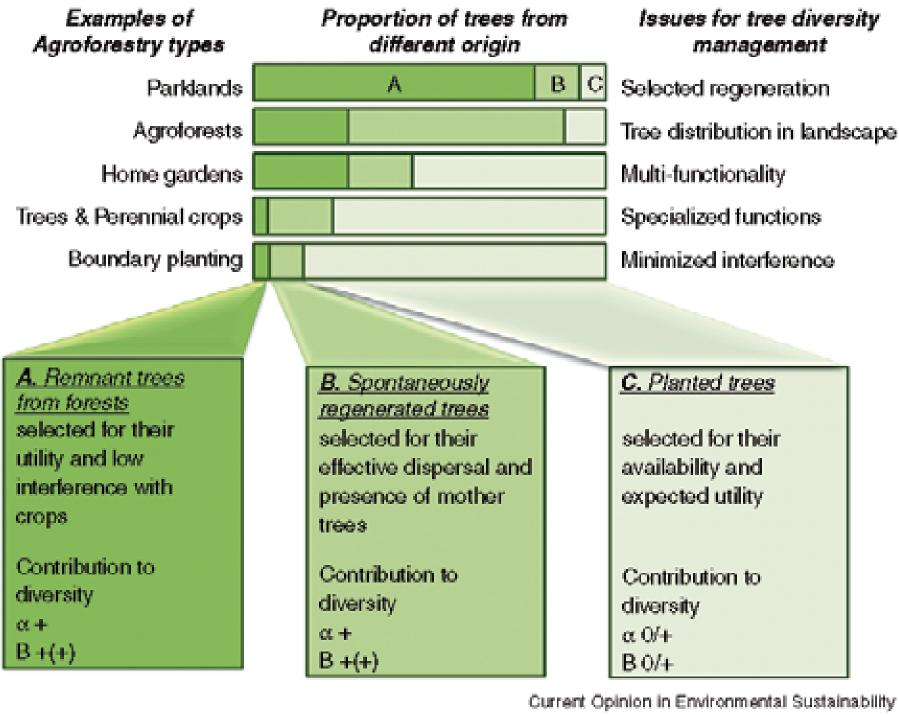

Figure 9a.2. Tree portfolios of agroforestry systems by origin of the trees

Source: Ordonnez et al 2014

Objectives

The WhichTreeWhere? tool systematically collects data of trees found on farms and in the landscape, allowing an analysis of tree portfolios with respect to functional properties as well as tree–site matching with respect to expected tree growth rates under current and future climate conditions.

Steps

1. Data collection of field occurrence of trees at plot, farm or landscape transect scale
   a. The choice of sampling scale (plot, farm or landscape transect) will often depend on the opportunities for synergy with other research, for example, economics (for which plot and farm are relevant), carbon stocks (plot or landscape scale) or watershed functions (specific landscape niches, such as riparian zones, slopes sensitive to landslides)
   b. Measurement protocols normally use tree stem diameter at breast height (1.3 m above the ground; for special cases see Hairiah et al 2011) as the basis for allometrics, accompanied by tree height for trees in more open landscape conditions (in closed stands it is difficult to measure and adds little information to allometrics); this is to be linked to tree identity in local taxonomy (linked to use value) and botanical taxonomy; the latter may require collection of specimens for herbarium comparisons

c. Assistance of local informants may be needed to record the origin of the tree as 1) retained from preceding vegetation; 2) spontaneously established; or 3) planted. An intermediate category is 'farmer-managed natural regeneration', which is mostly in category 2. Finer distinctions in 'planted' (3) can be: 3a) directly seeded; 3b) transplanted wildings; 3c) transplanted from nursery; 3d) grafted in nursery; 3e) grafted in situ on planted rootstock; 3f) grafted on spontaneously established trees. And further categories as locally appropriate

2. Linking local and botanical tree taxonomy to use values and other knowledge
   a. Local tree taxonomy tends to differ substantially from the botanical, as it is generally linked to use value. For fruit trees this may, for example, mean that varieties within a single species are differentiated by name; for timber species, terms such as 'medang' or 'meranti' can cover a wide range of botanical species
   b. Methods to explore local knowledge of trees and their properties are provided with AKT5
3. Linking tree data to functional attributes in dedicated databases

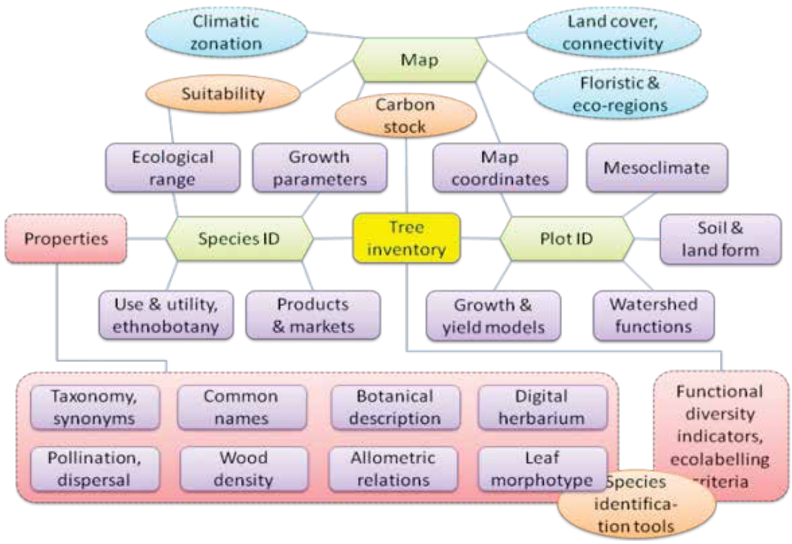

Figure 9a.3. Module diagram of Tree FUNATIC database

4. Analyzing tree growth in relation to site properties and climate
   a. If tree or site-level properties of soil, climate and management are recorded, as well as age of the tree, the predictive power of such variables[3] in accounting for tree growth rates can be tested (Santos-Martin et al 2010)
   b. Using existing spatial databases, the climatic conditions where the trees occur and basic soil and site properties can be used to map 'climatic suitability' for trees, especially for those with high use value. In combination with climate-change predictions, this may assist anticipating the growth conditions under which a tree will mature in the choice of what is currently planted.

[3] For example, landscape position, soil texture, organic matter, soil chemical and soil biological properties in order of increasing data cost; interacting with farmers' characteristics and management styles

A number of databases are now available that can assist with such analyses. The Agroforestry Species Switchboard (www.worldagroforestry.org/products/switchboard/index.php) provides easy access. It includes an option of searching for a genus or species by directly typing the name of the URL (hyperlink) in the web browser: http://www.worldagroforestry.org/products/switchboard/index.php/name_like/ .

Agroforestree database

The Agroforestree database is a species' reference and selection guide for agroforestry trees. In the context of the database, agroforestry trees are those that are deliberately grown or kept in integrated land-use systems and are often managed for more than one output. They are expected to make a significant economic or ecological impact, or both.

The main objective of the database is to provide detailed information on a number of species to field workers and researchers who are engaged in activities involving trees suitable for agroforestry systems and technologies. It is designed to help them make rational decisions regarding the choice of candidate species for defined purposes. Information for each species covers identity, ecology and distribution, propagation and management, functional uses, pests and diseases and a bibliography. To date, more than 500 species have been included. The specific aims of the database are to

1. enable quick and efficient access to a consolidated pool of information on tree species that can assume useful production or service functions, or both;
2. provide a tool that will assist with the selection of species for use in agroforestry and related research, using factors that are relevant to the chosen agroforestry technologies;
3. help researchers assess potential agroforestry trees for uses other than those commonly known, such as timber; and
4. provide indicators for the economic assessment of species through yield information on tree products.

Download from http://www.worldagroforestry.org/sea/Products/AFDbases/AF/index.asp.

Wood density database

The wood density database records the dry weight per unit volume of wood for particular species. It can be used in allometric equations that estimate tree biomass and carbon stocks from stem diameter values (for example, W = 0.11 r D2+c , Ketterings et al 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. *Forest Ecology and Management* 146:199–209) and indicate the use value (higher density wood tends to burn slower and is thus more useful as firewood or as source of charcoal, it also correlates with strength, although there are better parameters for strength per se).

Wood density varies with tree species, growth conditions and part of the tree measured. The main stem generally has a higher wood density than the branches, while fast growth is generally related to relatively low wood density. For most species, the literature thus gives a range with low, medium and high values. In this database we have collected quantitative information from a number of publicly available sources. As you will note, there is no standardization of the moisture content of the ('air dry') wood in the densities reported and some conversions may be needed. For questions and comments please contact s.rahayu@cgiar.org.

Download from http://worldagroforestrycentre.org/regions/southeast_asia/resources/wood-density-database.

Tree diversity analysis

A manual and software for common statistical methods for ecological and biodiversity studies

Effective data analysis requires familiarity with basic concepts and an ability to use a set of standard tools, as well as creativity and imagination. Tree diversity analysis provides a solid practical foundation for training in statistical methods for ecological and biodiversity studies.

This manual arose from training researchers to analyse tree diversity data collected on African farms, yet the statistical methods can be used for a wider range of organisms, for different hierarchical levels of biodiversity and for a variety of environments, making it an invaluable tool for scientists and students alike.

Focusing on the analysis of species survey data, *Tree diversity analysis* provides a comprehensive review of the methods that are most often used in recent diversity and community ecology literature including:

- species accumulation curves for site-based and individual-based species accumulation, including a new technique for exact calculation of site-based species accumulation;
- description of appropriate methods for investigating differences in diversity and evenness, such as Rényi diversity profiles, including methods of rarefaction to the same sample size for different subsets of the data;
- modern regression methods of generalized linear models and generalized additive models that are often appropriate for investigating patterns of species occurrence and species counts; and
- methods of ordination for investigating community structure and the influence of environmental characteristics, including recent methods such as distance-based redundancy analysis and constrained analysis of principal coordinates.

The BiodiversityR software was initially developed for the R 2.1.1 statistical environment. Please check for changes in installation procedures and some new options for data preparation in the document provided below.

Download from http://worldagroforestrycentre.org/resources/databases/tree-diversity-analysis.

Molecular markers for tropical trees: statistical analysis of dominant data

In the last decade, there has been an enormous increase worldwide in the use of molecular marker methods to assess genetic variation in trees. These approaches can provide significant insights into the defining features of different taxa and this information may be used to define appropriate management strategies for species.

However, a survey of the literature indicates that the implementation of practical, more optimal management strategies based on results from molecular marker research is very limited to date for tropical trees. In order to explore why this is the case, the World Agroforestry Centre undertook a survey of molecular laboratories in low-income countries in the tropics. The survey looked at the kinds of molecular marker studies that were being carried out on tree species and the problems faced by scientists in this research.

One of the constraints that the survey identified for the proper application of molecular markers is the effective handling and analysis of data sets once they have been generated. This guide has been designed to address this need for data obtained using dominant marker techniques. It has been created especially for students (MSc, PhD) and other researchers in developing countries who find themselves isolated from their peers and—when faced with an apparently bewildering array of options—find it difficult to settle on appropriate methods for analysis.

Most benefit will be obtained from this guide if it is used together with the companion volume on practical protocols for molecular methods (ICRAF Technical Manual no. 9) and so we recommend that scientists read both.

Download from http://worldagroforestrycentre.org/resources/databases/molecular-markers-for-tropical-trees.

Tree functional attributes and ecological database (Tree FUNATIC)

Tree FUNATIC is a web-based database that both stores and gives information about the attributes and ecological information of a variety of tree species, including taxonomy, geographic distribution, ecological range, functions and wood density. The database also stores tree entity information from observations, such as stem diameter, height and crown dimensions, as well as habitat information, including that geographic information on soils and climate.
Tree FUNATIC is a web application that can be accessed anywhere and anytime within internet coverage. The Tree FUNATIC application is made with a simple interface using the latest technology to enable easy access for users to get the information they need. Most of the database can be accessed by the public; some information can be accessed only through membership.

The Tree FUNATIC Database is accessible at http://db.worldagroforestry.org/.

- Tree site distribution based on climate, soil and elevation range of each species.
- Uses and function of each species.
- Wood-density information extracted from species, genus, family, common name.
- Carbon-stock information at plot level in various locations, especially Indonesia.
- Species allometry to estimate tree biomass.
- Tree market, supplier and location information.
- Tree-species identification based on morphotype and herbarium database.
- Watershed along with its climate information.

Tree FUNATIC Database is a relational database using MySQL as its server. Members can access the MySQL to do direct queries using the SQL language code. Currently, Tree FUNATIC has 452 allometry data per species to estimate biomass in various locations gathered from various literature sources. The database is still under active development.

9b | Gender perspectives in selecting tree species (G-TreeFarm)[1]

Sonya Dewi, Janudianto and Endri Martini

Gender Perspectives in Selecting Tree Species and Farming Systems using an Analytic Hierarchy Process (G-TreeFarm) reveals two layers of decision-making processes in selecting tree species and farming systems between different gender or other diversified groups, such as migrant and native groups. The tool produces 1) lists of tree species and farming systems based on the order of preferences (what); and 2) lists of selections and the order of perceived importance (why). The first list has direct uses for development programs to identify tree species that people want and the second list can guide to a broader search of tree species and farming systems that match the important criteria that people have, which are not in the first list.

Introduction

An important factor that affects the failure or success of development programs with tree planting and agricultural development is the buy-in and adoption rates of farmers. Understanding the perspectives and aspirations of farmers is crucial, since self-motivation will lead to high adoption rates of any introduced farming or land-use management system. In the past, many landscape rehabilitation or reforestation programs have failed owing to top–down approaches in selecting and introducing types of tree species and farming systems that were imposed on the farmers. On the other hand, there are success stories from development programs that supported and provided technology and good seedling material of tree species that people wanted.

Gender, social and cultural inclusions in a community should be captured to understand the diverse perspectives and preferences in selecting tree species and farming systems. Development programs should respect social diversity by not ignoring minor community groups; often these groups are the stakeholders in need of aid.

Introduction of new tree species and farming systems is often tricky since adoption rates are influenced by many unpredictable factors. However, criteria used for selecting tree species and farming systems can guide the task of searching for suitable new species and systems, along with success stories from other places. Addressing the criteria can also help to reconcile diverse preferences, if necessary, as well as stimulate discussion and negotiation among farmers. In addition, the criteria can be indications of constraints or barriers met in specific local areas that may burden intervention processes in development programs.

[1] This method will also be discussed in Janudianto et al. (2014). A related ranking technique is described by Kiptot and Franzel (2014); specifically for fodder shrubs Carsan et al. (2014) discusses options and preferences.

Analytic hierarchy process (AHP) is a decision-making framework used for large-scale, multiparty, multi-criteria decision analysis developed by Thomas L. Saaty in the 1970s. This framework was adopted and used in the TreeFarm[2] module to elucidate the gender differences in selecting tree species and farming systems in Sulawesi, Indonesia. Decision making in AHP is undertaken by:

- identifying criteria and assigning relative importance to each in selecting tree species and farming systems; and
- identifying potential tree species and farming systems in the area and the relative preferences of each with regard to each criterion.

Objectives

The objective of G-TreeFarm is to first clarify, for different stakeholder groups, the primary functions needed and then focus on which trees, crops and farming systems can fulfil these functions. Subsequent analysis can clarify gender and social differentiation in criteria and knowledge of options to provide the desired functions.

Steps

1. Prepare separate group discussions for men and women. The discussions can be held in parallel in the same area but at different places. The participants may represent certain villages, clusters or landscapes within the study areas, with 8–10 participants in each group.
2. Explain the discussion objective, the background of the study, and the general consensus at the beginning of the discussion. Encourage participants to relate the actual field or landscape conditions based on their perceptions and observations.
3. Ask the participants to develop a list of existing and potential farming systems (annual cropland, monoculture perennials, mixed perennials, mixed annual–perennials) based on their perceptions.
4. Rank the farming system according to their importance to farmers (for example, cash benefits, subsistence) (Table 9b.1).

Table 9b.1. List of existing farming systems in the community (the example is taken from a women-only group)

Farming system	Source of cash? (Yes/No)	Rank (1 as the highest source of cash)	Source of non-cash?[a]	Rank (1 as the highest source of food)
Annual cropland				
• Paddy	Y	3	1	1
• Patchouli	Y	2	2	
• Maize	Y	1	1	2
Monoculture perennials				
• Rubber	Y	1	3	
• Coconut	Y	2	3, 5	1

[2] The TreeFarm module is part of the Capacity-Strengthening Approach to Vulnerability Assessment (CaSAVA) tool developed to analyze decision making in selecting tree species and farming systems that incorporates gender specificities.

Farming system	Source of cash? (Yes/No)	Rank (1 as the highest source of cash)	Source of non-cash?[a]	Rank (1 as the highest source of food)
Mixed perennials	-	-	-	-
Mixed annual–perennials	-	-	-	-
Shrublands	-	-	-	-
Forests	-	-	-	-

Note: [a] Food=1; Medicinal=2; Timber=3; Energy=4; Handicraft=5; Cultural and aesthetics=6; Livestock=7; Bush meat=8; Other=9

5. Ask the participants to identify a list of criteria in selecting the farming system based on their perceptions (Table 9b.2). The criteria comprise the background used by participants when selecting the most profitable farming systems in the community (for example, price, market access, available technology).

Table 9b.2. List of criteria on selecting farming systems (or tree species) in the community

No.	Criterion	Notes
1	Easy to market	
2	High price	
3	Available good planting materials	
4	Low labour input	
5	Can be mixed in a plot	
6	Easy to harvest	
7	Quick to produce	

6. Assess the relative weight of the criteria by comparing each pair of criteria using a score of 1 to 5 based on importance to livelihoods (Table 9b.3). Note that the shaded cells should be left empty because the matrix is symmetric and the diagonal cells are left blank since they are self-comparison. Put 1/1 if each pair of criterion has the same weighting; otherwise 1/5 if one criterion has extremely strong weighting compared to another. The first number represents the row cell, the second one the column. For example, the weighting 5/1 of the red shaded cell in the second row, fourth column of Table 9b.3 means that the first criterion (easy to market) was extremely important compared to the second criterion (available good planting materials). Give attention to the weightings that are given, such that there are no conflicts or inconsistencies across the weighting schemes. Ideally, the scores should be entered and tested in the AHP software for consistencies but it is often not possible to be run during a group discussion without disturbing the flow of the discussion. Take notes if there are consistent disagreement among particular sub-groups: it is an indication that there are marked diversity within a group. Explore further what characterize sub-groupings, for example, size of land owned.

Table 9b.3. Criteria weighting (the example is taken from a men-only group in Southeast Sulawesi)

Criterion	Easy to market	High output price	Available good planting materials	Low labour input	Can be mixed in a plot	Easy to harvest	Quick to produce
Easy to market		1/1	5/1	5/1	5/1	5/1	1/1
High output price			1/1	1/1	3/1	1/1	1/1
Available good planting materials				1/1	1/1	1/1	1/1
Low labour input					3/1	1/1	1/1
Can be mixed in a plot						1/3	1/3
Easy to harvest							1/5
Quick to produce							

Note: Criteria weighting is done by comparing each pair of criteria (1=same, 5=extremely strong). In this example, only five criteria are given

7. Assess the farming system weighting in each of the criterion by comparing each pair of farming systems with a similar procedure. In the example in Table 9b.4, we seem to have a tree species list but in this area farmers manage their farm mostly in mixed systems: fruit farming system means various fruit tree species dominate the plot, which has several other species as well. Put 1/1 if each pair of farming systems has similar importance to the criterion and 1/5 if one of the farming systems is extremely important compared to the others. The weighting 1/5 in the red shaded cell of Table 9b.4 means that in terms of marketing, pepper was deemed far easier to market than patchouli. Similarly to Step 6, pay attention to inconsistencies.

Table 9b.4. Farming system weighting using criterion 'easy to market' identified by a male group

Tree-Farming	Patchouli	Cocoa	Pepper	Fruit	Timber	Coconut	Sago
Patchouli		1/5	1/5	1/5	5/1	5/1	1/5
Cocoa			1/1	5/1	5/1	5/1	1/1
Pepper				5/1	5/1	5/1	1/1
Fruit					5/1	5/1	1/5
Timber						1/5	1/5
Coconut							1/5
Sago							

Note: For each criterion, do comparisons between farming system options for couples as in the previous step

8. Conduct similar steps for tree species selection using a similar table. Create a list of existing and potential tree species (Table 9b.1), identify a list of criteria in selecting the tree species (Table 9b.2) and conduct the criteria weighting and tree species weighting (tables 9b.3 and 9b.4).
9. Enter the data in spreadsheet format and run the AHP software to get the results. Table 9b.5a shows an example of results: low labour input is being perceived as by far the most important criterion, which perhaps indicates other livelihoods' options and/or available labour market. Introducing a farming system that is labor intensive to this group will have a low probability of success. Table 9b.5b shows the weighting results of farming systems based on each criterion. For example, in terms of low labour input, patchouli and pepper systems are the two most-preferred systems. Cocoa and pepper are perceived as the most preferred as far as easy to market is concerned. Table 9b.5c shows the combined weights between criteria and preferences based on each criterion. Patchouli comes first, mostly because it is being perceived as having low demand for labour compared to other farming systems, while low labour input is the criterion most important within the list of criteria.

Table 9b.5a. Ranking of importance of criteria

Criterion	Weight	Rank
Low labour input	0.4454	1
Easy to market	0.1804	2
Easy to harvest	0.0990	3
Quick to start producing	0.0934	4
Planting material is easily available	0.0685	5
High output price	0.0618	6
Can be mixed	0.0515	7

Table 9b.5b. Weightings of farming systems based on each criterion

	Easy to market	High price	Available good planting materials	Low labour input	Can be mixed in a plot	Easy to harvest	Quick to produce
Patchouli	0.0663	0.1262	0.1328	0.2850	0.0513	0.0807	0.4519
Cocoa	0.2464	0.0614	0.1805	0.1148	0.1146	0.0807	0.1420
Pepper	0.2464	0.1378	0.1805	0.2467	0.0449	0.0807	0.1420
Fruit	0.0827	0.0417	0.1805	0.1319	0.2609	0.3278	0.0796
Timber	0.0396	0.2082	0.1647	0.0719	0.2245	0.0511	0.0523
Coconut	0.0880	0.2582	0.1328	0.1148	0.2609	0.3278	0.0680
Sago	0.2306	0.1665	0.0282	0.0350	0.0430	0.0511	0.0643

Table 9b.5c. Rank of preferences of farming system across all criteria

Farming systems	Weights	Rank
Patchouli	0.2086	1
Pepper	0.1988	2
Coconut	0.1443	3
Fruit	0.1419	4
Cocoa	0.1389	5
Timber	0.0848	6
Sago	0.0827	7

Example of application

The method has been applied in 40 villages in Sulawesi, across gender groups, and showed some interesting findings regarding the perceptions of male and female groups on an existing farming system, variations of preferences in tree species and farming system, and criteria perceived as most important in selecting tree species and farming system.

- Across the 20 group discussions held in different places, the variations in lists of criteria and the orders of importance were marked. In addition to low labour input and easy to market criteria, land and climate suitability, food self-sufficiency, customary and cultural values, acquired cultivating skills, long productive lifespan and multiple benefits of the farming system were perceived as being important. The local context, such as cultural factors, market access, infrastructure, land access etc, shaped the criteria and their importance in selecting tree species and farming systems. This finding can be used to guide broader research of potential tree species and farming systems than what appeared in the list during the discussion.
- The Sulawesi exercise showed that segregation data was possible to collect through the separate-but-parallel discussion sessions with male and female groups. The gender differences were clearly shown in the process of tree and farming system selection within the community. As an example, the results of the women-only group of the same study area as the example given above show more even weightings across criteria but nevertheless low labour input is the lowest while land and climate suitability is the highest. The two gender groups agree that the criterion 'easy to market' is the second-most important criterion.

Key references

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Saaty TL. 2008. Decision making with the analytic hierarchy process. *International Journal of Services Sciences* 1(1):83–98.

10 | Access to trees of choice (NotJustAnyTree)

James M. Roshetko, Pratiknyo Purnomosidhi and Endri Martini

The choice of trees that are planted is unfortunately often dominated by supply (what is available) rather than by what is prioritized by planters. The NotJustAnyTree tool provides an evaluation approach of the planting material that can be obtained from existing local nurseries, and its quality. The tool also includes evaluation criteria for outcome and impact studies of efforts to support nurseries of excellence.

Introduction

Preceding tools help in defining which trees might be suitable where, and what level of tree diversity (between and within species) is desired or prioritized. Unfortunately, tree-planting programs are mostly evaluated by the numbers of trees planted rather than by the number of trees that actually survive and grow and even less in the quality of products and services that they provide. A major shift is needed from supplying what is easily available to what is prioritized. Past evaluations of tree-planting programs have focussed on the number of seedlings supplied and program funding rather than on the appropriateness of what was supplied and planted.

It is possible for farmers to obtain tree seed, sow it directly or use it to produce seedlings in a small-scale family nursery. Larger-scale tree nurseries, oriented towards local needs, offer economies of scale and other advantages. These can be managed by a farmers' group or as part of a broader community training and education program; they may also evolve into private enterprises focused on serving market demand. Often such enterprises grow out of external or community efforts to develop the technical skills and experience, access to tree seed and information, and awareness of market mechanisms necessary for individuals or groups to effectively operate a tree nursery.

An important step for any nursery that wants to supply the markets is the production of reliable quality seedlings through informal or formal quality control; in government-monitored markets this may include certification programs. The actual quality of a tree can only be assessed many years after it has been planted, but molecular markers that allow early identification of cultivars or strains are becoming more widely available.

Objectives

The aim of the NotJustAnyTree tool is to assess the supply and demand of quality tree germplasm, the capacity of local nurseries, and the effectiveness of support to local nursery development.

Steps

1. Survey of existing tree nurseries in a geographic area to assess the species and types of species produced, seedling quality (origin of seed, budwood, other material; type of seedling propagation; size and age of seedlings etc), the quantity of seedlings produced, average number of seedlings per sale, business capacity of the nursery, relation to other components of the tree seed sector (other nurseries, germplasm suppliers, government agencies, the private sector,

customers etc) (Roshetko and Purnomosidhi 2013). Gap analysis that starts with potential demand can identify opportunities for new species to enter into the nurseries (Narendra et al 2013).

2. Similar surveys of germplasm suppliers (government and private) that operate at local, national or international levels; and assessment of government support to facilitate local access to these suppliers (Roshetko et al 2003).
3. Needs assessment of nurseries' human resources and infrastructure to identify any training and equipments inputs required to enhance nursery operations[1].
4. Evaluation of the technical and cost effectiveness of the inputs required to enhance nursery operations.
5. Forecast of future seedling demand (government, project, private sector) and evaluation of local nurseries potential to meet that demand (Martini et al 2013).

Case study: nurseries of excellence in Indonesia

Aceh, the northern- and western-most province of Indonesia, covers an area of 57 000 km^2 and has a population of just over 4 million. Household economies were based on rice production for household consumption, fisheries for income generation and tree crops for both income generation and household needs. In Aceh Barat, tree crops provided 60% of household incomes. Across the province, smallholders cultivated mixed tree and crop systems under non-intensive management. Key species were rubber, cocoa, coconut, betel nut and fruits.

Figure 10.1. Participants in a NOEL nursery establishment and management training course

The tsunami of 2004 had catastrophic effects in Aceh. Approximately 200 000 people were killed and 500 000 displaced. Local economies were devastated and many Acehnese communities lost vital capacity and experience in tree-garden management. A generation of young farmers was not mentored by skilled elders. As a result, tree management practices were non-intensive and farmers'

[1] An appropriate assessment could be testing various types of nursery containers. A comparison of seedlings grown in biodegradable containers with those grown in normal polythene bags showed that although physical appearance was less appealing, seedling success after planting on farm was higher (Muriuki et al 2013).

access to quality tree germplasm, professional technical assistance and market links was limited. Efforts towards livelihoods' enhancement and land rehabilitation began in 2007 but many of the aid agencies in Aceh lacked staff, experience and information related to tree-garden management. Most nurseries in Aceh did not produce seedlings. They purchased them from outside the province for resale in Aceh, which meant resources used to buy and transport seedlings were not available for local investment. The quality of the purchased seedlings was often poor and damage occurred during transportation. Poor seedling quality lead to poor post-planting survival and performance.

It was important to help farmers produce high-quality germplasm, improve tree-garden management skills and enhance their market awareness. The Rehabilitation of Agricultural Systems in Aceh: Developing Nurseries of Excellence (NOEL) project, implemented by the World Agroforestry Centre and Winrock International aspired to do exactly that. The program aimed to improve agroforestry-based livelihoods and tree gardens through the use of productive tree crops produced in community-based 'nurseries of excellence'.

Implemented in Aceh Barat, Aceh Jaya and Pidie districts, NOEL facilitated the access of smallholders—both men and women—to high-quality planting materials and trained them to establish and operate tree nurseries and tree gardens. Initiated in April 2007, NOEL operated until March 2009. Program activities included introductory nursery training, bi-weekly follow-ups, intensive vegetative propagation training, technical consultations, cross-visits, market studies, nursery development and demonstration plot establishment.

NOEL partners included farmer groups, 'dayah' (community Islamic organizations), NGOs, international development organizations, universities and local technical agencies.

What did the NOEL program achieve? In just 18 months, 178 capacity-building events were conducted, training 3582 people. Across all NOEL activities, the involvement of women exceeded 30%. Fifty 'nurseries of excellence' were established, 32 by program partners and 18 'susulan' (spontaneous) nurseries by neighbouring farmers who were inspired by the success of NOEL. Over 400 000 seedlings were produced. There was a 92% success rate in nursery establishment, which is in huge contrast to many post-tsunami, pre-NOEL community nurseries where farmers were provided with only a small amount of nursery training and no follow-up technical support, as a result of which the nurseries ceased to function or operated at very low levels.

The NOEL farmers' extension approach demonstrated that a program of training, intensive follow-up and material support could facilitate the successful development of farmers' technical capacity, community tree nurseries and related infrastructure, even with partners previously unfamiliar with tree nursery operations. Supporting susulan further expanded the program's impact. The NOEL approach can effectively be replicated in other sites in Indonesia and Southeast Asia, where land rehabilitation and community livelihoods' enhancement are key objectives. (Roshetko et al 2013, Selvarajah 2013.)

■ Key references

Del Castillo R, Roshetko JM. 1998. A*groforestry seed technology and nursery management: a training manual.* Bogor, Indonesia: Institute of Agroforestry; International Centre for Research in Agroforestry Southeast Asia Regional Program; Winrock International; Rockefeller Brothers Fund.

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Tree seeds for farmers: a toolkit and reference source

This toolkit has been developed to provide information on sustainable production of seeds and seedlings of agroforestry species.

The prime objective of the toolkit is to provide information and examples of how the quality of seeds and seedlings can be maintained from collection to field planting for the great diversity of agroforestry species that are useful to small-scale farmers. The toolkit was developed recognizing the wide range of actors and stakeholders that are involved in expanding agroforestry systems. Its format is designed to answer the questions that various actors may have in relation to seed production. The toolkit is based on a review of existing documentation and extension materials on seed production. Useful references to augment the toolkit information are also provided.

The toolkit complements existing materials on seed production in two fundamental ways. Firstly, it provides information on how joint strategies can be made by the various actors and stakeholders in expanding tree planting in defined regions. Secondly, it explores in further detail the option of developing sustainable systems that provide quality material by involving the private sector in seed production. The final section of the toolkit primarily focuses on tree nursery management.

The toolkit contains three sections: 1) strategies for expanding seed production; 2) technical guidelines in seed production; and 3) the private sector and seed production.

Download the *Tree Seeds for Farmers* toolkit: http://worldagroforestrycentre.org/research/tree_diversity_domestication/genetic-resources-unit/articles-documents/tree-seeds-for-farmers.

Indonesian local tree nursery directories

Individuals and organizations often do not know what nursery resources are available to meet their tree seedling needs. The development and publication of local tree nurseries helps publicize the existence of nurseries and availability of seedling resources. The directories also increase business opportunities for nurseries. The publishing of a local tree nurseries directory in an inexpensive and practical output, which can expand the impact of a project or program.

Below are listed four examples of local tree nursery directories from Indonesia.

Purnomosidhi P, Roshetko JM, Prahmono A, Moestrup S. 2012. *Direktori usaha pembibitan tanaman buah, kayu dan perkebunan di Propinsi Jambi*. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program; Little Rock, AR: Winrock International; Copenhagen: Faculty of Life Science, University of Copenhagen.

Purnomosidhi P, Roshetko JM, Prahmono A, Moestrup S. 2012. *Direktori usaha pembibitan tanaman buah, kayu dan perkebunan di Propinsi Lampung (edisi II)*. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program; Little Rock, AR: Winrock International; Copenhagen: Faculty of Life Science, University of Copenhagen.

Purnomosidhi P, Roshetko JM, Prahmono A, Moestrup S. 2012. *Direktori usaha pembibitan tanaman buah dan perkebunan di Kabupaten Aceh Barat, Aceh Jaya, Pidie/Pidie Jaya dan Nagan Raya*. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program; Little Rock, AR: Winrock International; Copenhagen: Faculty of Life Science, University of Copenhagen.

Purnomosidhi P, Roshetko JM, Prastowo NH, Moestrup S. 2012. *Direktori usaha pembibitan tanaman buah, perkebunan, kayu dan hias di Kabupaten Bogor dan sekitarnya (edisi II)*. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program; Little Rock, AR: Winrock International; Copenhagen: Faculty of Life Science, University of Copenhagen.

International tree seed suppliers directory

This directory is intended to contribute to the informed use of tree germplasm, which is an essential component of sustainable forestry and agroforestry practices, and promote wider use of quality germplasm.

Quality has both a genetic and a physiological component, and both are described in the directory. Quality descriptors can be used as criteria to select suppliers, and this will ensure that both the users and the suppliers recognize seed quality requirements. The directory also highlights the importance of biosafety issues, and it presents biosafety information that suppliers have provided

Although the directory focuses on tree taxa of importance in the tropics, it lists temperate taxa as well. It does not discriminate between taxa used for agroforestry and forestry. The purpose is to ensure that the information is useful to a wide range of users.

The directory lists suppliers by country. Download from http://www.worldagroforestry.org/our_products/databases/tssd.

Indonesian seed suppliers directory

Seed is the most important input of any tree-planting or reforestation program. Adequate quantities of seed assure planting targets can be achieved. The use of quality seed, combined with good planning and management, leads to high survival rates, fast growth and program success.

Unfortunately, the availability of tree seed is often limited. Surveys indicate that nearly all Indonesia-based NGOs and farmers' groups active in tree-planting activities lack access to tree seed of adequate quantity and quality. Many projects and government agencies face similar shortages. This problem is exasperated by a paucity of information concerning tree seed suppliers. At the national and provincial levels some lists of tree seed suppliers exist but they are not widely circulated or frequently updated. This directory supplements the international directory, above.

The majority of tree seed used in Indonesia is collected, exchanged and traded through the informal sector. The seed collectors and traders involved in this sector generally have little formal training in seed technology. They record and report little information concerning the source and quality of the seed they collect. This lack of information makes it difficult for consumers to evaluate the seed available from these suppliers. The informal seed sector operates on personal links of past contacts and word of mouth. Some suppliers are able to sell large quantities of seed because of strong customer links. Based on past experience, these suppliers collect seed to fill specific orders and meet anticipated last-minute orders. However, the potential of most suppliers is limited because they lack strong consumer links. Likewise, most consumers (seed users) have little idea where to secure seed and consistently suffer seed shortages. Projects and NGOs may contract local farmers to collect small volumes of seed but for large volumes they contact big seed suppliers in Central and East Java. Some of the seed sold by these big suppliers is collected on outer islands, shipped to Java and then re-sold to consumers on outer islands; sometimes to the same islands from which the seed was originally collected. The information and links gap between consumers and suppliers in Indonesia causes the national tree seed collection and distribution pathways to be inefficient, resulting in higher prices and seed of sub-optimal quality.

The directory was developed to address the tree seed information and links gaps prevalent in Indonesia. It provides reliable information to seed consumers—farmers, NGOs, projects, government institutions and others—and promotes the services and products of seed suppliers*. Most importantly, the directory provides a channel for consumers and suppliers to build links. The information in the directory was collected through a survey of 140 seed suppliers operating throughout Indonesia. The seed suppliers were identified by compiling the experience of five forest tree seed centres: Balai Perbenihan Tanaman Hutan in Palembang, Bandung, Denpasar, Banjar Baru, and Ujung Pandang; Directorate of Forest Tree Seeds, Ministry of Forestry; and the World Agroforestry Centre and Winrock's network of NGOs, farmers' groups and development organizations. In addition to the survey, more information was gathered through interviews with key seed suppliers in Wonogiri, Central Java, and Ponorogo, East Java, which are the primary sources of tree seeds in Indonesia (Roshetko et al 2003).

Available at http://worldagroforestry.org/regions/southeast_asia/resources/db/seedsuppliers

11 | Climate: using local tree influences (CooLTree)

Meine van Noordwijk, Jules Bayala and Kurniatun Hairiah

Trees have a substantial influence on windspeed, maximum temperature during the day (especially on the hottest days of the year), humidity, minimum temperature and possibly play a role in modification of rainfall. Where the actual climate for crops, livestock and people is involved, one of the most effective things that people can do is manage trees, including tree planting. However, the official climate data that form the basis for climate policy exclude such effects and scientists are only slowly coming to grips with this issue. The CooLTree method contrasts the local, public/policy and science-based knowledge.

Introduction

People associate climate issues with trees. Tree planting as a ceremonial activity has intuitive appeal in the context of climate change and is popular among politicians who want to show that they're not just talking about climate but are willing to act. At the micro-scale, this is a logical association as we seek the shade of trees on a hot day, seek shelter under trees if surprised by a rainstorm (but some know that deep-rooted trees attract lightning), select tree-covered roads to cycle against the wind (if living in a bicycle culture) and prefer trees around our houses to buffer both the heat of summer (or the day) and the cold of winter (or the night). Yet, trees have mostly been discussed in the climate-change debate in terms of their carbon storage and the contributions they make to the global carbon balance. Their more direct effect on micro- and mesoclimate is largely absent from the debates, including that involving agriculture.

Recent discussions about 'climate-smart' landscapes are changing the paradigm that adaptation to climate change will have to primarily consist of a change of crops and crop cultivars. Active management of 'cool' and cooling trees may offer opportunities that farmers are generally aware of but that have not yet been part of climate-adaptation planning in the formal and public knowledge domains. Van Noordwijk et al (2014) posed the hypothesis, and reviewed available evidence for it, that the presence of trees increases the degree of buffering of climate variability from the perspective of an annual food crop and that retention and increases of trees in agricultural landscapes can be a relevant part of climate-change adaptation strategies.

Objectives

1. Explore the differences and synergy between the understanding of microclimatic effects of trees in local (LEK), modellers' and hydrologists (MEK) and policy makers' (PEK) ecological and climatic knowledge.
2. Contribute to the evaluation of 'climate smartness' of current landscapes and the options to modify the quantity, quality and spatial pattern of tree cover to obtain greater buffering.

Steps

- **LEK:** Landscape transect walk during the hottest part of the day, with focus on microclimatic differences between parts of the landscape, discussing any advantages or disadvantages associated with the tree-cover effect on climatic variables of local concern.
- **MEK1:** Instrument typical transects in the landscape with various levels of tree cover with data-loggers that record temperature, windspeed and/or humidity and relate the neighbourhood effects of trees to the annual cycle of seasons and daily variability within seasons.
- **MEK2:** Discuss with local climate experts how information on microclimatic effects of trees in the local context can be used in existing downscaling routines for climate models to explore both the effects of macroclimatic change that are beyond local control and the tree effects that can be managed and optimized locally.
- **PEK:** Discuss with development agencies, local NGOs and government agencies interested in adaptation to climate change and reduction of human vulnerability to climate extremes the options trees offer to buffer climatic variation and provide a suitable microclimate.
- **LEK * PEK * MEK interaction:** Describe discrepancies between the three knowledge systems in an effort to get PEK and MEK closer aligned to LEK, for greater chance of success of any action plan.

Example of application

1. In a case study in the Kali Konto landscape in East Java, Indonesia, farmers expressed a strong preference to have an intermediate level of shade trees in their coffee gardens. Measurements by students from a local university quantified the daily cycle of air temperature (measured inside the standard boxes of weather stations, thus avoiding direct radiation on the thermometer, and inside the soil at different depths), as summarized in Figure 9.1. This type of MEK confirmed the farmers' opinion and preferences and could be brought into discussions of climate-change vulnerability and adaptation.

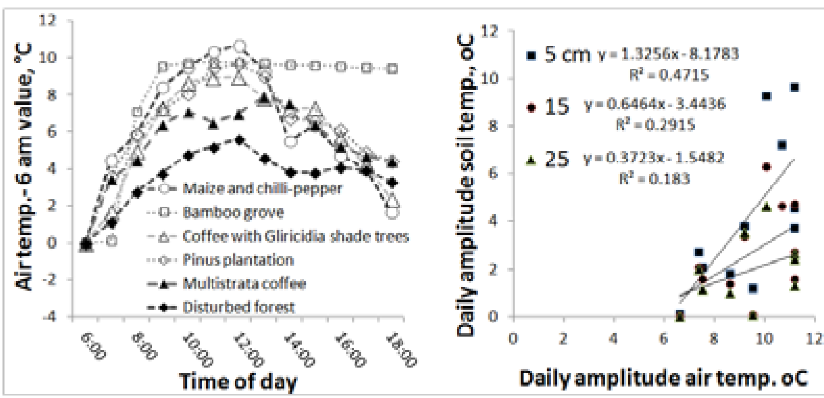

Figure 9.1. Daily temperature, air amplitude and soil temperature profiles for an East Java mountain location (Ngantang, Indonesia)

Note: A. Daily temperature profile for different land-cover types, including simple shade and multistrata coffee agroforestry systems, compared to (degraded) forest and open field agriculture (data were averaged for dry season and rainy season measurements); B. Relationship, across seasons and land-use systems, between daily amplitude of air temperature and temperature at 5, 15 or 25 cm depth of soil.

2 In the parkland agroforestry systems of West Africa, temperatures tend to be above the optimum for crop growth, at least during part of the growing season. Farmers have long since retained tree species with useful fruit in the landscape where they grow crops. The trees also provide welcome shade for domestic animals and people during the hottest part of the day. A network of microclimatic measurement with automatic data-loggers gives a quantitative idea of the effects (Figure 9.2). Temperature in the cropped zone under the tree canopy was found to be 2 ^{0}C cooler but in the next circle beyond the canopy it was still 1 ^{0}C cooler than in-between the trees. Further analysis will have to clarify to what extent this 'control' was influenced by the presence of trees in the wider landscape.

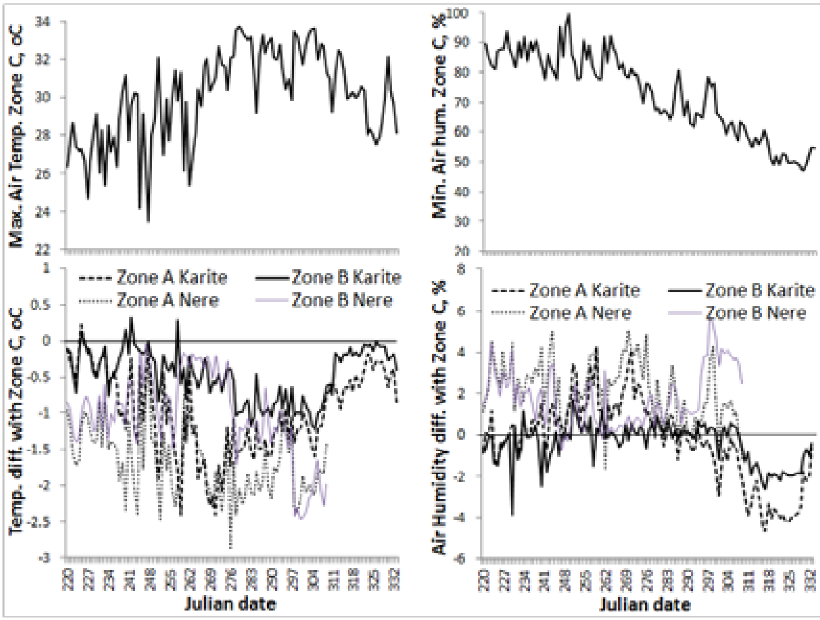

Figure 9.2. Effect of tree position

Note: Effect of position relative to a 'karité' (Vitellaria paradoxa) or 'néré' (Parkia biglobosa) tree on maximum daily temperature at crop level (left panels) or minimum air humidity (right panels) for zones A (under the tree) and B (edge of tree canopy) compared to zone C (in-between trees) in the parkland landscape of Sapone, Burkina Faso.

Data source: Bayala et al 2013

As in the first case study, the immediate effects of trees on maximum temperature were found to be of a magnitude that is relevant for buffering macroclimatic change.

Key references

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Van Noordwijk M, Bayala J, Hairiah K, Lusiana B, Muthuri C, Khasanah N, Mulia R. 2014. Agroforestry solutions for buffering climate variability and adapting to change. In: J Fuhrer, PJ Gregory, eds. *Climate change impact and adaptation in agricultural systems*. Wallingford, UK: CABI.

12 Tree and farming system resilience to climate change and market fluctuations (Treesilience)

Sonya Dewi, Endri Martini and Janudianto

Two of the biggest external sources of uncertainties in farmers' livelihoods are 1) impacts of changes in the mean and fluctuations of annual rainfall and shifts in seasons; and 2) market fluctuations of agricultural products. Tree and Farming System Resilience to Climate Change and Market Fluctuations (Treesilience)[1] uses focus-group discussions to encourage farmers to 1) identify the fluctuations that cause shocks to their livelihoods in a guided process thinking though the shocks-exposure-responses-capacity chain; 2) reveal the impacts of the shocks to their farming systems; 3) characterize the impacts of the shocks on dominant tree species; and 4) semi-quantitatively assess the price fluctuations of dominant tree products.

Introduction

Global warming does not only alter the mean annual rainfall but also the fluctuations and seasons, which have major impact on ecological processes; hazards such as floods, landslides, fire, erosion and sedimentation; and the productivity of trees and annual crops. Apart from low and fluctuating productivity per unit areas of land managed by farmers in developing countries and fluctuations owing to climate-related uncertainties, market uncertainties are huge in developing countries for tree and agricultural products. A basic pattern of boom followed by bust is repeated, with sudden increases in process owing to disasters (drought, civil war, frost) elsewhere.

These two issues have a huge influence on farmers' incomes but since conceptually they are not easily grasped, addressing the problems is not easy. Most farmers are unaware of the roots of the problems, what impacts the shocks can bring, how to respond, what capacities are needed and which are available.

A preventive, long-term strategy—rather than a survival strategy after a shock—is most cost effective. The majority of aid, however, addresses the latter, while strengthening capacity to increase resilience and the adaptive capacity of farmers in shock-prone, poor areas is crucial. Such aid is effective in helping in emergencies immediately after incidence of a big shock but accumulative impacts of smaller shocks become a latent problem that is left unaddressed. Further, the sustainability of such aid usually is not considered.

1 The term Treesilience was first coined by Mary Njenga, Jan de Leeuw, Miyuki Iiyama, Jeremias Mowo and, Ramni Jamnadass: http://worldagroforestry.org/sites/default/files/Need%20to%20Build%20Resilience%20ICRAF%20Seminar%2015%20November%202013.pdf

Awareness of shocks-exposure-responses-capacities are necessary as part of local knowledge to address uncertainties. Further, it is imperative for the farmers to have strengthened capacities in 1) identifying resilience of tree and farming systems to climate-related factors; 2) resilience of tree products to market fluctuations.

Objectives

- Identify fluctuations in 1) climate-related factors that have an impact on tree and agricultural products; 2) price and other factors that have an impact on the production system and marketing
- Reveal the impacts of shocks to farming systems
- Characterize the impacts of shocks on dominant tree species
- Semi-quantitatively assess price fluctuations of dominant tree products
- Guide the thinking process through the shocks-exposure-responses-capacities chain to identify gaps in capacities in order to increase farmers' resilience

Steps

Before the focus-group discussion, facilitators are recommended to:

- collect rainfall data for the past 10 years and identify any anomalies, for example, droughts, extreme humidity, high fluctuations;
- discuss with key informants in the village the climate- and market-related factors and others that create shocks to tree and agricultural products and to farmers' livelihoods;
- identify any unusual events stimulated by external factors that might have an impact on the majority of farmers in the village; and
- discuss with key informants the distinct characteristics of farmers in the village that possibly causes different levels of vulnerabilities, different responses to shocks etc and use this to decide ways to organize the focus-group discussions, for example, by gender or place of origin.

The focus-group discussion is divided into six steps. Steps 3 and 6 have been modified from Quan et al (2012).

1. List and rank, based on the perceived importance, the dominant farming systems and the most common tree species that are managed by farmers in the area.
2. Identify the years of shocks during the past 15 years, describe the causes and the impact, ranked from the most severe to the least. Choose the first three highest ranked and label those years with the type of shocks, for example, '2002: extremely wet year; 2007: long drought'. Choose the most recent year that is considered to be a normal year and use this as the base year.
3. For each of the three years of shocks, guide the causal thinking process of shocks-exposure-responses-capacity and the identification of necessary capacities to act in response to the shocks and the impacts of shocks, in real time and for the long term (Figure 12.1). Starting with identified shocks, invite participants to nominate the causes, followed by what they are exposed to as impact. List the immediate responses that they had during that year of shock, and the long-term responses to reduce exposure in the future (increased resilience), both those that have been done already or are perceived to be important to do. Lastly, list perceptions of the necessary actions. The findings can help government and aid agencies develop an adaptation program.

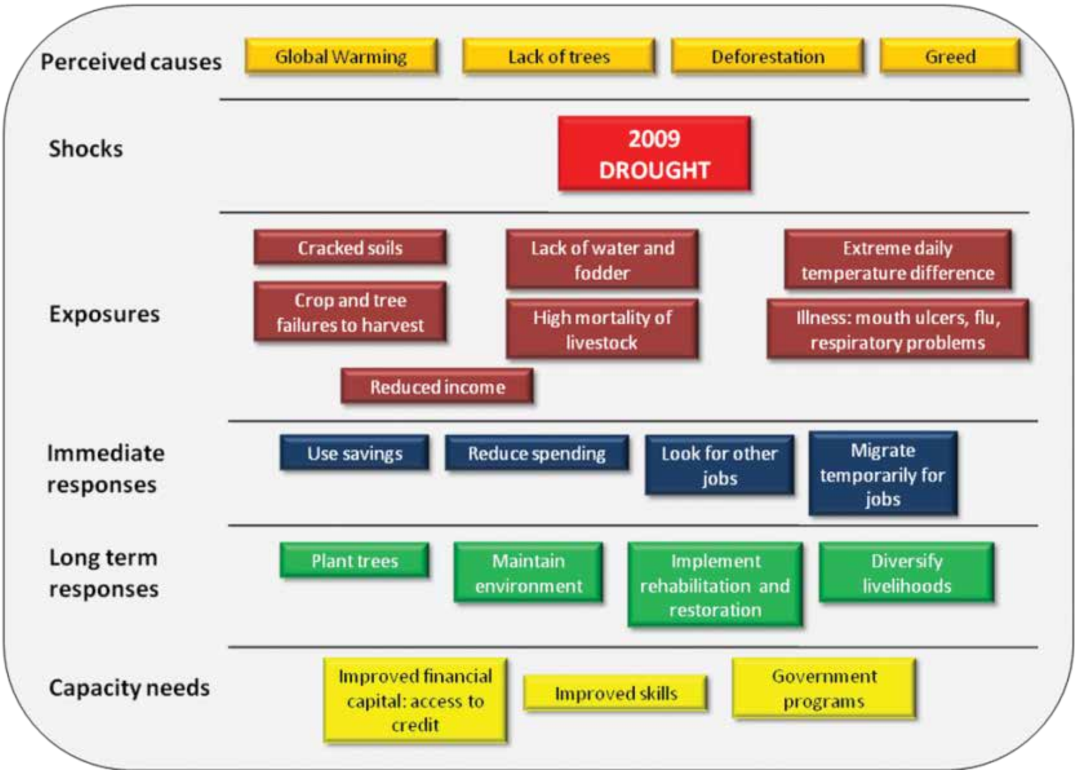

Figure 12.1. Example of a result from a guided thinking process for identifying shock-exposure-responses-capacities in one village in Sulawesi

4. Establish relative monthly rainfall calendar for the base year and the activities for each dominant farming and tree management system. Develop similar calendars for the three years of shocks (Table 12.1). Compare the activity calendars across the multiple years to identify farming systems and commodities affected by each shock and how farmers alter their labour allocation accordingly.

Table 12.1. Example of results from an activity calendar during the base year in a male group in a village in Sulawesi

Farming system	Commodity		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual productivity per ha
Annual crop	Maize	Planting			■								■		2–2.5 tons
		Managing	■			■	■	■						■	
		Harvesting		■					■						
	Ground nuts	Planting				■							■		1 ton
		Managing	■	■			■	■						■	
		Harvesting			■				■						
Agro-forestry	Fruit–maize–yam	Planting													30 trees (approximately 1 ton)
		Managing													
		Harvesting					■	■							
Mono-culture tree crop	Cashew	Planting													50 trees (approximately 0.3 ton)
		Managing										■	■	■	
		Harvesting													
	Teak	Planting													Harvest only in 20–30 years
		Managing													
		Harvesting													
Other activities															
Max. rainfall						■	■								
					■	■	■								
				■	■	■	■								
			■	■	■	■	■	■				■			
			■	■	■	■	■	■	■			■	■	■	
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	

5. Based on the list produced in Step 1, select 5–10 dominant tree species. Record the prices, price fluctuation within certain period of time, and within certain radius of areas, for example, the minimum and maximum price per unit during the past two years within the surrounding villages.
6. Copy the list of the 5–10 dominant tree species from Step 5. Discuss and fill for each tree species, the impact of droughts, extreme rainfall, pests and diseases, shift in seasons, fires, strong wind, lack of fertilizer, lack of management such as pruning, and other climate-related factors that frequently occur, and have an impact on trees and tree products in the area. The impacts are further differentiated between young trees and mature, producing trees, in terms of mortality rate, growth and productivity.

Table 12.2. Example from subset of results of Step 6 from Sulawesi

Tree species	Annual production per ha during base year	Extreme rainfall					Drought				
		Effects on young plants	Score	Effect on mature plants	Score	Effect on productivity (% from base year)	Effects on young plants	Score	Effect on mature plants	Score	Effect on productivity (% from base year)
Cashew	100 kg/tree	Good	3	Fruits are damaged	3	10	Do not grow well	3	Fruits are of bad quality	3	85
Clove	100–200 litres	Good	3	Flowers fall	3	60	Mortality is high	5	Leave fall	3	70
Cocoa	500 kg	Good	2	Fruits are damaged due to pests and diseases	5	60	Leaf disease, mortality is high	5	Leaf fall	5	50
Langsat	150 kg/tree	Good	1	Some do not produce fruit	3	50	Mortality is high	3	Do not produce fruit	3	60
Candle nut	100 kg/tree	Good	1	Flowers fall	2	70	Good	1	Low productivity	3	25
Durian	100/tree	Died		Productivity decrease		60	Leaves fall	1	Low productivity	1	75
Rambutan	4200 kg/tree	Good		Fruits fall	3	50			Flowers fall	3	75

Example of application

The full range application of the tool has just been successfully conducted in 10 clusters of 40 villages in South and Southeast Sulawesi provinces, Indonesia. Figure 12.2 shows one result, drawn from the information collected in steps 5 and 6. Resilience of tree species to fluctuations in climate-related factors are calculated from the effect of extreme rainfall (either low or high) on productivity. The less productivity of one particular tree species is affected by extreme weather, the more resilient that tree species is. This applies similarly for resilience to fluctuations in price. Four main types of tree species were identified. In Sulawesi, Type 1 tree species (low resilience to climate-related factors, high resilience to price fluctuations) are dominated by export commodities such as cloves and cocoa. The results can further be used to help identifying the intervention or support that can be provided in increasing the resilience of particular tree species to fluctuations in climate-related factors and/or in price and therefore increasing farmers' resilience to both types of fluctuations that are specific to tree species.

Application of steps 3 and 6 in Viet Nam, which were adapted for Treesilence, can be found in Quan et al (2012).

Figure 12.2. Example of findings derived from information collected in steps 5 and 6

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The talking toolkit: how smallholding farmers and local governments can together adapt to climate change

Elisabeth Simelton, Dam Viet Bac, Rodel Lasco and Robert Finlayson

Download: http://worldagroforestrycentre.org/regions/southeast_asia/vietnam/products/tools/talking-toolkit.

13 | Functional branch analysis (FBA): Tree architecture and allometric scaling

Meine van Noordwijk, Rachmat Mulia and Degi Harja

Functional Branch Analysis (FBA) is a tool to generate tree architecture and allometric scaling. It can be used as a non-destructive approach to develop allometric equations that are often used to estimate plot-level carbon stocks.

Introduction

Trees come in various shapes and sizes, grow at different rates, and interact with their neighbours during development. However, many of the properties of an individual tree can be predicted by the diameter of its stem. The relationship between this diameter and properties such as tree height, tree biomass, leaf area and harvestable timber are called 'scaling rules' or allometrics.

Empirical allometric scaling equations for tree biomass—Y on the basis of stem diameter D—are often used in forest inventories and for assessments of carbon and nutrient stocks in vegetation. The most common form is $Y = aD^b$. The equations are based on cutting selected trees and obtaining destructive measurements that can then be related to the stem diameter. However, a non-destructive approach is sometimes used. In addition to reducing cost and time, it is particularly desirable when shifting from homogenous plantation forestry to mixed forestry or to multispecies agroforestry systems.

Certain regularities in the development of tree form are captured in 'fractal branching' models. Such models can provide a transparent scheme for deriving tree-specific scaling rules on the basis of easily observable, non-destructive methods. Apart from total tree biomass, the models can provide rules for total leaf area and the relative allocation of current growth to leaves, branches, stem or litter, or the ratio of green to brown projection area that modulates tree-crop interactions in a savannah.

Objectives

The FBA protocol and program are designed to efficiently describe the architecture and key properties of a tree and to use the derived parameters to reconstruct trees with simple, repetitive ('fractal') rules. They are also used to derive scaling rules that relate stem and/or proximal root diameter to total biomass and to other properties. The allometric scaling relations derived with the FBA module can be directly used in the Water, Nutrient and Light Capture in Agroforestry Systems (WaNuLCAS) model of tree–soil–crop interactions

Steps

The model needs information about link diameter and length (that is, shoot or root segment) and about final structure (that is, leaves or fine roots). Not all, but at least 50 and preferably 100, successive links need to be measured to get a precise estimate of branch parameters. The elements of the model governing the branching pattern can be calculated using the FBA Help File. The independency of p (proportionality factor) and q (equity factor) to link diameter should be checked since independency is a requisite for the self-repetition rule.

Fractal branching models repeatedly apply the same equations to derive subsequent orders of the branching process ('self-repetition rule'). For practical applications, a rule is added for stopping when a certain minimum size is reached. The rules can refer to the diameter, length and/or orientation of the next order of branches. Figure 13.1 describes the elements of a functional branch analysis scheme, which can be applied to above- as well as belowground parts of trees. The combinations of the various parameters can be used to predict total size—weight, surface area, length, height, lateral extent—and the allometric scaling equations between these.

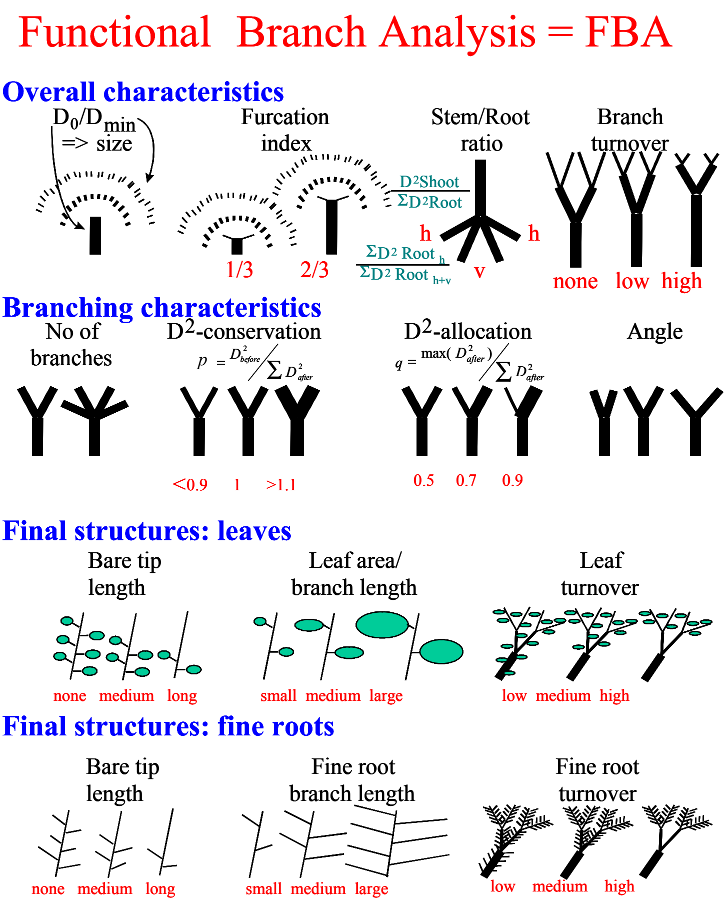


Figure 13.1. Elements of the functional branch analysis model for deriving allometric scaling equations between above- or belowground tree parts

Example of application

A comparison between model estimation and real observation of tree biomass aboveground and its components was carried out for four tropical tree species in the Philippines: *Shorea contorta*, *Vitex parviflora*, *Pterocarpus indicus* and *Artocarpus heterphyllus* (Figure 13.2). Total aboveground tree biomass, as calculated with the allometric equations from the FBA model, fit well with the biomass measurements obtained from destructive methods (Figure 13.2A). Slight differences were found for the tree components: wood (Figure 13.2B) and leaf biomass (Figure 13.2C) for all four tree species.

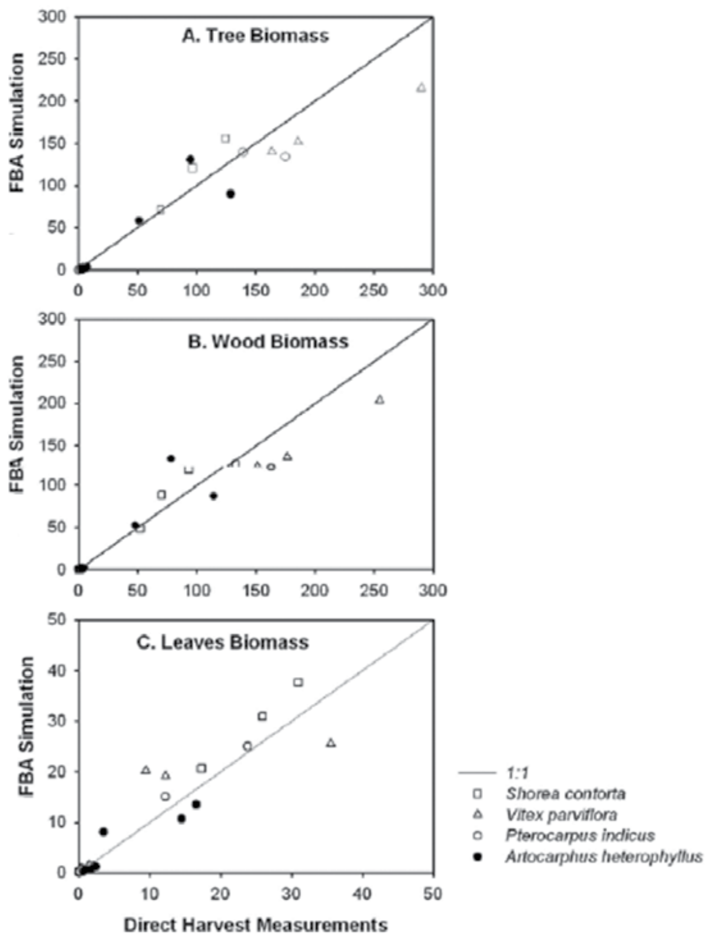


Figure 13.2. Comparison between FBA estimation and direct harvest biomass values of tree biomass

Note: (A) wood biomass; (B) and leaves biomass; (C) for four tropical tree species in the Philippines: *Shorea contorta*, *Vitsex parviflora*, *Pterocarpus indicus* and *Artocarpus heterphyllus*. Points along the 1:1 line means that values simulated by the FBA exactly match the actual measured values. Source: Martin 2008

FBA is also equipped with visualization tools that can be used if the angles between branches are also measured (figures 13. 3 and 13.4).

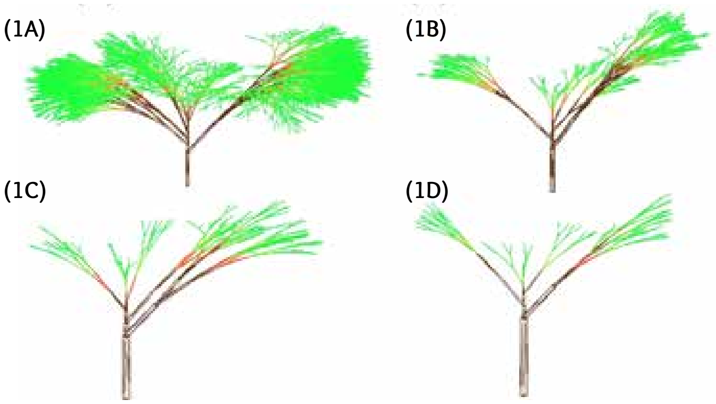


Figure 13.3. Example of tree shapes by varying just one parameter in the fractal branching routine

Note: In the example above, variation of the proportionality factor, p, for change of stem diameter at a branching point, has the values 0.8, 1.0, 1.2, and 1.4 respectively, in figures A–D. Trees with low p value are endowed with more branches and leaves; those with high p value have fewer branches and leaves owing to more significant branch tapering

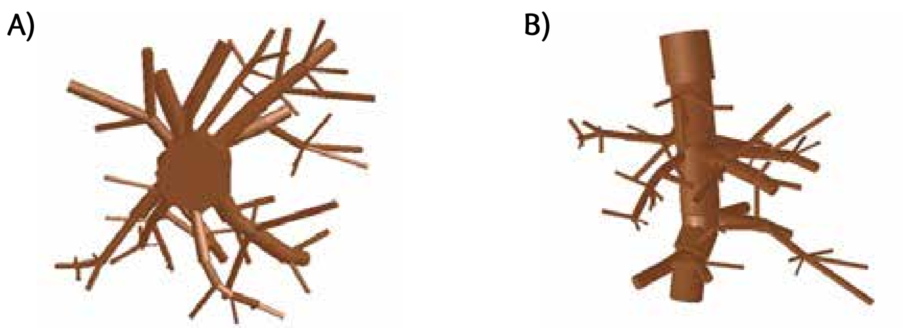


Figure 13.4. An example of tree root architecture produced by the FBA model as seen from the top (A) and from the side (B).

How to get the FBA model

The FBA model, embedded in an Excel worksheet, can be downloaded from the World Agroforestry Centre website: http://www.worldagroforestry.org/sea/Products/AFModels/WaNulCAS/downloadc.htm.

The model allows users to derive results for new parameter combinations and/or to seek new applications.

Key references

Van Noordwijk M, Mulia R. 2002. Functional branch analysis as tool for fractal scaling above- and belowground trees for their additive and non-additive properties. *Ecological Modelling* 149:41–51.

Smiley G, Kroschel J. 2008. Temporal change in carbon stocks of cocoa–gliricidia agroforests in Central Sulawesi, Indonesia. *Agroforestry Systems* 73:219–231.

14 | Simple light interception model (SLIM)

Degi Harja and Gregoire Vincent

The purpose of the Simple Light Interception Model (SLIM) is to compute canopy closure (an index of long-term light levels) at any height above the ground within a forest canopy. The forest canopy in SLIM is a 3D geometrical object modelled from measured tree properties. SLIM can be used for stand profile visualization.

Introduction

Measurement of canopy closure and its projection on the ground is not a straightforward process. While direct field measurement may require more time and effort, using a profile model allows exploration of canopy closure on any position in a stand of trees.

The amount of light received at any point in space is calculated by exploring a range of directions (combination of azimuth and zenith angles). Each time a beam originating from that point intercepts a crown envelop of a given porosity it reduces its contribution correspondingly. Total canopy openness at that point is obtained by summing up results for elementary beams. The weight of each beam is determined by the relative surface of the associated sky vault fraction.

From this information and the elevation grid, the software then computes the canopy openness either at regular grid points or at irregular spacing defined by the user or else for each tree of the stand.

Objectives

SLIM aims to produce three-dimensional visualizations of tree stands and to compute canopy closure (canopy porosity) at individual tree or plot level.

Steps

The steps to use the tool are:

1. Profile measurement of a stand (tree diameter, height and crown shape)
2. Crown porosity estimation of each individual tree or species' group
3. Data tabulation and model calibration

Example of application

SLIM can be used to visualize canopy stand at plot level. When compared to hemispherical photographs, SLIM was able to produce similar configuratiosn (Figure 14.1).

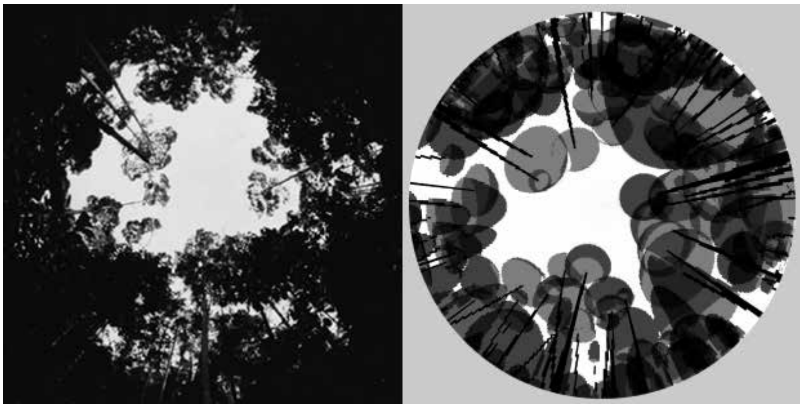


Figure 14.1. A set of hemispherical photographs was used to test SLIM predictions. Left picture was taken by camera and right picture was generated by SLIM for the same point in a real forest (left) and forest data input to SLIM (right)

Detailed stand measurement can also be visualized to better understand the configuration of the stand from various positions (figures 14.2, 14.3, 14.4, 14.5).

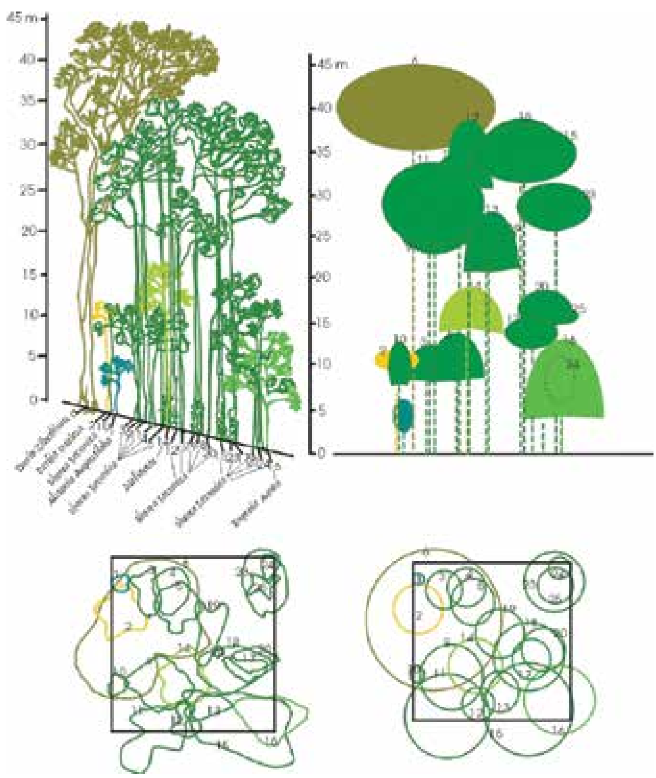


Figure 14.2. A simplified 3D description of the trees composing a stand

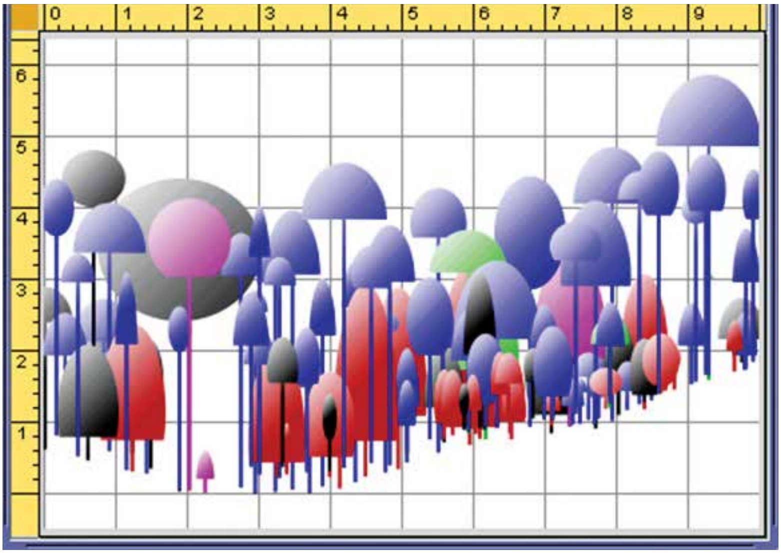
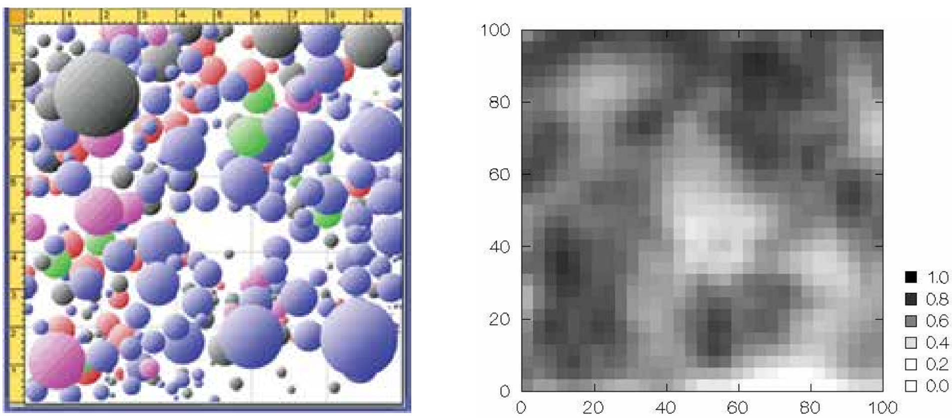


Figure 14.3. An elevation grid interpolates individual tree altitude



Aerial view of a one-hectare stand of Damar agroforest in Sumatra

Map of canopy closure of stand

Figure 14.4. Depictions of canopy openness in SLIM

A visualization of a damar (*Shorea javanica*) agroforest stand is shown in Figure 14.5. From this simplified 3D geometry of the stand, researchers can explore canopy openness in any position within a plot.

Figure 14.5. Three-dimensional view generated by SLIM of a 1 hectare stand of damar agroforest in Sumatra, Indonesia

■ Key references

Vincent G, Harja D. 2002. SLIM software: a simple light interception model for multi-species, multistrata forests. *Bois et Forets des Tropiques* 272(2):97–100.

Vincent G, Harja D. 2007. Exploring ecological significance of tree crown plasticity through three-dimensional modelling. *Annals of Botany* 101(8):1221–1231.

Website: http://worldagroforestry.org/regions/southeast_asia/resources/slim

15 Water, nutrient and light capture in agroforestry systems (WaNuLCAS): at the plot level

Ni'matul Khasanah, Betha Lusiana, Rachmat Mulia and Meine van Noordwijk

Water, Nutrient and Light Capture in Agroforestry Systems (WaNuLCAS) is a tree–crop–soil interactions model at plot level with daily time steps. The model simulates interactions between crops and trees in sharing and competing for aboveground resource, that is, light, and belowground resources, that is, nitrogen, phosphorous and water. The model can be used to assess the performance (production and profitability) of agroforestry systems under different management regimes with different spatial and temporal configurations.

Introduction

A focal point in assessing the performance of agroforestry systems is how trees and crops use resources of light, water and nutrients and at what point their interaction becomes competitive or complementary. Tree–crop–soil interactions occur both in space and time. Thus, in modelling agroforestry systems a balance should be maintained between dynamic processes and spatial patterns, between temporal and spatial aspects.

The WaNuLCAS model (van Noordwijk and Lusiana 1999, van Noordwijk et al 2004) was developed to deal with a wide range ofagroforestry systems: hedgerow intercropping on flat or sloping land; fallow–crop mosaics or isolated trees in parklands; with minimal parameter adjustments. The model was developed using the STELLA platform and based on physiology and above- and belowground architecture of trees and crops. Trees and crops interact and share resources (light, water and nutrients) (Figure 15.1) in four soil layers and four horizontal zones (Figure 15.2A). Their interactions are interpreted in different modules (Figure 15.2B).

Assessment of tree–crop interaction in different systems and practices such as agroforestry can be tested and analyzed directly in the field by establishing experiments but this requires a lot of time, labour and cost. The assessment is needed to manage trees and crops in order to maximize production and to minimize negative competition. WaNuLCAS can be used to overcome these limitations.

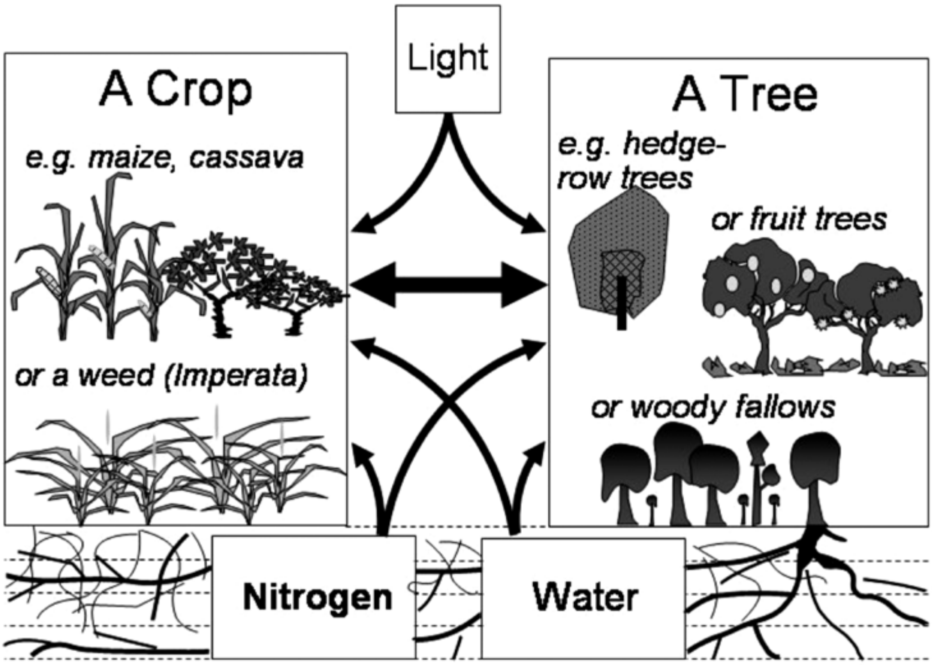


Figure 15.1. Components in WaNuLCAS

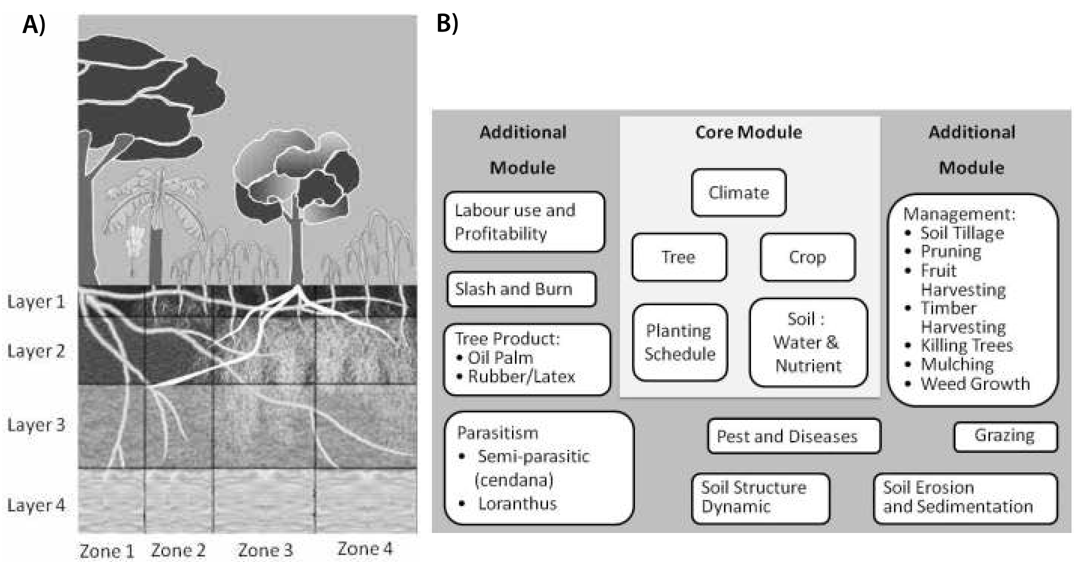


Figure 15.2. A) General layout of zones and soil layers in WaNuLCAS. B) Modules in WaNuLCAS that represent trees and crops sharing light, water and nutrient resources

Objectives

The objectives of WaNuLCAS are:

1. to explore new agroforestry practices before they are applied in the field;
2. to explore tree–crop interaction that cannot be done in the field.

Steps

Steps involved in WaNuLCAS application:

1. model parameterisation for calibration and validation test;
2. model calibration and validation;
3. model performance evaluation by comparing measured and simulated data; and
4. simulation of scenarios.

Example of application

In Indonesia, a decreasing forest area and a logging moratorium have seen timber production increasingly coming from smallholding systems. Inadaquate tree management in these systems has often led to low quality timber and hence low revenues for farmers. Researchers carried out ex-ante analysis with WaNuLCAS to explore the effect of different management practices on growth and production of intercropped teak and maize.

The study considered a three-treatment factorial: 1) initial teak density (1600 trees ha^{-1} (2.5 x 2.5 m), 1111 trees ha^{-1} (3 x 3 m) and 625 trees ha^{-1} (4 x 4 m)), 2) thinning (light (25%), moderate (50%) and heavy (75%) of tree density); and 3) pruning (40% and 60% of crown biomass). Researchers compared intercropping with both teak and maize monocultures to examine the trade-offs in different management options. An economic evaluation using profitability analysis was also carried out that took into account the cost of labour (for thinning and pruning) and its effect on additional timber revenue.

Result 1. Trade-off between trees and crops

Cumulative maize yield in the first years of teak growth was negatively correlated with tree density and 10–38% higher when tree density was reduced. All intercropping practices produced higher wood volume when compared with monoculture because the trees benefited from crop management and fertilization.

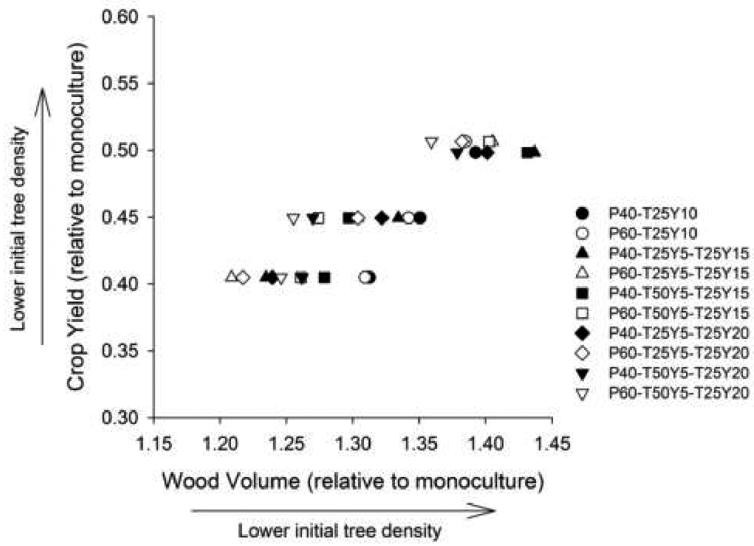


Figure 15.3. Trade-off analyses between tree and crop performance for various scenarios

Note: P: pruning, T: thinning, Y: Year; i.e P40-T25Y5-T25Y15: 40% crown pruned, thinning 25% at year 5 and 25% at year 15. Wood volume is the volume of remaining trees in field at year 30 (harvest time)

Result 2. Wood volume

Maximum wood volume (m^3 ha^{-1}) was provided by the system with initial tree density of 625 trees ha^{-1}: 25% of it was thinned at year 5 and another 25% at year 15; 40% of the crowns were pruned at years 4, 10 and 15. However, greater stem diameter per tree was provided by 50% of thinning at year 5 rather than 25% of thinning at year 5.

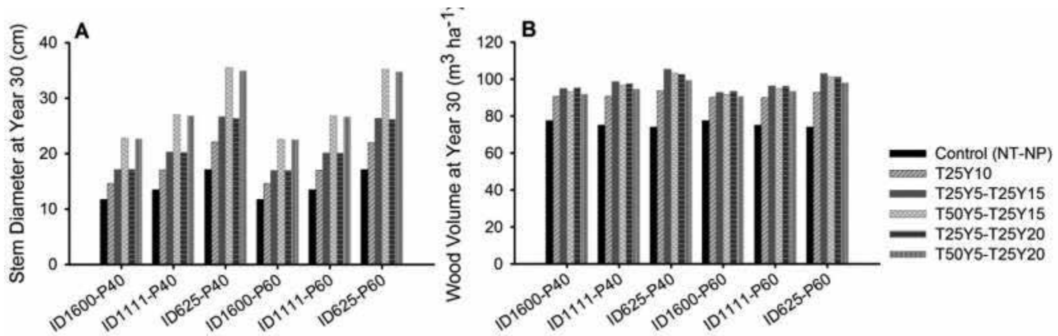


Figure 15.4. A) Wood volume, m3 ha^{-1}; and B) stem diameter, cm; presented at various treatments

Note: P: pruning, T: thinning, Y: Year, ID: initial tree density, i.e. T25Y5-T25Y15: thinning 25% at year 5 and 25% at year 15; ID1600-P40: initial density 1600 and 40% crown pruned. Wood volume is the volume of remaining trees in field at year 30 (harvest time)

Result 3. Economic analysis

The highest NPV and return to labour was provided by the system with initial tree density of 625 trees ha^{-1}: 50% of it was thinned at year 5 and another 25% at year 15; 40% of the crowns were pruned at years 4, 10 and 15.

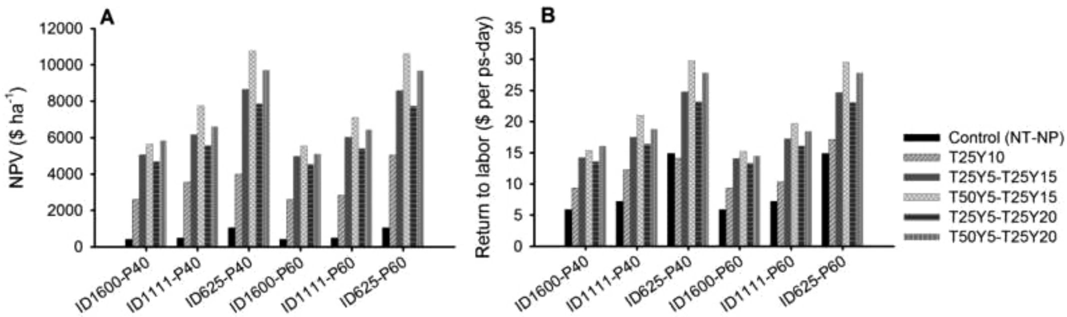


Figure 15.5. A) NPV; and B) return to labour; presented at various treatments

Note: P: pruning, T: thinning, Y: Year, ID: initial tree density, i.e. T25Y5-T25Y15: thinning 25% at year 5 and 25% at year 15; ID1600-P40: initial density 1600 and 40% crown pruned. Wood volume is the volume of remaining trees in field at year 30 (harvest time)

How to get WaNuLCAS?

WaNuLCAS can be downloaded from http://worldagroforestrycentre.org/regions/southeast_asia/resources/wanulcas.

Further reading

Khasanah N, Perdana A, Rahmanullah A, Manurung G, Roshetko J, van Noordwijk M, Lusiana B. 2013. *Trade-off analysis and economic valuation of intercropping teak (*Tectona grandis*)–maize under different silvicultural options in Gunung Kidul, West Java*. Paper presented at the Tropentag Conference 2013, 17–19 September 2013, Stuttgart-Hohenheim, Germany.

Van Noordwijk M, Lusiana B. 1999. WaNulCAS: a model of water, nutrient and light capture in agroforestry systems. *Agroforestry Systems* 43:217–242.

Van Noordwijk M, Lusiana B, Khasanah N, Mulia R. 2011. *WaNuLCAS version 4.0: Background on a model of water nutrient and light capture in agroforestry systems*. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

16 | Spatially explicit individual-based forest simulator (SExI-FS): for management of agroforests

Degi Harja and Gregoire Vincent

The Spatially Explicit Individual-based Forest Simulator (SExI-FS) simulates tree-to-tree interactions in multispecies agroforests. The model uses an object-oriented approach whereby each tree is individually modelled. Individual trees interact by modifying their neighbours' environment and competing for two major aboveground resources: space and light. An optimum scale for 3D representation of the agroforest plot is 1 hectare.

Introduction

The structural complexity of traditional agroforestry systems defies classical forestry approaches in optimizing management practices. To cope with this complexity, farmers have adopted tree-by-tree management, which is closer to gardening than to the usual tropical forestry or estate crop management model. Care and regular tending of individual trees can involve transplanting seedlings, selective cleaning and felling, and adjusting harvesting intensity.

The way that farmers approach these traditional systems appears to be in line with two basic tenets of biology: first, all individuals are different with their own particular behaviour and physiology resulting from a unique combination of genetic and environmental influences and, second, interactions are inherently local. Based on these premises, SExI-FS was developed to explore different management scenarios. SExI-FS provides insights about the critical processes and parameters of a system's dynamics in a complex agroforest. It also allows for the exploration of prospective management scenarios and helps with assessing the relevance of current management techniques. More direct applications of SExI-FS include using the model to compare the financial returns from alternative scenarios, such as the financial returns of rotational agroforests against those of permanent agroforests. The schematic diagram of SExI-FS is shown in Figure 16.2.

Objectives

The major objective of the model is to achieve a coherent and dynamic representation of a complex agroforestry system. This includes predicting the dynamic growth of a mixed-tree stand, its potential productivity and aspects of tree-growth competition. Graphical user interfaces help the user to explore various scenarios and plot designs and to predict the performance and productivity of each species' component (Figure 16.1).

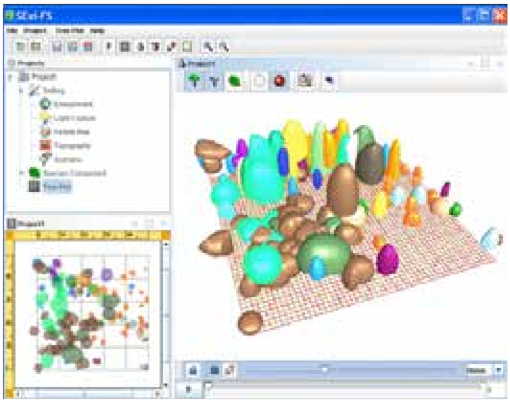


Figure 16.1. SExI-FS includes 3D visualization interfaces for a better view of a simulated scenario

Steps

SExI-FS (http://worldagroforestrycentre.org/regions/southeast_asia/resources/SExI-FS) runs on any platform that supports Java Virtual Machine (http://java.sun.com).

Species-specific parameterizations required for the model are: growth rate function, allometric relationship diameter at breast height (DBH) with height, allometric relationship of DBH with crown width and species' sensitivity to light. Ecological parameters include topography, soil-fertility map and parameters related to how light is captured by trees.

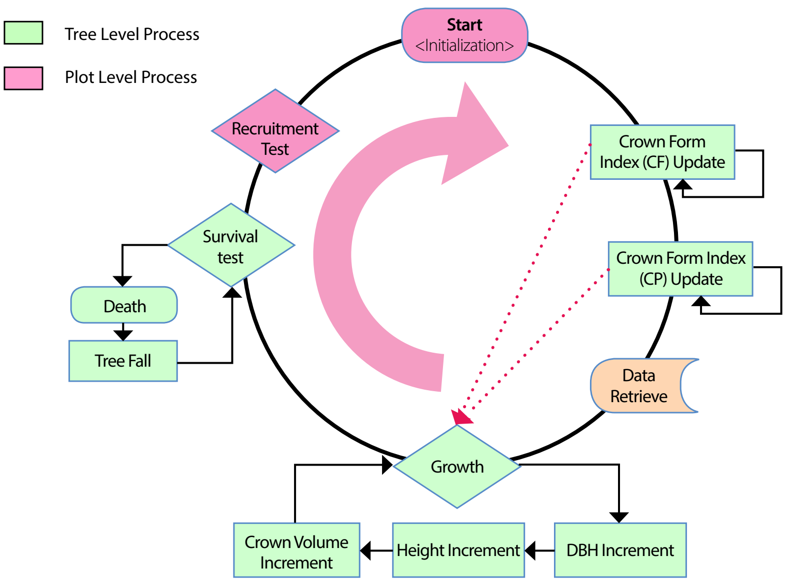


Figure 16.2. Main loop in the SExI-FS computer model. The loop runs on a yearly basis and starts with an initialization. Next, the tree-crown attributes, Crown Form Index (CF) and Crown Position Index (CP) are updated. Tree growth is then computed (diameter, height, and crown volume increment). At each step and for each tree, a survival test is undertaken. Finally at the stand level, a recruitment test is conducted

Case study: SExI-FS with RaLMA

SExI-FS has been used to explore the performance of various agroforestry scenarios (Harja et al 2005) and the potential role of trees in reducing the risk of landslides.

In the district of Bogor, West Java province, Indonesia, urban development had led to a significant reduction in tree cover and the conversion of agroforests to other land uses. This had triggered large landslides that caused the loss of lives as well as major economic losses and damage to infrastructure. In February 2007, about 300 households were considered to be at risk from landslides and were advised by the government to evacuate.

A bioengineering strategy for reducing land movement and preventing accidents requires information on the location of trees that have a confirmed capacity to anchor soil. The rate of root development will determine the options for stabilization. The study of areas at risk in Bogor could contribute to the development of prevention strategies, particularly in the context of climate-change adaptation, when the incidence of periods of extreme rainfall is expected to increase and the need for landslide prevention will become more pronounced.

The use of SExI-FS was aimed at exploring differences between tree species in terms of root development (in both the topsoil and in deeper layers of soil) that contribute to differences in soil binding and anchoring that can reduce downslope movement (at the level of the tree-root system).

Landslide risk needs to be evaluated at the hill-slope rather than at the tree level. For this reason, we recorded all trees in a 50 x 50 m plot and measured the indices of root anchoring (IRA) and binding (IRB) of tree species under local conditions (Figure 16.3). The SExI-FS model was able to simulate the role that trees can play to reduce the risk of landslide by quantifying the IRA and IRB within a tree plot (Figure 16.4).

The result of simulations of plot-management sensitivity scenarios showed that it was better to maintain plot density at an optimum size. This is because increasing plot density above the optimum size does not significantly increase plot root binding (although plot root anchoring does increase).

The selection of species based on IRB and IRA (van Noordwijk et al 2006) values is an acceptable approach to reducing landslide risk. Other considerations are farmers' preferences and the costs and benefits of various agroforestry scenarios.

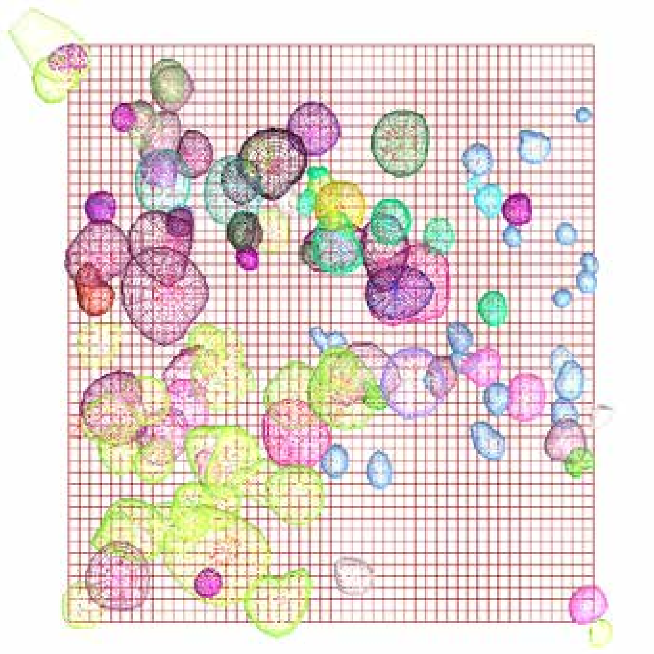


Figure 16.3. A schematic aerial view of all trees in a 50 x 50 m plot

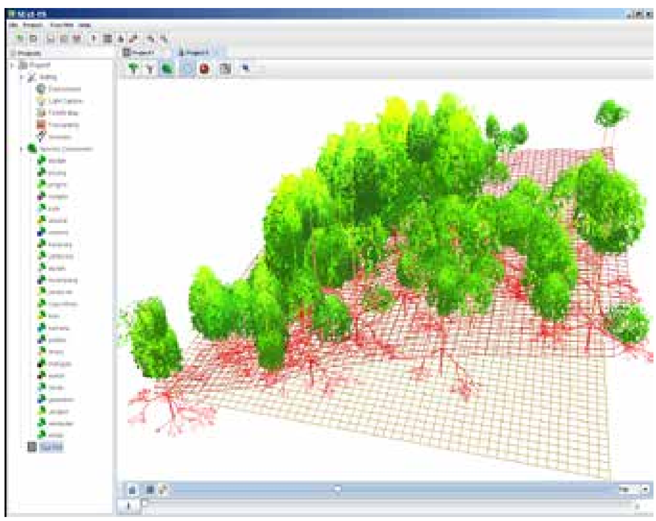


Figure 16.4. Representation of canopy and root systems in the 50 x 50 m plot using SExI-FS, showing how the trees' anchoring and binding function prevented landslides

■ Key reference

Harja D, Vincent G. 2008. *Spatially Explicit Individual-based Forest Simulator: user guide and software.* Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program; Marseille, France: Institut de Recherche pour le Développement.

17 Adopt and learn: modelling how decisions are made and the flow of information

Meine van Noordwijk, Betha Lusiana and Desi A. Suyamto

Adopt and Learn is a simple model of an 'adoption' process. It explores how farmers learn of new technology or information and eventually make a decision to adopt or not. The model is useful for understanding factors influencing the success or failure of a technology-dissemination project, including the role of extension agents. The model works at community scale with a diversity of agents and their multiple learning styles.

Introduction

Adoption of 'new' or 'better' land-use practices, compared to the existing ones, depends on many factors. These factors can be broken down into two main factors: internal and external factors. How and by whom (agent of change) the technology was disseminated are external factors that influence farmers' perceptions and trust of the technology. Internal factors relate to the style of learning of the farmers themselves, whether they tend to be 1) conservative, that is, resisting change and preferring 'old' technology'; or 2) experimental, that is, always trying new and quickly discarding 'old' technology. Usually, farmers' learning styles will be in-between the two extremes: they will be willing to experiment but need experience or to see how others experience the new technology before they make a decision to adopt or not.

Adopt and Learn was developed to simulate such a situation. The model was initially developed as a module to be incorporated into dynamic models of land-use change. The model assumes that farmers make decisions among the options available on the basis of their perceptions of the relative merits of these options for local conditions. Farmers also take into account the specific constraints and availability of resources on their farms. The perceptions of the relative merits can change with time on the basis of experience obtained through external contacts with extension agents.

Objectives

Adopt and Learn provides an analytical framework for understanding factors influencing the success or failure of a technology dissemination project, including the role of extension agents.

Steps

Adopt and Learn was developed in the STELLA programming language and can be incorporated as a module in more comprehensive models. Specifically, the model explores eight aspects.

1. The expected performance of the 'new' technology with existing practices, taking into account local resource options and constraints.

2. The variability of performance of the 'new' technology' in the various local settings (different farmers with different learning styles; different plots with different inherent soil fertility; and different financial capital). The variability measures the degree of risk involved in the 'new' technology project to fail in meeting its minimum targets.
3. The actual year-to-year performance of the 'new' technology' in the various local settings.
4. The divergence between farmers' perceptions of the 'new technology' with distribution of actual performance carried out by all farmers.
5. The way actual experience with the performance of land-use options (managed using 'new' technology) in the local environment can lead to changes in perception ('learning style').
6. The way decisions are made, in particular how relative preference is given to the option that is perceived to be the best ('prioritization').
7. The fraction in the total population that follows an 'experimental' strategy in its learning style (with the remainder assigned the 'conservative' strategy).
8. The impact of 'adaptation' or local fine-tuning of the performance of the various options, indicated by increase in average performance mean and/or increase in stability.

Adopt and Learn simulates the interactions between the above factors and allows users to focus on five important questions.

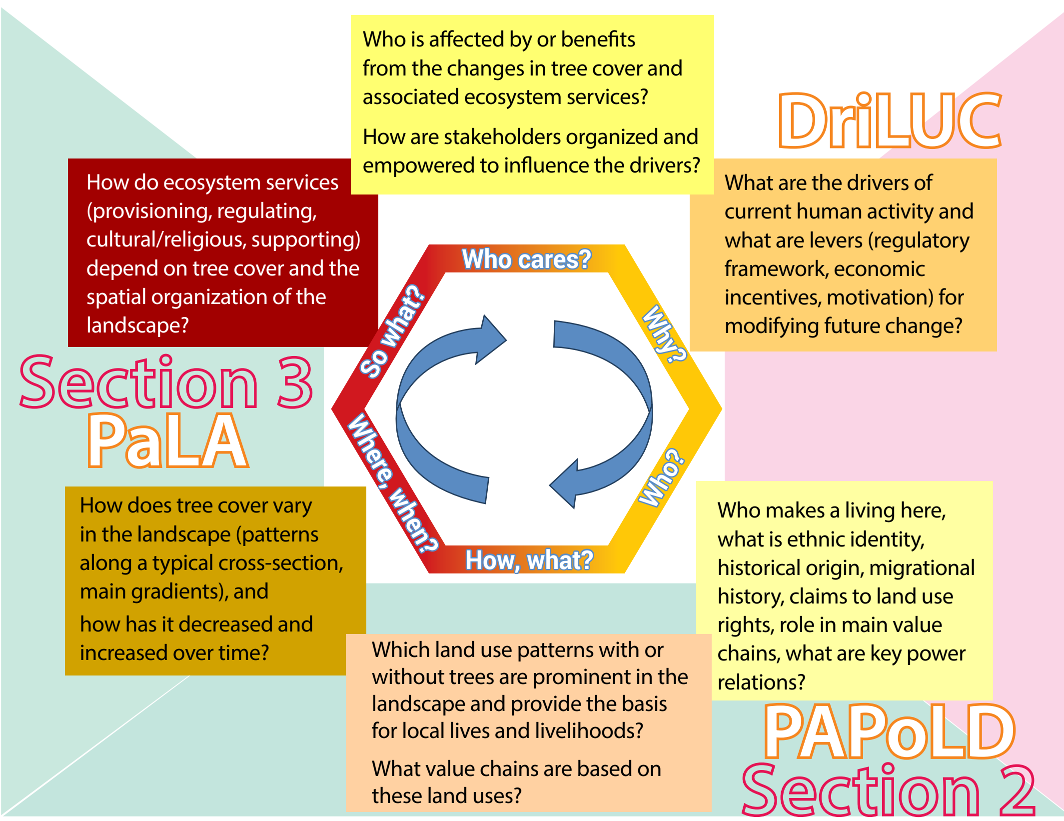
1. How long will it take before 'superior' land-use options will become the preferred choice for the two strata of farmers (conservative and experimental)?
2. What impact will the 'adopt and learn' process have on the actual benefits that the farmers gained in both groups, relative to that prior to use of 'new technology'?
3. Does the magnitude of fraction of experimenters modify the time to adoption and the actual benefits achieved by the conservatives?
4. Under what conditions can the exposure of farmers to the 'perceptions' of extension agents help in the adoption process?
5. How long can we expect the transient state with mosaics of different land-use types to last and contribute to agrobiodiversity?

Example of application

Adopt and learn concept is at the heart of the scheme used in Figure 8.2 to explore gender differentiation of land-use decisions (Villamor et al 2014).

SECTION 03

Landscape: ecosystem services, tradeoffs



18 | Analysis of land-use and -cover trajectory (ALUCT)

Sonya Dewi and Andree Ekadinata

Analysis of land-use and -cover trajectory (ALUCT) provides basic spatial information to support other tools in appraising watershed functions, agrobiodiversity conservation and carbon stocks, and building land-use and land-use-change scenarios.

Introduction

Maps representing the landscape have to represent land cover (what is there), land use (what it's used for) or some combination of the two. Land-cover maps can be derived from the multi-spectral reflectance of the Earth's surface recorded from satellite or airborne sensors, supported by ground information of spatial patterns and processes (Thomas et al 2004). A land-use interpretation will generally require further information sources beyond current cover. Different interpreters may come up with different maps from the same satellite imageries because the potential legend categories of land-use/-cover maps are infinite. Figure 18.1 shows multiple concepts of forest leading to differed deforestation rates.

ALUCT plays an important role in several of the tools described in this book, including RaCSA, RHA, RABA, FALLOW, RaTA and DriLUC.

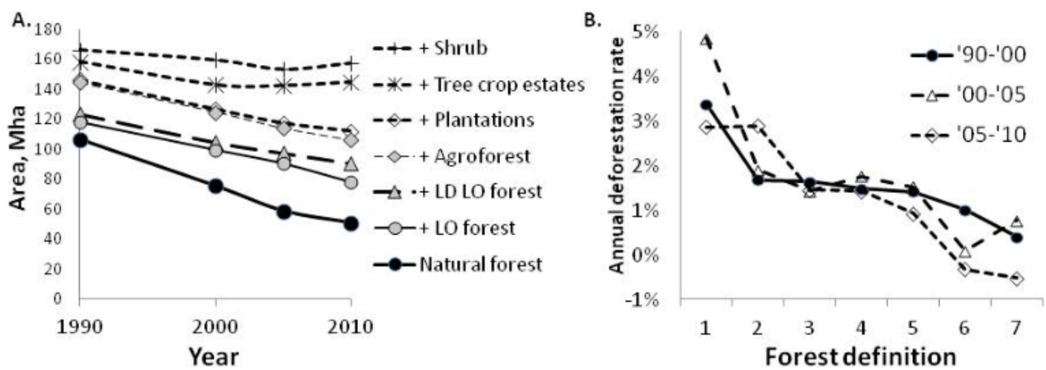


Figure 18.1. Dependence of Indonesia's 'deforestation rate' on the operational definition of forest
Source: van Noordwijk et al 2013

Objectives

The ALUCT procedure was designed to form a systematic approach to spatial analysis, where the intended users of information in interdisciplinary contexts and with science-policy interfaces in mind, interact with the distinctions that can technically be made.

Steps

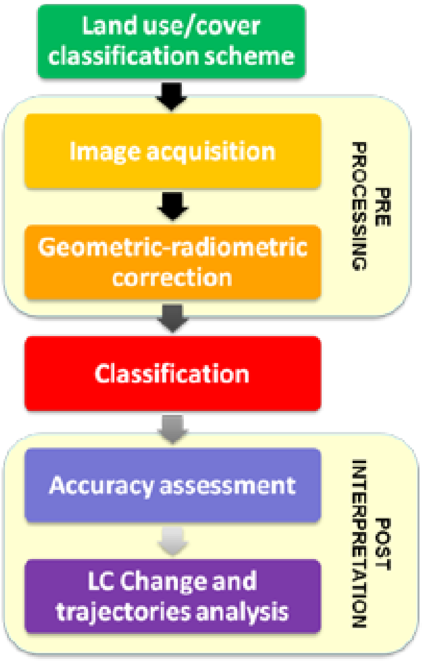


Figure 18.2. The ALUCT workflow

1. *Clarification of the questions*, leading to the level of detail needed in the legend of land-cover types and the resolution of images needed to do so
2. *Image acquisition* and *pre-processing*: selecting the resolution, spectral properties and source of the images, selecting an image date relevant to the study and of sufficient quality (low cloud cover)
3. *Image classification* based on field-tested sample points and/or pre-established spatial patterns
4. *Post-interpretation analysis* focussed on the research questions of interest, usually linking 'land use' and system lifecycles to the land-cover types that can be recognized

1. Clarifying the questions: designing legend categories

In deciding on legend categories, the researchers have to consider: 1) the information content and its limitation for specific image sources ; 2) the on-the-ground reality of agents and drivers of land-use systems and land-use changes; 3) the description of each category of land use and land cover; 4) and the application of the produced maps.

Often, remote-sensing specialists tend to focus on what is technically achievable without much consideration of what should be recognized and so classification efforts result in empirical representation only, unguided by any theoretical basis. To avoid this, legend categories should be designed such that they can reveal differences among categories in providing environmental services, as results of varying drivers, and as perceived by land managers, especially farmers and local people, as an integral part of their livelihoods, that is, local use value. Figure 18.3 provides an example of legend categories in the context of measuring GHG emissions of oil palm plantations in Indonesia. For this purpose, the researchers specified the oil palm categories: old, mature and young.

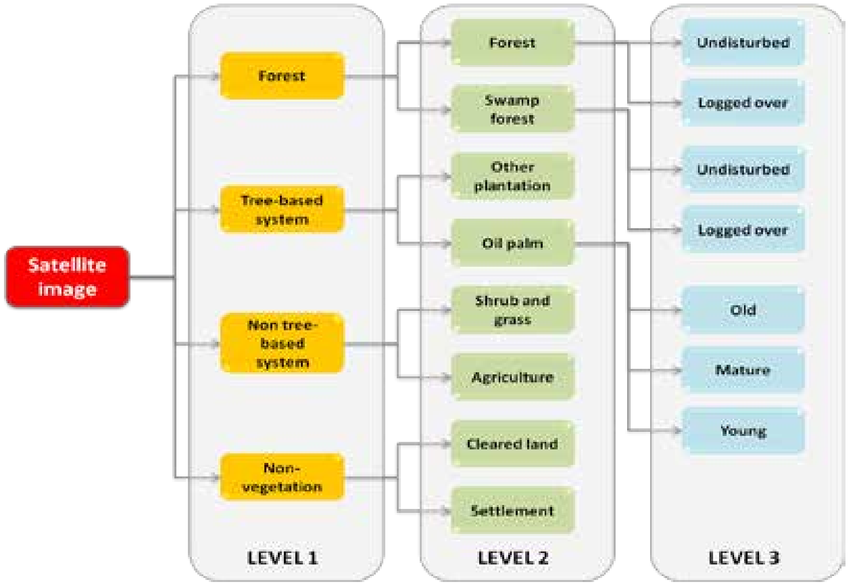


Figure 18.3. Land-use-system legend categories in a hierarchical classification structure

2. Image acquisition and pre-processing

Time coverage, spatial resolution, and *amount of cloud cover* are three main criteria used in selecting the best satellite images for any study. Middle-resolution satellite images, such as Landsat (30 m resolution) and SPOT (20 m resolution) are usually used for basic studies (Figure 18.4), with high resolution imagery, such as IKONOS and RapidEye (< 1 m) for specific areas. Coarser resolution but frequent data acquisition, such as SPOT Vegetation, NOAA-AVHRR and MODIS, are commonly used for regional and global monitoring of changes. In the tropics with high incidence of cloud cover, sometimes a combination of optical and radar imageries is necessary.

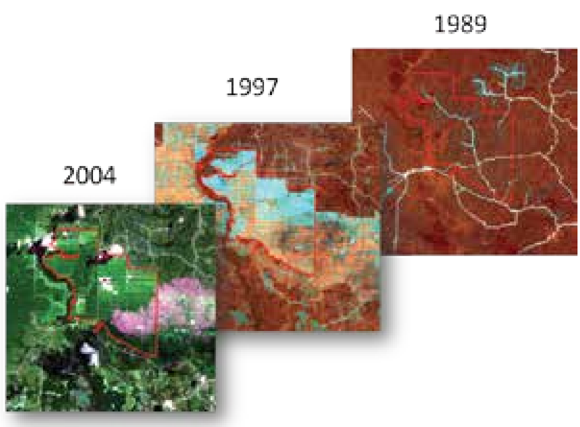


Figure 18.4. Time-series Landsat image

3. Image classification

There are several options for image classification, ranging from visual interpretation, which relies on manual delineation and ground familiarity of the operator, through to unsupervised classification, which uses statistical analysis to differentiate spectral reflectance based on digital numbers only. Between the two extreme approaches there are gradients and hybrid approaches, such as supervised classification and a mix of object-based and unsupervised classification. There is no one best approach within the huge variation involved with mapping, resolution of imageries and objectives of the mapping. However, three main principles, regardless of the approaches, should be observed: 1) given the same imageries and legend categories, the resulting maps should not be too different; 2) using ground information is a 'must' in assessing the accuracy of the maps; 3) for a map to be useful the accuracy has to be high enough; as a rule of thumb, 80% accuracy should be achieved.

4. Post-interpretation analysis

Once a series of maps is produced from multi-year image acquisitions, several analyses can be conducted in conjunction with other data layers, such as land-use plans and road network:

1. temporal changes of areas of each land-use and land-cover class, for example, primary forest cover declines from x hectares in 1990 to y in 2000;
2. trajectories of changes of each particular area in the landscape and areas of each trajectory, for example, x hectares of primary forests in 1990 converted into rubber plantations in 2005 and settlements in 2010;
3. areas of each land-use and land-cover class within a particular zone, for example, x hectares of oil-palm in the protected forest zone in 1990;
4. trajectories of changes within particular zones, for example, x hectares of secondary forests converted to oil-palm plantations in the protected forest zone and y hectares in the production forest zone between 1990 and 2000.

Example of ALUCT in a study of oil-palm plantations in Indonesia

To analyze the plantation history and associated 'carbon debt' of plantation establishment, ALUCT was deployed in two pilot areas in Indonesia using time-series, land-cover maps from satellite images. In the context of understanding carbon debt, data was required to cover a sufficient time period of before and after plantation establishment. To get a complete picture of the area, it was also necessary to quantify the changes in the plantation's surrounding area. Therefore, three main outputs from the analysis were:

1. time-series, land-cover maps covering the period before and after oil-palm establishment;
2. land-cover-change quantification of the estate area and its surroundings; and
3. land-cover trajectories for the period of analysis.

Legend categories were designed in a hierarchy and structured within three levels, from general to finer classes (Figure 18.3). 'Forest' as a class was separated further into 'dry' and 'swamp' forest of different density, that is, 'undisturbed', 'logged-over high density' and 'logged-over low density'. This separation is important as we know that by lumping together varying densities of forests the uncertainty of magnitude of carbon stock is huge, which has consequences for the conclusion of the study if not managed properly. The hierarchy itself was designed such that the classification process was most efficient. Time-series, orthorectified, Landsat images covering the periods 1989, 1997, 2001 and 2004 were used to produce the land-cover maps (Figure 18.4).

The object-based hierarchical classification approach (Ekadinata and Vincent 2011) was used at the stage of image classification. In this approach, image classification began with a series of image segmentations. The result is called multiresolution image segments, which serve as a basis for the hierarchical classification system (Figure 18.5).

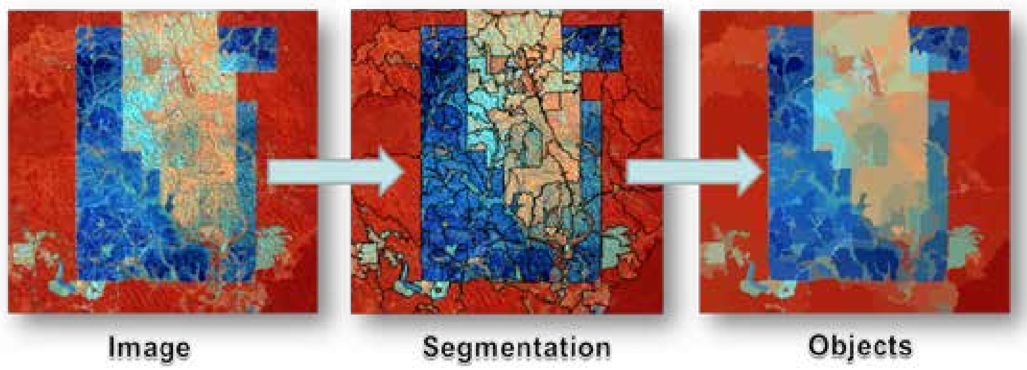


Figure 18.5. Multiresolution image segments

Following the segmentation process, image classification was conducted using the hierarchical structure developed in Step 1. The hierarchy is divided into three levels. At each level, land-cover types were interpreted using spectral and spatial rules. Level 1 consisted of general classes, such as 'forest', 'tree-based systems', 'non-tree-based systems' and 'non-vegetation'. These classes could be easily distinguished using visual inspections and a simple vegetation index. The result of Level 1 was further classified in Level 2, using field reference data. A 'nearest neighborhood' algorithm was used to distinguished a total of nine land-cover types: 'forest', 'swamp forest', 'oil palm', 'shrub', 'grass', 'agriculture', 'cleared land' and 'settlement'. Some of the classes in Level 2 were further classified in more detail in Level 3. At this level, spectral value was not the only parameter used. Spatial characteristics, such as distance to settlement, proximity to visible logging roads, forest concession status, and plantation maps could be used as rules in the classification. At the end of the classification process, an accuracy assessment was conducted by comparing the resulting maps of most recent imagery with the data collected in the field.

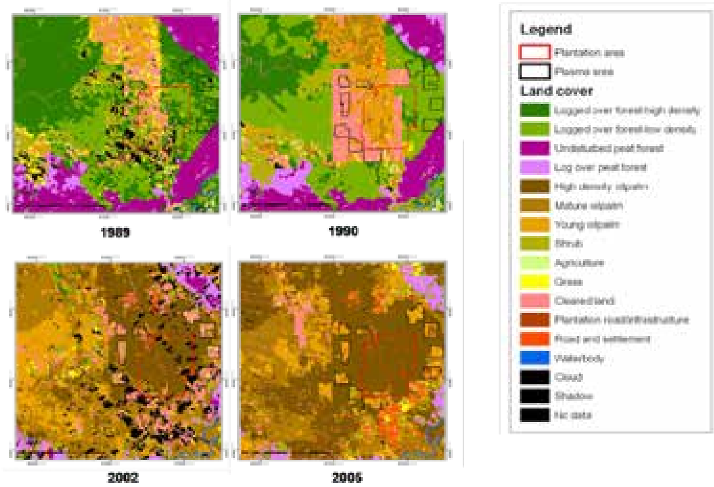


Figure 18.6. Time-series, land-cover map

The last step in ALUCT is the land-cover-change analysis itself. Two forms of analysis were conducted for each study site: area-based-change and trajectories. These were conducted for three zones: 1) plantation areas; 2) plasma[1] areas (if any); and 3) all areas outside plantation and plasma. The result provided an indication of the overall trend of land-cover changes in an area and its surrounding.

Further information was needed on the location and trajectories of changes, so a trajectories analysis formed the next step. Trajectories of changes are the summaries of a change sequence over all time periods, observed at pixel level (Figure 18.7 and 8). In the context of understanding the carbon budget for oil-palm plantations, types of trajectories were designed to be able to capture changes in carbon stock caused by land-cover changes.

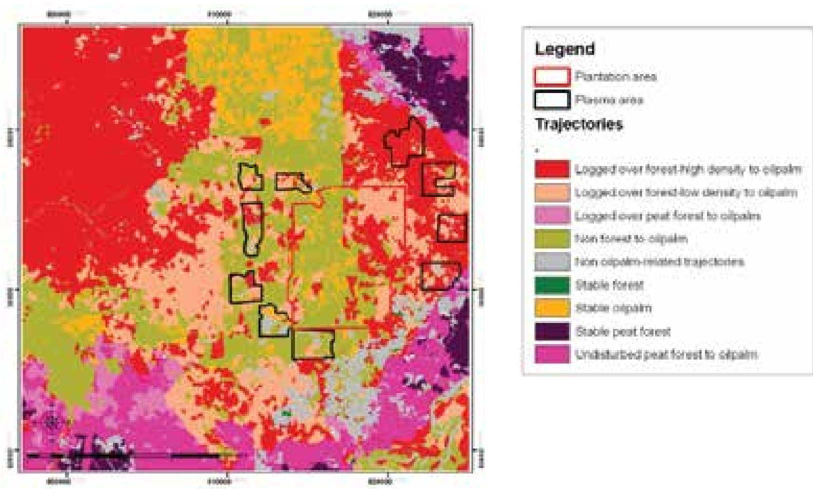


Figure 18.7. Trajectories map

[1] 'Plasma' in this context describes a scheme whereby a large plantation forms a 'nucleus' around which there are smallholding plantations, the 'plasma'.

The trajectories map showed all oil-palm-related sequences of changes, the locations and spatial patterns in the study area. Trajectories analysis clearly showed that more than 40% of conversions inside plantation areas started from logged-over forest. Nearly half were in the high-density, logged-over forest areas.

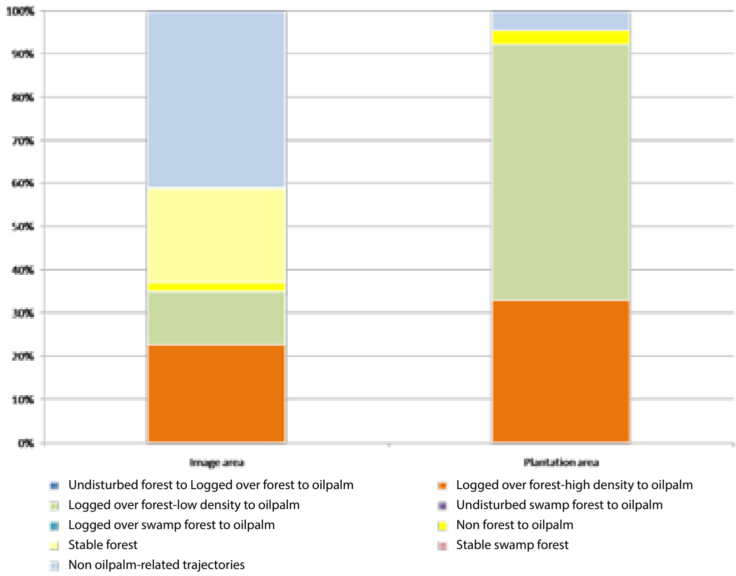


Figure 18.8. Summary of trajectories analysis

Often, for quick and qualitative references, publicly available maps, such as those provided by Google Earth, are very useful (Figure 18.9). As many of the scenes are available in graphic format of high resolution, interpreters also use these as additional data to assist interpretation, especially if GPS points of data in the field are scarce.

Figure 18.9. Google Earth: a public-domain perspective on how oil-palm plantations are spatially and chronologically linked to logging concessions in Kalimantan, Indonesia

■ Key references

Dewi S, Khasanah N, Rahayu S, Ekadinata A, van Noordwijk M. 2009. *Carbon footprint of Indonesian palm oil production: a pilot study*. Bogor, Indonesia:World Agroforestry Centre (ICRAF) Southeast Asia Regional Program. http://worldagroforestry.org/sea/publications?do=view_pub_detail&pub_no=LE0153-09.

Hairiah K, Dewi S, Agus F, Velarde SJ, Ekadinata A, Rahayu S, van Noordwijk M. 2011. *Measuring carbon stocks across land use systems: a manual*. Bogor, Indonesia:World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

Useful websites

http://www.google.com/earth/index.html
http://rst.gsfc.nasa.gov/Front/overview.html (online remote-sensing tutorials)

19 Trade-off matrix between private and public benefits of land-use systems **(ASB Matrix)**

Thomas P. Tomich and Meine van Noordwijk

The Trade-off Matrix between Private and Public Benefits of Land-use systems (ASB Matrix) provides in one table an overview of key characteristics of land-use systems that coexist in a landscape and form alternatives to each other. The rows form the land-use systems and the columns hold key characteristics that are of local, national and/or global concern, such as employment, profitability, sustainability, biodiversity and carbon stock.

Introduction

Policy-makers need accurate, objective information on which to base their inevitably controversial decisions. The ASB Matrix can help them consider the difficult choices they must make. In the ASB Matrix, natural forest and the land-use systems that replace it are scored against different criteria reflecting the objectives of different interest groups. To enable results to be compared across locations, the systems specific to each are grouped according to broad categories, ranging from agroforests to grasslands and pastures (Tomich et al 1998).

The ASB Matrix is a key example of a 'boundary object' (Clark et al 2011). It is the result of 'boundary' work at the interface between science, policy and local concerns and reflects the effort to jointly define knowledge products and a legitimate pathway to derive them.

Objectives

The objective of the ASB Matrix is to summarize and synthesize information about the multiple functions that land-use systems fulfil in a landscape, combining economic and environmental perspectives, and to allow quantitiative trade-offs between the functions to be explored (with true win-win solutions as a rare exception). The method of deriving the matrix is aimed at two types of boundary work: between the various disciplines of science; and between science, policy and local stakeholders.

Steps

Construction of the table relies on the use of methods for a consistent classification of land-use systems (see RAFT) that is compatible with spatial analysis (ALUCT), profitability analysis (LUPA) and the derivation of time-averaged carbon stock (RaCSA). The final choice needs to be made in an interdisciplinary team where categorization of initial classifications that are based on various disciplinary preferences and limitations is jointly considered. The resulting list must be explicit in all distinctions that are important in current public discourse and policy debates, as well as reflecting local knowledge and concerns.

Before beginning, it will be good to discuss with policy-makers (through in-depth interviews and participation in meetings where policy issues are being discussed) which columns and possibly new indicators are relevant. The list for the sample matrix can be taken as a starting point.

Data collection for the various cells in the matrix will, to the degree possible, have to be based on co-location of socio-economic and ecological sample points to ensure that the system properties are aligned, and trade-off estimates are unbiased.

Example of application

The ASB Matrix was first used in the Alternatives to Slash and Burn (ASB) project phase 2 synthesis report for Indonesia in 1998 (Figure 19.1). The numbers and indicators have subsequently been refined.

In 2005, the increasing interest in reducing greenhouse gas emissions led to the profitability and carbon stock data of the matrix becoming the basis of the opportunity cost method (see REDD Abacus).

Table S1. The ASB matrix as a boundary object

	Global environmental concerns		Agronomic sustainability			National policymakers' concerns		Smallholders concerns/ adoptability by smallholders	
	Carbon storage	Biodiversity	Plot-level production sustainability			Potential profitability	Labor requirements	Returns to labor	Household food security
Land use system	Aboveground tC/ha (time-averaged)	Aboveground (plants), species per standard plot	Soil structure	Nutrient export	Crop protection	Returns to land (private prices), $/ha	Labor person, d/ha/y	Dollars per person-day (private prices)	Entitlement path (operational phase)
Forest	306	120	0	0	0	0	0	0	NA
Community-based forest management	120	100	0	0	0	5	0.2–0.4	4.77	$ + consumption
Commercial logging	94	90	−0.5	0	0	1,080	31	0.78	$
Rubber agroforest	79	90	0	0	−0.5	0.70	111	1.67	$
Rubber agroforest with clonal material	66	60	−0.5	−0.5	−0.5	878	150	2.25	$
Oil palm	62	25	0	−0.5	0	114	108	4.74	$
Upland rice/bush fallow	37	45	0	−0.5	−0.5	−62	15–25	1.47	Consumption
Continuous cassava/imperata	2	15	−0.5	−1.0	−0.5	60	98–104	1.78	$ + consumption

ASB created the ASB Matrix to show the relationship between alternative land uses (including natural forest) and key evaluation criteria. The matrix served as a "boundary object" at the interface of a variety of information users (who defined the rows and columns of the matrix) and scientists (who devised the metrics and conducted the measurements that fill the cells). Reproduced here is the original version of the matrix as reported in an internal ASB report in 1998 (1). A fuller discussion of the matrix and its uses, together with the final version of the matrix for a number of ASB cites, has been published in the project's final report (2).

1. Tomich TP, et al. (1998) *Alternatives to Slash-and-Burn in Indonesia, Summary Report of Phase II. No. 8* (International Center for Research in Agroforestry, Bogor, Indonesia).
2. Tomich TP, et al. Balancing agricultural development and environmental objectives: assessing tradeoffs in the humid tropics. *Slash-and-Burn Agriculture: The Search for Alternatives*, eds Palm CA, Vosti SA, Sanchez PA, Eriksen PJ (Columbia Univ Press, New York), pp 415–440.

Figure 19.1. ASB Matrix for humid lowlands of Sumatra as represented in Clark et al (2011)

Key references

Tomich TP, Lewis J, eds. 2003. *Balancing rainforest conservation and poverty reduction*. Policybrief 5. Reprinted July 2004. Nairobi: Alternatives to Slash and Burn. http://www.asb.cgiar.org//PDFwebdocs/Policybrief5.pdf.

Clark WC, Tomich TP, van Noordwijk M, Guston D, Catacutan D, Dickson NM, McNie E. 2011. Boundary work for sustainable development: natural resource management at the Consultative Group on International Agricultural Research (CGIAR). *Proceedings of the National Academy of Sciences of the United States of America.* DOI:10.1073/pnas.0900231108.

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20 Rapid hydrological appraisal (RHA): watershed functions and management options

Meine van Noordwijk, Betha Lusiana and Beria Leimona

Rapid hydrological appraisal (RHA) diagnoses the hydrological situation of a landscape and perceptions and ecological knowledge of its important stakeholders: local, general public and scientific domains. These perceptions and knowledge include information concerning trade-offs between local decisions on land-use practices that influence watershed functions, types of local institutions that can increase effective management of the watershed, and social relationships among stakeholders. The RHA enables an appraisal of the opportunities for negotiating land-use agreements that include rewards for protecting and rehabilitating watershed functions.

Introduction: watershed functions under threat

Water supplies are increasingly unreliable and insufficient during dry seasons; water quality at sources is increasingly poor and damaging floods are becoming more frequent. Improved watershed functions to circulate and store freshwater is an essential solution for such pressing problems. A number of initiatives are working to protect the critical functions of watersheds, including through providing incentives for people in the uplands to modify their land-use practices.

Land use can significantly affect water quantity and quality, water flow regularity, and watershed capacity to prevent landslides and erosion and to stop sedimentation in downstream areas. However, developing an effective incentive system requires clarity of the relationship between land use and provision of environmental services that are of sufficient value to stakeholders to become the basis for rewards (see general introduction to this volume).

Moreover, there are often substantial differences in perceptions among stakeholders in identifying watershed problems and their causes and providing solutions for improved watershed functions. Downstream stakeholders may perceive that only natural forests with high tree density can guarantee provision of environmental services. Upland land-users may encourage more open land-cover types, such as agroforestry, or even open-field agriculture or pasture, to meet their need for livelihoods and watershed functions. On the other hand, a government's response to this situation can either improve the situation or even worsen it, triggering conflict among stakeholders.

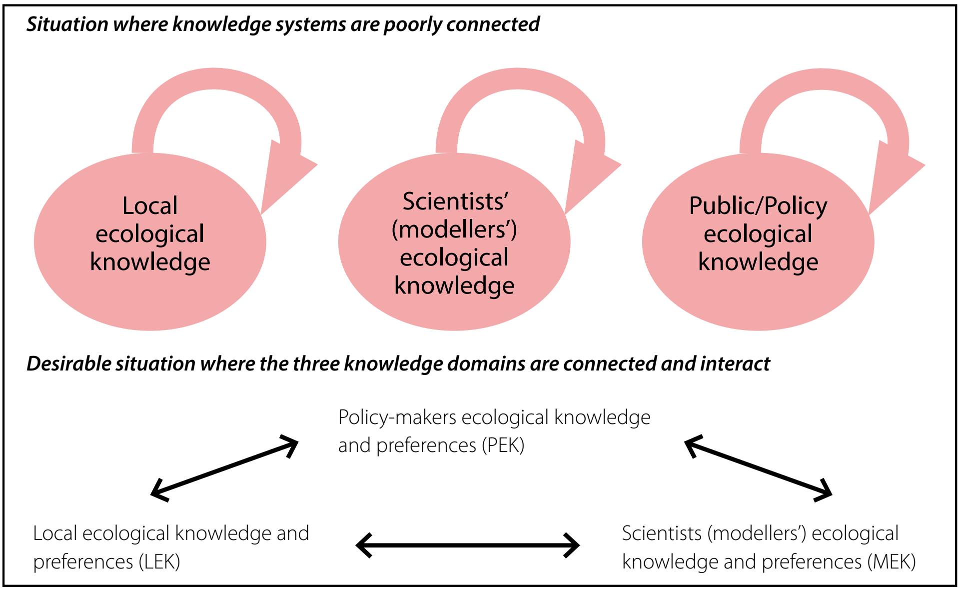

Figure 20.1. Disconnected and desirable interrelationships between three ecological knowledge systems
Note: compare with Figure 0.7

Developing a range of plausible scenarios for change may help negotiations among stakeholders. Appreciation of the various quantitative indicators probably varies by stakeholder group. Therefore, it's important to include the varying perspectives of 'local upland', 'local lowland', 'public policy' and 'ecological hydrology' in any negotiation process (Figure 20.1).

To understand the differing perceptions and their degree of similarity, we use RHA.

Objectives

RHA combines the participatory appraisal process and the use of computer-based, landscape-hydrological simulation models to:

- compare the overlap between stakeholders' perceptions of current and past patterns, process and impacts of land and water use;
- assess biophysical parameters of the watershed and its hydrological and environmental characteristics; and
- project forward the hydrological and environmental implications of current trends or future challenges in land- and water- use patterns through modelled land-use scenarios.

For negotiation purposes, the RHA contributes to a better knowledge system, thus, all stakeholders will be able to:

- understand local land-use patterns, the benefits they provide, alternative land-use options and the drivers of change;

- understand the impact of local land-use changes on watershed functions and the potential 'buyers' who are willing to provide incentives to maintain or enhance specific services; and
- evaluate the level of investment in future negotiations that can lead to a rewards mechanism that will deliver on stakeholders' expectations.

Steps

The approach includes the following activities, which can be carried out in less than 6 months.

1. Land cover/land-use change analysis (see ALUCT).
2. Exploration of the local knowledge of stakeholders about hydrological functions, water movement and the consequences of different land-use options for the landscape.
3. Exploration of the local knowledge of policy-makers about hydrological functions, water movement and the consequences of different land-use options for the landscape.
4. Compilation and analysis of existing hydrological data on the watershed, including a scenario analysis of plausible land-cover change and the likely impact on watershed functions. While watershed functions can include a range of hydrological functions, the RHA focuses on the subset that relates directly to surface water flows. These hydrological functions of watersheds include the capacity to 1) transmit water to freshwater stocks and flows; 2) buffer peak rain events; 3) release water gradually; 4) maintain water quality (sediment, nutrient, pollutants, bacteria leading oxygen demand); and 5) reduce mass wasting, such as landslides.

Table 20.1. Local, public/policy-makers', and modellers/hydrologists' ecological knowledge components

Local ecological knowledge	
Goal	Locally specific analysis of the problem and its causes and effects
Source of information	Key informants and village members
Documents needed	Base map as a foundation for participatory mapping
Questions asked and topics explored	Where are the 'hotspots' within the watershed that cause degradation? What are the existing land-use patterns in the watershed? Who contributes to the current land-use patterns? Why have these land-use patterns developed? What are examples of areas that decrease or buffer watershed degradation? Do good practices for solving watershed problems exist? What are those practices?
Public or policy-makers' ecological knowledge	
Goal	Analyse perceptions regarding watershed-level environmental and water resource problems and their causes and effects
Source of information	Government officers, community leaders and the general public, including downstream stakeholders
Documents needed	Base and thematic maps Environmental reports and watershed profiles
Questions and topics	What and where do watershed problems occur? Who caused the watershed problems? What are the reasons?
	What are the past and current 1) land-use; 2) forest-cover; 3) river-flow; 3) water quality and use; 4) lake; and 5) river problems?
	Are any development projects planned within the watershed? Will these projects cause environmental degradation?

Modellers or hydrologists' ecological knowledge	
Goal	Plausible land-use-change scenarios to analyse drivers and effects on watersheds
Source of information	Land-use modeller and hydrologist
Documents needed	Spatial data: topographic, landform, geology, soil, natural vegetation, land-use time-series and administrative maps Climatic data: daily rainfall Hydrological data: daily water level
Questions and topics	What changes have occurred in the watershed? What are the land-use-change drivers?
	How do land-use changes affect water balance and use within the watershed?
	What are the main indicators affecting watershed water quantity and quality?
	What are the land-cover effects on watershed water balance and river flow?

Case study: RHA at Lake Singkarak, West Sumatra, Indonesia

The first RHA was conducted at Lake Singkarak in West Sumatra, Indonesia, to assess the hydrological situation in the context of developing a payments for environmental services scheme aimed at rewarding the upland poor for protecting or rehabilitating watershed functions.

The study focused on the relationship between the operations of a local hydroelectricity company, fluctuations in the level of the lake, the water quality in the lake and the land cover in the catchment areas that contribute water to the lake. Payments made by the power company to the local government can, in part, be seen as rewards for maintaining or improving environmental services. Nevertheless, there was no shared understanding of the relationship between land cover and the environmental services provided.

The Singkarak Basin hosts rice fields (17%), agricultural crops (15%) and forests (15%). Rice fields occur in the lowland area, below 1000 masl and with slopes of less than 30%, commonly found in the southern part of the basin. Besides rice, other crops—mostly vegetables—are also found in the lowland plains up to 1000 masl. Mixed gardens, shrubs and grass are found in smaller patches all over the basin. In the higher elevations and where the slopes are steeper along the western range of the basin and on the upslopes of Mt Merapi, forest is the dominant land-cover type.

The study included consultations that found there was broad agreement on the need to maintain a clean lake and productive landscapes on hills and irrigated plains that met the food and livelihoods needs of the population and produced electricity for the provinces of West Sumatra and Riau. There was a widely held perception that the landscape was not currently meeting these expectations. The power company was not able to provide as much electricity as needed; fluctuations in water levels were of concern to the people living around the lake; water quality in the lake was poor; the population of the endemic fish, *ikan bilih*, was declining and two prior attempts to rehabilitate the *Imperata* grasslands in the area had not been very successful.

Stakeholders disagreed on the best approaches to watershed management, particularly with regard to reforestation and other means for achieving land rehabilitation. While policy-makers favoured reforestation, using either the local *Pinus merkusii* or another fast-growing tree species, villagers were convinced that reforestation with pine trees caused streams to dry up whereas natural forests provided regular stream flows during the dry season.

A water balance model confirmed a higher water use by pine trees owing to canopy interception and transpiration as compared to more open landscapes but no substantial differences between pine and natural forests. The model further suggested that the performance of the hydroelectric plant was only mildly influenced by land cover (Figure 20.2). Compared to the land-use mosaic at the time, an increase or decrease of 5% of the maximum electricity production could be expected, while the variation between wet and dry years of the 1991–2002 period was much larger. A change in the average annual rainfall owing to climate change would likely have a strong effect on the plant's performance. Declining water quality in the lake and weed infestation would offset any gains in water supply that could result from land degradation. Reforestation with fast-growing evergreen trees would slightly affect the plant's access to usable water. A basic assumption underlying payments for environmental services is that the supply of these services depends on the activities of those receiving the payments. For the power company, this assumption was not supported by evidence.

Payments made by the company could have various rationales.

1. Compensation for damage caused by the hydroelectricity company to the farmers along the Ombilin River whose waterwheel irrigation systems were disturbed and to farmers with rice fields surrounding the lake affected by increased flooding.
2. Shared responsibility for maintaining the quality of the water in the lake as the hydroelectricity company modified outflow rates and increased debris accumulation.
3. Tax payments to the local government.
4. Payments to enhance goodwill with the local community.
5. Payments for environmental services conditional on the delivery of these services.

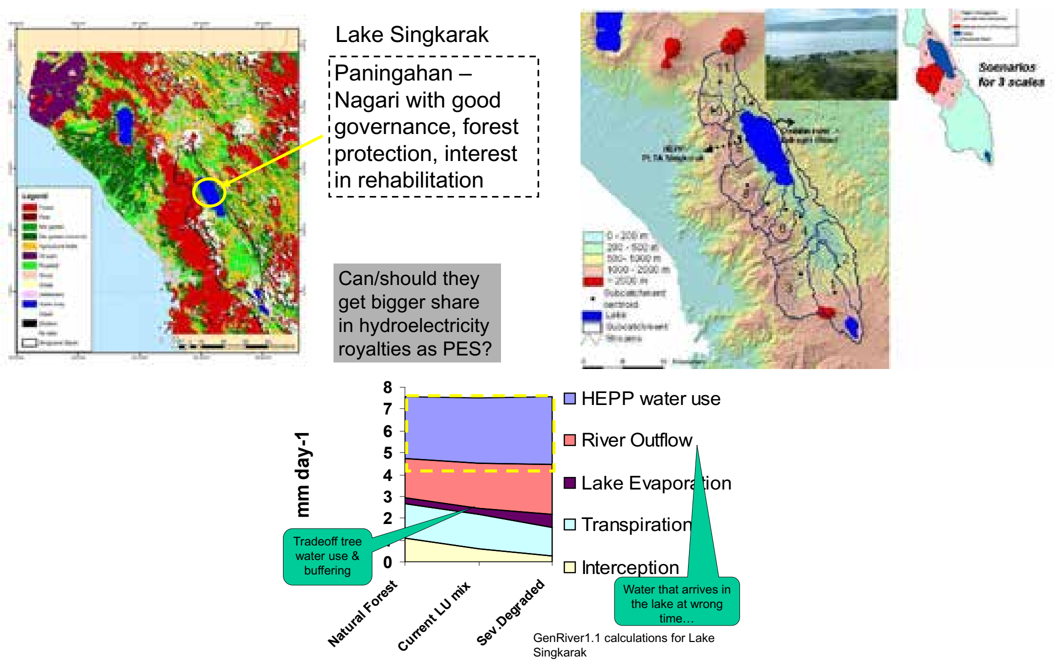

Figure 20.2. Summary of a rapid hydrological appraisal of Lake Singkarak

Table 20.2. State of knowledge before and after the RHA of Lake Singkarak

Before RHA Singkarak	After RHA and follow-up negotiations
▪ Deforestation seen as the main cause of all problems, including electricity blackouts ▪ Tree planting seen as major solution ▪ Belief that the village with most tree cover should get highest share of royalties ▪ Reduction in fish population linked to deforestation.	▪ Focus on lake and water quality ▪ More awareness of the impacts of climate variability ▪ Less blaming of upland deforestation for blackouts ▪ Less focus on tree planting as the principle solution to environmental problems ▪ *Ikan bilih* problem is understood to be caused by polluted breeding grounds and overfishing ▪ Adjust scale of institution in managing the watershed ▪ *Management implications from local perspectives* o Reforestation uses trees with low evapotranspiration. o Local wisdom maintains clean water stream in the upstream and conserving native *ikan bilih* ▪ *Management implication for watershed management and RWS* o Upstream village level: maintaining current intact environment, that is, biodiversity conservation such as organic coffee, voluntary carbon market scheme and watershed services o Villages surrounding the lake: improving water quality of the lake and river

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21 | Rapid landslide mitigation appraisal (RaLMA): managing trees for improved slope stability

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Trees can protect slopes from landslides, but can also be a risk factor. Rapid Landslide Mitigation Appraisal (RaLMA) explores local knowledge and the science of landslides and their relationship to trees. The result is an analysis of which trees have complementary functions in protecting slopes. However, not building houses in the likely pathway of landslides remains the primary way to avoid human loss of lives.

Introduction

Major landslides have become have become almost yearly phenomena in Southeast Asia, killing hundreds of people and causing major economic damage.

Heavy rainfall on wet soil on hill slopes can trigger the movement of large amounts of soil. The root systems of forest vegetation and trees play an important role in holding the soil together and the removal of trees and subsequent decay of tree roots may be part of the reason behind the growing number of landslides in the region. Ironically, trees contribute to the build-up of soil that eventually becomes too heavy for the steepness of the slope. Landslides, or slope instability, can also be caused by the construction of roads and other structures that interfere with the paths of water flow down a slope.

In public discussions, landslides in Southeast Asia are often attributed to deforestation. However, other factors need to be considered when it comes to understanding landslides and how to prevent them.

A. No one would notice landslides (which are a natural part of soil–vegetation processes, especially on geologically young soils in steep terrains) if there were no people living nearby. People can become victims of landslides simply by being in the wrong place at the wrong time.
B. The increased use of a landscape by people normally involves reducing tree cover and increasing infrastructure, which may intensify the occurrences of landslides. Where the slope incisions of roads lead to slope instability, the correlation with the loss of tree cover is only indirect.
C. Tree roots play a real role in protecting the soil profile and the decay of tree roots and tree felling eventually increases the risk of landslides.

Only in case C does it make sense to expect that tree planting will reduce the risk of landslides once the young trees have established their root systems.

The complexity of the relationship between the causes and effects of landslides, the destruction of evidence by the landslide itself and the occurrence of landslides after cases of extreme rainfall make it desirable to have a relatively fast and inexpensive appraisal method that can be used by local natural resource managers to take precautionary measures and/or to respond to early signs of slope instability. Changing rainfall patterns in the light of global climate change make the need for such tools even more urgent.

Objectives

RaLMA is designed to provide a basic understanding of the way tree roots can contribute to slope stability and how tree and agroforestry management can enhance or maintain slope stability and protect people and ecosystems from the damage caused by landslides.

Steps

1. Conduct a spatial analysis of the landscape and gather data on the recent history of land-cover change. This includes identification of the area; characterization of the soils and of the potential planes of weakness in the soil profile; characterization of the geological substrate and of the process of soil formation (including colluvial soils derived from previous slope instability); characterization of the slope and recent changes in land cover; and characterization of climate and extremes in rainfall distribution.
2. Explore local ecological knowledge (LEK) of cause and effect relations, local regulations concerning changes in tree cover and local people's preferences about trees in the landscape.
3. Explore policy-maker's ecological knowledge (PEK) of cause and effect relations; considering whether existing land-use plans take landslide risk into account and investigating stakeholders' preferences and aspirations with regard to the presence of trees in the landscape;
4. Explore modellers´ ecological knowledge (MEK) of site-specific risks and of the likely timing of response to mitigation actions. It is important to bear in mind that trees on slopes have both positive and negative effects on stability. Negative effects include:

   a. the aboveground biomass adding weight and wind exerting a lateral force; and

   b. highly porous soil supported by active soil fauna feeding on the litter layer increases infiltration and the likelihood of positive pore pressure after heavy rainfall.

   The positive effects include

   a. binding topsoil into a root mat that either moves as a whole, or stays in place; and

   b. the anchoring of this rooted layer to the subsoil through vertical roots.

   Whether the effects are positive or negative depends on the species and age of the tree and the type of tree management involved (see Figure 21.1).
5. A synthesis of the outputs of the steps, which can inform local negotiations between the different stakeholders involved in landscape management.

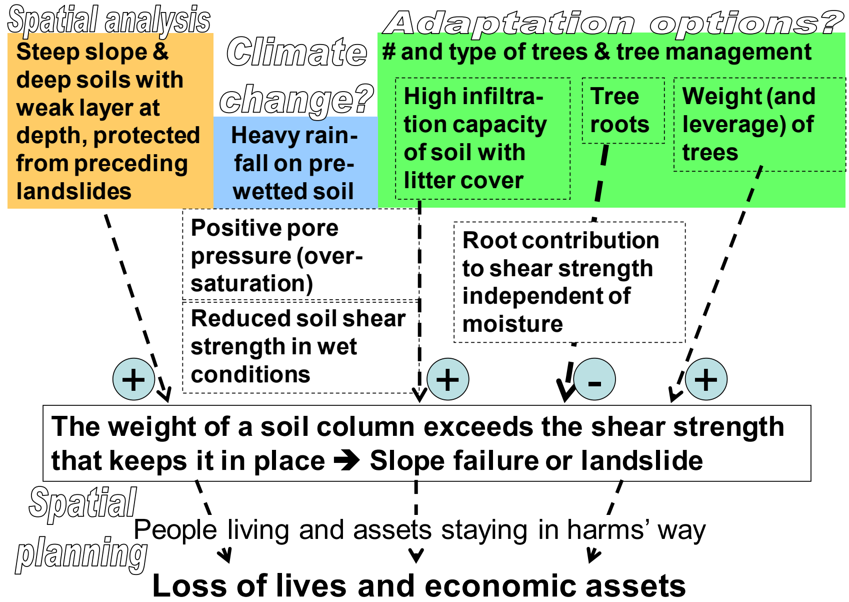

Figure 21.1. Schematic diagram showing the relationships between landslides and soil, climate and vegetation

Compiling parameters for MEK of trees and landslide risk:

- Survey of tree species and tree population density in the landscape in relation to signs of previous landslides.
- Inventory of proximal tree root architecture of the major species that grow in the area to assess soil binding and soil anchoring properties; two tree root indices —Index of Root Anchoring (IRA) and Index of Root Binding (IRB)—can be used to evaluate tree suitability for stabilizing slopes.
- Standardized strength measurement of tree roots in relation to their lignin content.
- Estimation of dynamic root pattern at the hill-slope scale using the SExI-FS and the IRA and IRB parameters derived from the survey.

Case study

Case studies from different parts of Indonesia (West Lampung, West and East Java) suggest a number of options for implementing a 'right tree in the right place' management approach to mixed agroforestry systems. Such an approach can help to reduce the risk of landslides on slopes and can be combined with biomass carbon storage as a contribution to climate-change mitigation.

Research was carried out between January and May 2008 in the Bukit Sentul area of the Bogor district in West Java. The research took place in areas that had been classified as being at high risk of landslides. Based on geological maps and the recent occurrence of landslides, the survey focused on the Ciherang and Cibadak sub-catchments and was followed by an inventory of tree species and population density in the selected area.

Four types of landslides occurred in the village of Karang Tengah: 1) overland; 2) slope failure (topple); 3) creep; and 4) road-cut. Sixty percent of the total were superficial landslides. Factors affecting landslides were found to include rainfall intensity, topography (slope > 45%) and features of the soil profile: the existence of bedrock or compacted soil layer as a sliding plane; and the existence of unstable soil layers, such as sandy loam layers in the subsoil, with a low soil shear strength owing to higher sand content.

Figure 21.2. Durian tree protecting, through its superficial roots, a slice of land from sliding

Vegetation in the study area was dominated by homegarden types of agroforests with banana (non-woody), *Maesopsis eminii* (an introduced timber species), *Pangium edule* (a source of oil and spice), *Ceiba pentandra* (kapok) and *Sandoricum koetjape* (a local fruit tree) dominating. The highest tree population density was found in agroforestry systems near the scarps of overland landslides. The weight of the aboveground tree biomass probably increased the risk of landslides.

The local fruit tree species, 'duku' (*Lansium domesticum*), 'kemang' (*Mangifera kemanga*), 'limus' (*Mangifera foetida*), 'mindi '(*Melia azedarach*) and durian (*Durio* sp) (Figure 21.2) played a relatively important role in anchoring the soil (where the IRA was higher than 2.0). A mix of tree species with deep roots, and of ground cover species with intense and strong fine roots, provided the highest slope stability in the area.

The SExI-FS model was able to simulate the role of trees in reducing the risk of landslides through the quantification of the IRB and IRA of species in a tree plot (Figure 21.3). The simulation showed that increasing plot density over the optimum size did not significantly increase root binding.

The combined results of the LEK, MEK and PEK studies helped inform discussions concerning the choice of species while at the same time taking into account direct economic gain, the local utility of species and landslide risk.

The primary recommendation that might be given by advisers visiting a village at risk of landslides would be to look for another location for the village but the options for doing so are limited. Maintaining the tree root mat of the village homegardens, avoiding houses with rigid walls that collapse under pressure and encouraging traditional flexible building materials such as bamboo may help to reduce the risk to locals in the short term.

Figure 21.3. RaLMA process and 3D reconstruction using SExI-FS

■ Key reference

Hairiah K, Widianto, Prayogo C, Kurniawan S, Harja D, Khasanah N, van Noordwijk M. 2008. *The role of trees outside forest in anchoring soil and reducing landslide risk during high rainfall episodes.* TroFCCA project on the role of tropical forests in climate change adaptation.